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History of the Plurality of Worlds

The Myths of Extraterrestrials Through the Ages

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Editor's Foreword

In February 2019, I received a manuscript written by a colleague I had met many times before: Pierre Connes. He was a bright physicist and astronomer who had renewed the field of very high-resolution spectroscopy and had applied it to many experiments in the laboratory and observations in the sky. To my surprise, the manuscript had nothing to do with spectroscopy, revealing another aspect of the personality of Pierre Connes. I found it very interesting and well-written, so I decided that it was worthy of publication and that I would take charge of this publication myself, as Pierre was already on his deathbed. He was made aware of this project by his family, before passing away on 22 February 2019, aged 90, unfortunately too soon for him to have had the pleasure of knowing that his work has indeed been accepted for publication.

Pierre Connes was born in Paris on 28 June 1928. He spent his childhood in Dijon, where he attended the University. After passing the highly competitive *agrégation* in Physics and Chemistry in 1953, he taught physics for 2 years and then entered the Aimé Cotton Laboratory in Bellevue. He later moved to Orsay where he obtained his PhD in Physics in 1958. He specialized in very high-resolution spectroscopy with Michelson-type interferometers, introducing several important improvements to these instruments. He used them for laboratory physics with great success. He also installed them at the focus of various telescopes, including the Palomar 5-m, and on several space observatories, in a long-lasting collaboration with NASA and the US Air Force. He obtained in this way many important results on the atmospheres of stars and planets: detection of chlorhydric and fluorhydric acids in the atmophere of Venus, variations of the concentration of oxygen and ozone on Mars (contrary to what occurs in the Earth, this oxygen has nothing to do with life but results from the action of solar ultraviolet on CO_2), etc. During the 20 last years of his scientific career, he developed concepts that were at the basis of the discovery of planets around other stars than the Sun. He was awarded several important prizes as a reward for his scientific contributions.

According to Pierre's wife, Janine, mathematician and computer scientist with whom he worked as a team throughout his life, the origin of this book goes back precisely to 24 September 1964. For the first time, their working duo resolved completely into individual lines the infrared bands of CO_2 in the tenuous high atmosphere of Venus. The same method was used in 1966 and 1967 to study the atmosphere of Mars and to analyze the structure of its CO_2 bands, from which was deduced the planet's atmospheric pressure. This feat triggered his lifelong interest in the Universe and in possible planets around other stars. He then became convinced that life should indeed exist elsewhere than on Earth and decided to study the history of the plurality of worlds.

The writing of his book extended roughly from 1970 to 2000, with no thought given to possible publication. When he suffered a stroke in December 2018 and could neither correct, add, nor subtract anything to the manuscript, he decided to have a few copies printed just as it stood and sent them to some astronomer friends, me among them. He wrote: "My very vague hope is that somehow the said text will ultimately reach some English language editor. Of course I realize it will require drastic shortening."

In the 1970s, there was little interest in France for the Search for Extra-Terrestrial Intelligence (*SETI*), which was much more developed in the USSR and in the USA, and Pierre was almost the only French scientist to attend the relevant conferences in both countries. He was at the time an ardent believer in the existence of Extraterrestrial Intelligence (*ETI*), but he became increasingly skeptical. According to him, "chiefly responsible was a collection of papers, *Extraterrestrials, Science and Alien Intelligence* (Regis 1985), in which scientists of various callings, together with some philosophers, provided their own highly-critical views of those foreign galactic civilizations… Extraterrestrial intelligence is undemonstrated and quite possibly never demonstrable."

This was not enough to deter him from pursuing his history of the myth of extraterrestrials. Some thorough work had already been published on the subject (Dick 1982, Crowe 1986), but Pierre thought that he could do more and deeper. For example, he found that Kepler, perhaps the most fascinating personality met throughout the whole tale, had been rather forgotten. Moreover, the book, while not a history of astronomy, sometimes gets close to a history of astrophysics up to the seventeenth century, i.e., long before the word astrophysics was invented.[1] The reason is that speculations about other Worlds were at first not distinct from those concerning the material constitution of our own. Precise descriptions of planetary motions are of less importance here than figures (or fancies) about the size, nature and matter of planets. Moreover, while the history of the geometrical world picture has long been recognized as an important subject and very thoroughly narrated by historians, here, the viewpoint is different: Ptolemy and Copernicus do appear, but briefly; Aristarchus will be followed more for his estimates of astronomical distances or sizes than for anticipating Copernicus. The three Laws that constitute Kepler's main lasting achievement will be barely mentioned, but his notions regarding the structure of the Moon as well as his utterly wrong model of stellar distribution and his dithyrambic

[1] Here and in the rest of this foreword, I borrow some parts of the original introduction of the book, which cannot be reproduced here in its full extent.

view of the Sun deserve to be discussed in full. Scientists whose contribution to astronomy has proved fundamental but who (perhaps wisely) showed little interest in our Myth shall play but a small role: Newton is the most noteworthy example. On the other hand, actors much less well-known, at least to astronomers, deserve well-developed parts: for instance, Cardinal Nicolaus Cusanus and Dominican Giordano Bruno, the first a revered Prince of the Church while the second a martyr by (not of) that same church.

Many of the ancient texts profusely quoted in these pages will make for arduous perusal, even when rendered by the most skilled translators, and a special effort has been made to place them in the context and to clear up their meaning. After the beginning of the seventeenth century, the path does get much smoother; while neither metaphysics nor theology vanish, the thought of all writers (whether still expressed in Latin or in modern idioms) becomes progressively easier to follow, at least to today's readers, because closer to present science. Nevertheless, the author has chosen to stop after Christiaan Huygens and his *Cosmotheoros* (Huygens 1698); such had been the original decision, and this choice was to be preserved even after the above deplored loss of faith of the author in *SETI*. The reason is that the core of the book has turned out to be an attempt to follow the passing of thought about Plurality of Worlds from antique/medieval to modern due to the rise of the truly scientific tools. That transition was for all practical purposes complete with Huygens, when advancing technology provided suitable means for gauging the space, thus establishing the possibility (and even likelihood) of other solar systems. Somehow, the great technical novelties of the nineteenth century, spectroscopy and photography, while of immense benefit to astrophysics, did nothing at all to advance the concept nor understanding of Plurality, which nevertheless became immensely popular, as shown by the number of relevant publications (very aptly followed by Crowe 1986). Still, from the viewpoint adopted here, nothing of importance was added in those times; the contributions of Maxwell and Hertz were to prove essential indeed, but this was not understood before the following century.

However, the present picture of Alien civilizations and of the possibility of communication with them, i.e., *SETI*, cannot be understood solely from the static model of Huygens. The age of the Earth (and Universe) had to become a measurable quantity, and Time and Evolution came into the picture. For the same reason, the immense distances of the nearest stars and exoplanets, in spite of the very large velocity of light, largely mess up the prospect of inter-sidereal dialogue, in which may well reside the only definitive proof of *ETI*. If we scientists were able to say "let us broadcast a set of messages today" and the answers (if any) would show up as newspaper headlines tomorrow morning, the attitude toward *SETI* would be quite different. Instead of a pleasurable game for a handful of devotees, it would grow to a pressing concern for most Governments and be included within the next 10-Year Plans. The last chapter of this book will discuss this problem as it stands now in the light of the discovery of many planets around other stars than the Sun.

Then, why bother about the history of the myth of extraterrestrials? Not a few active scientists tend to condemn the long past history of their craft. Is there any reason for taking that history differently in the case of the modern search for Aliens?

Is it a complete waste of time to read some historical account for those who either work in the field or give it a serious thought? A possible answer will come from attempting to take the viewpoint of our own descendants, i.e., those people who may get the final answers to that Search, either positive or negative. Seen from their perspective, our present-day convictions (or lack of) regarding actual mechanisms for the origin of life and rise of intelligence should not be of overwhelming importance. How much of a contribution shall they grant to the present epoch? Undoubtedly, a single capital one: this was the time when *SETI* entered the field of experimentation, because of the various technological developments leading to the birth of radioastronomy. What else shall they attribute to their ancestors? Nothing truly essential: the crucial steps for modeling the birth and spread of intelligent life in the Universe had not been reached; and the core beliefs regarding the Plurality myth remained primitive and of partly metaphysical origin, just as those of our Greek forefathers.

Just as those of the Greeks: that is precisely the central point. Except for passing that technological (and scientific) milestone of the first radiotelescopes, we have conquered very little ground not already covered by our predecessors in the game, at least in imagination. Most of us believe in some form of Plurality; so did they. When we take the trouble to analyze our belief, we find it rooted in a few basic principles, speculations aplenty, and scant observations; they did no better and no worse. However, the principles themselves have changed, and theirs were essentially different. Their most relevant one has been called the Principle of Plenitude, which expresses the conviction that the Universe, being an essentially good (hence complete) piece of work, could not be either empty or useless in any of its parts. Such a Principle may be traced back to Plato and was later incorporated within the Christian world picture, not without some infighting. It was often taken as implying Plurality up to the early nineteenth century. This Principle is unabashedly teleological and even theological; today, it no longer carries any weight within science, since we have done away (or try to do) with all final causes, even within life sciences. By what strange twist of events did the theme of Plurality manage to survive unscathed and even gain great popularity among the most sober-minded scientists of today? Because it is now taken as deriving from a totally different principle, known under several names, none of them fully adequate: it has been variously called the Generalized Copernican Principle or the Cosmological Principle, but to the layman, Principle of Universal Mediocrity would do fairly well.

In essence, this Principle means the belief in a Universe that looks essentially the same seen from any place; hence, the location of Man in space is utterly mediocre. This means applying to the entire perceptible Universe the central idea of Copernicus: the Earth-bound reference frame is not in any way remarkable. As we shall see, such a sweeping generalization was definitely not Copernicus' contribution but rather that of Nicolaus Cusanus, who wrote a century before him and was not concerned with planetary orbits at all. Moreover, that extension means applying the same principle to the biological world: if there is nothing peculiar about the geometry, the physics, or the chemistry of our home planet, it cannot hold any exclusive privilege for developing life or intelligence. Like all principles, this one may be checked or failed only by its distant consequences. So far, the record in its favor is remarkably good, an unbroken succession of victories, even if none was won without a lengthy battle. The Chinese thought themselves as dwellers of a Middle Kingdom, while Westerners expressed much the same view with their beloved Mediterranean world. Both were similarly wrong, as their experience had been confined to that minor and unremarkable portion of the spherical surface they happened to be born upon. Surely, that sphere was at least the stable center of the visible Universe? Not so, and under closer inspection, it proved an errant body, one planet among others, neither the largest nor the smallest, nor the hottest nor the coolest…. What about our Sun? For Kepler, who provided the definitive picture of our planetary system, this Sun remains a one-of-kind body, occupying the center of an empty cavity around which are scattered much smaller stars; these cannot have nor hold planets, and the night sky seen from any of them would look different from our own. In the next episode, the true nature and shape of the familiar Milky Way slowly emerged, the location of the Sun within turned out to be unremarkable, and the development of photometry and spectroscopy unveiled its nature as equally mediocre. What about the Milky Way itself? Around 1900, it was possible to argue that our home Galaxy was identical to the visible Universe, and 50 years later, it still held the distinction of being a remarkably large galaxy, but today, this is no longer true. Whether he looks at the World on a planetary, stellar, or galactic scale, Man feels his abode to be but a small and random dwelling within Megalopolis.

What is the true worth of our present beliefs? How solid is this Mediocrity Principle, and could it hide even deeper convictions? Does it stand a chance of weathering as well as the defunct Plenitude, which held the stage for about two millennia? Not a bad record on a human time scale anyway. Such thoughts are rather unsettling; Do the scientists living presently know their own minds? At least, most of them do not know the minds of the past thinkers who had so long dabbled with the Plurality notion no less intelligently than we do today. Here, you may see the motivation, scope, and limitation of the present enquiry. As long as we do not have an observational proof that Other Worlds indeed exist, we should fully review the available knowledge; this is standard practice. And such, a review should not cover just the collection of papers that could be presented at the next *SETI* symposium, e.g., *The Present Picture of Planet Formation*, *A Summary of Recent Work on the Origin of Life*, etc. A truly valuable review has to extend much farther into the past.

The present history of the Great Myth is written with the intent of providing the reader with the background information in proper perspective. Such a history, should it be written well enough, would prove a useful tool because of the peculiar standing of the problem: adequate technology available, but without sufficient theoretical basis. If we were attempting to predict, say, the course of atomic theory over the next few generations, putting on a par the utterances of Democritus with those of the latest Nobel laureates would not be particularly helpful: modern physics has uncovered quite a few hard facts, and Greek atomism is of mere historical interest. Not so when cogitating about Extraterrestrials: those crucial facts are unavailable, and we are not wholly out of the metaphysical forest yet. Hence, it is quite sensible to increase the size of the poll and include long vanished thinkers. First-class ones are so much easier to discern across the gap of time (the historian's privilege!);

furthermore, overspecialization is but a recent calamity, and up to the seventeenth century, universal minds were still numerous. Surely, their opinions are still worth considering when we tackle what is, by essence, a multidisciplinary problem. Let us not dismiss them out of hand because they built over a philosophical ground base on which most living scientists no longer stand. Altogether, after reaching the last page, the reader will not feel one day closer to the greatest potential discovery of all time, that of intelligent Aliens; but he may fancy that he has labored up to a summit providing a fair prospect.

*

A final word by the editor: although the body of the book ends with Huygens' *Cosmotheoros* of 1698, for reasons given above, I found it of interest to rapidly review in the last chapter the following fancies regarding the Plurality of Worlds, the attempts to communicate with other Worlds, and their chances of success, especially since we are now aware that there are probably, in our Galaxy, billions of planets similar to our own.

Contents

Chapter 1
From Anaximander to Lucretius: Plurality From Chance

They have dethroned Zeus, and Vortex is King.

Aristophanes, *The Clouds*[1]

(Left) Anaximander, Roman mosaic from Trier, early third century AD. Rheinisches Landesmuseum Trier. Wikimedia Commons
(Right) Democritus, by Giuseppe Torretti (1705). Ca'Rezzonico (Venice), Portego. Wikimedia Commons

[1] Aristophanes, *The Clouds,* 380–4. Translation in Santillana (1970) p. 39.

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Half a millennium: one may hardly expect the journey of any concept across such an ocean of time to be straight, linear and free of buffeting winds. Nevertheless, from the founders of the Ionian-Milesian school up to Epicurus and Lucretius through the Atomists, the vision of Nature has remained essentially the same, and this is most true for the Plurality concept. Any history of early scientific thought shows that, as soon as they started building models of the Universe, humans have produced wildly different and contradictory ones, out of which some were fated to hit closer to the actual truth, or what we take as such today. No great wisdom seems required to postulate that there is either one World or many. Wrong: there is a third solution, zero world(s), exhaustively explored by the illusionist schools, but traditionally unpopular with scientists.

All the main building blocks used for edifying the Plurality palace seem to have been put in place at the dawn of Greek thought; but we must reconstruct the process through texts written much later, themselves often mutilated and reduced to brief or cryptic sentences. Moreover, merely unraveling how similar to our own world model was the one of the Ionians is not, by itself, greatly helpful if we cannot explain how and why they were led to paint the picture. The task is arduous: little is known about the actual cosmology of the first philosopher-scientists, and even less about the observations and hypotheses on which their beliefs were grounded; which is highly frustrating. Very few lines written by the Ionians have survived; from what is known of their teachings, one fancies that their style may have been similar to that of the historian Herodotus: objective, no-nonsense, matter of fact. Later, tiny fragments begin to appear, and when we reach Epicurus, longer ones. The main scientific interest of Lucretius, who did not contribute original notions of his own, is that his complete Latin poem *De Natura Rerum* (De Natura Rerum) has been preserved and gives a highly-readable exposition of the Atomist-Epicurean philosophy, at least as remembered in the first century BC.

Plato and Aristotle comment briefly on earlier beliefs about world models. Theophrastus, their disciple and head of the *Lyceum* after Aristotle, wrote eighteen books on *the physicists*, followed by sixteen more on *the opinions of physicists*; they have all vanished, and Theophrastus himself is directly known only from his popular *Characters*. Still, his lost works have been the source of much later "doxographers", i.e. reporters of opinions, or mere compilers, such as Aetius in the first century AD, who wrote a treatise called the *Placita* (Opinions); but one has to postulate one more lost link between him and Theophrastus. Laertius (perhaps in the third century AD) has left an invaluable but infuriating compilation of his own on the *Lives and Opinions of Eminent Philosophers* (Laertius s.d.), which we often have to use for lack of anything more substantial. He is usually very short on the opinions, which he seems to have half-understood anyway, and much fonder of the lives, accounted for through little anecdotes in the genre of journalistic reporting. Other authors are more than mere doxographers; in the time of Caesar and Augustus, Diodorus of Sicily wrote an extensive and well-preserved *History* that contains fascinating samples of Greek thought (Diodorus s.d.). Cicero, in his *De Natura Deorum,* transmits some ancient doctrines (Cicero 45 BC). Athenaeus of Naucratis

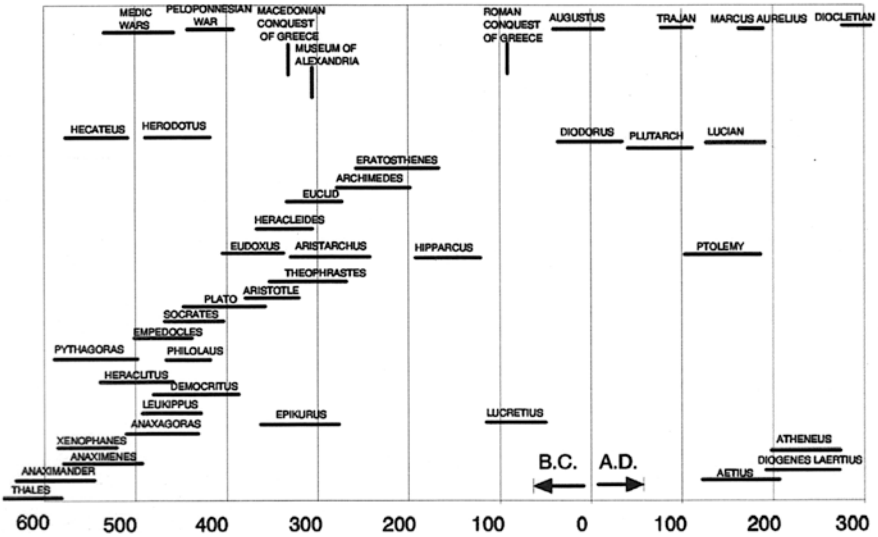

Figure 1.1 Chronology of ancient thinkers

(third century AD), himself a Sophist, left a large treatise, the *Deipnosophistae* (Banquet of Sophists) in which no less than fifteen hundred lost works are mentioned (Athenaeus s.d.). Simplicius, a sixth century AD Neo-Platonician, was mostly concerned with conciliating Aristotle and Plato and refuting Christian thinkers; but in the process, he reproduced valuable fragments of lost works (Figure 1.1).

The Ionians

The main Ionians philosophers were Thales, Anaximander and Anaximenes, all three of Miletus. While not related in a regular chain of master and disciples, they are nevertheless held to form the Ionian (or Milesian) school, which came to an end after the conquest of Ionia by the Persians under Darius in 494 BC. By their exclusive interest in Nature, and the materialistic character of their explanations, they were remarkably close to modern scientists; from their successors they earned the name of "physiologers", i.e. students of Nature. Anaxagoras of Clazimenes, who moved to Athens and was a friend of Pericles, marks the transition to the Atomist school; and a few other names, like that of Xenophanes of Colophon, the first of the Eleatic philosophers, still stand out. Little is known about the Ionians personally, only mere anecdotes survive; everybody remembers the popular one about Thales, gleefully reported by Laertius: "once, when he was taken out of doors by an old woman in order that he might observe the stars, he fell into a ditch… and drew the retort: How can you expect to know all about the Heavens, Thales, when you cannot even see what is just before your feet?",[2] thus giving the whole astronomical profession an enduring reputation for absent-mindedness. Which is still most damaging with the general public, hence with funding committees: how can you entrust expensive machinery to such all-out dreamers?

The problem of Plurality may be divided into three sub-themes. First, what kind of stuff has been used to build celestial bodies, and might they be essentially comparable to our Earth? Second, beyond the limits of the observable world, are there any others? Since these two questions will recur at all epochs, it is convenient to provide them with names; the first be called *Internal Plurality*, i.e. occurring within the visible world, and the second *External Plurality*. There is a third problem: how were these Worlds generated, and why and how did they come to be inhabited? A question that is of course not separate from: how is this very strange feature of Mother Earth itself explainable? These three themes will be followed here as they develop within the Ionian school; however, the discussion would hardly be understandable if some notions were not first given about their more general views of Nature, and in particular, about their embryonic system of the World. One cannot attempt to answer the question: What is the Moon made of, and is it inhabited? without first forming some crude opinion about its size and distance, and even about its motion. However, any full account of geometrical astronomy is beyond our scope: it can be found in books about the history of astronomy.

The first and central characteristic of the Ionian vision of Nature is monism: the World is One, and a common principle is responsible for its organization everywhere; but that principle itself is not the same for all the Ionians. Thales chose water, Anaximenes air, and Xenophanes needed both earth and water, all familiar substances forming a large part of the sublunary world. Cicero reports (Cicero s.d., 29): "Thales of Miletus who was the first person to investigate these matters, said that water was the first principle of things, but that God was the mind that molded all things out of water…" However, Anaximander and Anagoras used far less homely principles, called the *απειρον* and the *νουσ* respectively. Rivers of ink have flowed and dried in vain attempts to translate them properly. The *απειρον* (*Apeiron,* Infinite? Unbounded? Unlimited?) appears to be some kind of substance, but with no specific property except that of being infinite; as reported by Aetius (Aetius, s.d., I, 3, 3): "Anaximander… says that the principle of beings is the infinite (or indefinite), since everything arises from it and everything returns to it. Hence Worlds in infinite (or indefinite) number have been successively formed and destroyed, returning to their principle." We do not feel overly enthusiastic with all that indefiniteness, but neither did Aetius: "He is wrong when he fails to say what that infinite (or indefinite) really is, whether it is air, water, earth or some other body." However,

[2] Laertius s.d., I, 35; but the same Laertius, I, 135, also gives to the same story a far more tragic twist: Anaximenes, in a letter to Pythagoras, had written that Thales, going out to view the stars and "forgetting where he was, got to the edge of a steep slope and fell over. In this way the Milesians lost their astronomer." The Thales story must have been popular in various forms throughout Antiquity; see e.g. Plato in his *Theaetetus* (Heath 1932, 1).

Anaximander should be remembered for having achieved the first "demonstration" of a Plurality of Worlds; most subsequent ones will not prove any more solid.

The Anaxagoras *νουσ* (*Nous,* Intelligence? Mind?) is even more troublesome:

> Mind is infinite and self-ruling, and is mixed with no Thing… it has complete understanding of everything and has the greatest power… Mind took command of the universal revolution so as to make [things] revolve at the outset. At first things began to revolve from some small point but now the revolution extends over a greater area… All [things] were arranged by Mind and also the revolution now followed by the stars, the Sun and the Moon and the Air and the Æther which were separated off…

Even so, those Things remain essentially the same everywhere: "Nothing is absolutely separated off or divided the one from the other except Mind." (texts collected and translated by Freeman 1983a, 84–5); thus one should visualize that *Nous*, permeating the Universe, as more a cause than substance. We shall often make use of the monumental *Anthropic Cosmological Principle* of J.D. Barrow and F.R. Tipler (Barrow 1986, a gold mine, where the gold is sometimes hard to steal); here, they provide a helpful hint: "Anaxagoras aims to explain the orderly motion and arrangement of matter by some subtle and fluid entity which exercises a guiding influence, like a man's mind controls his body."[3] However, it clearly does not signify anything like a personal God: *Nous* acts as an efficient cause, not as a final one. Consequently, it will prove a dangerous heresy to Plato, as will be seen in the next chapter; the *Nous* introduces order within the initial chaos solely through understandable (or at least describable) mechanical actions, such as heavenly rotation. An analogy with Newton's universal gravitation is far-fetched, but does not seem completely absurd.

Within the limits of our subject, the differences between individual Ionians do not warrant further discussion, and the main common feature is their adoption of monism: from such a starting point, they were bound to paint a Universe essentially the same in all its parts and at all times. Right at the beginning of historically recorded rational thought, we can discern the germ of our present Cosmological Principle: all places and all viewpoints are basically equivalent.

Some other features of Ionian thought must at least be mentioned. Ionians are remarkable from being mostly interested in Nature, not in politics nor morality. Somebody once asked Anaxagoras why he was born, and he answered: "To study Sun, Moon and Heavens" (Laertius s.d. I, 141). Hence they were able to teach a materialistic view of Nature, with no similarity to human society and free of any notion of good or evil. Their explanations were as mechanical as those of Descartes in principle, and quite often not so much worse in actual detail. Anaxagoras "held that winds arise when the air is rarefied by the sun's heat; that thunder is a clashing together of the clouds, lightning their violent friction; an earthquake a subsidence of air into the earth" (Laertius s.d. I, 139). As to the rainbow, Xenophanes had a simple explanation: "She whom they call Iris, she too is actually a cloud, purple and flame-red and yellow to behold" (Freeman 1983a, 84–5). His view of the Gods is best

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[3] Barrow 1986*,* 32. Their entire first chapter, devoted to *Design Arguments* at all epochs, is very relevant to the present History.

understood from the very famous fragment: “If oxen (and horses) and lions had hands or could draw with hands… horses would draw pictures of gods like horses, and oxen of gods like oxen…” (Freeman 1983a, 22), which anticipates by two-and-half millennia Voltaire’s “If God has made Man according to his own image, Man has well returned the compliment.” Never has anthropocentrism been more efficiently ridiculed, and the point is worth stressing, as tangled and mostly hostile relations between Plurality and anthropocentrism will occupy a large fraction of the present history. In the Xenophanes world picture, the human vantage point was bound to be unremarkable. He was also first to stress the essential subjectivity of sensation: “If God had not created yellow honey, [men] would say that figs were far sweeter” (Freeman 1983a, 24). This highly-modern outlook (here it is Galileo who is anticipated), freely developed and flourished in Ionia six centuries before Christ; however, it was to cause plenty of trouble when later transplanted to Athens by Anaxagoras, because of a very different political and ideological climate.

A common saying is that Ionians provided the program of modern science, but were quite unable to apply it themselves. Nowhere is this truer than when applied to their system of the World, where they combined quasi-Cartesian method with near-Homeric cosmology. For Thales, (as reported by Aristotle 350BCa, II, 13, 225) “the Earth is at rest because it can float like wood, whose nature it is to rest upon water.” For Anaximander (text known through Hippolytus s.d., citations in Heath 1932, 6) “the Earth is poised aloft, supported by nothing, and remains where it is because of its equidistance from all other things. Its form is rounded, circular like a stone pillar; of its plane surfaces one is that on which we stand, the other is opposite.” The Anaximander geometry is rather crude, but his physics are not so bad; he is also said to have drawn the first map, and to have invented the gnomon. For Xenophanes “this is the upper limit of the Earth that we see at our feet in contact with the air; but the part beneath goes down to infinity.” (Freeman 1983a, 23). Fairly often, we have to make do with such poor crumbs of information. Anaximander writes that the Earth is like “a stone column” (the preserved fragment consists of just these three words), but he may also have believed “that the Earth, which is of spherical shape, lies in the midst, occupying the place of a center” (from Laertius s.d., I, 131); however, since Laertius is here contradicted by all other sources, it is safer to attribute that capital notion to Pythagoras.

On such a flimsy base, it is difficult to build up a geometrically correct system of the world. Thales is at the origin of Greek geometry; according to Laertius, “he was the first to inscribe a right-angled triangle in a circle; whereupon he sacrificed an ox.” (Laertius, s.d. I, 27). Surely, that ox deserves a statue on a huge pedestal as the first innocent victim of Science. Still, Thales does not seem to have applied any of his theorems to celestial motions. All thinkers studied in the present chapter had little use for his geometry, and also made very few quantitative statements. One of the rare ones worth quoting is the estimate of Sun and Moon distances by Anaximander; both were carried by large wheels, and “the circle of the Sun is twenty seven times as large as the Earth, and that of the Moon is nineteen times as large.” (through Hippolytus, Heath 1932, 6). These particular figures must have been selected by pure numerology (Santillana 1970, 29); nevertheless, they also proceeded from a commonplace observation: celestial bodies look the same from any place, hence their distance has to be large compared to the range of our longest travels. This result is an important conquest of the mind on the path to Plurality: the Earth becomes at least roomy enough for other lands, if not yet the Cosmos for other Earths.

Not everybody was convinced, and Heraclitus of Ephesus, half a century later, was to believe that the Sun "is the breadth of a man's foot", and also that "the Sun is new each day" (Freeman 1983a, 25), while Herodotus wrote in his *History* that the Sun, when setting, was closer to India.[4] Anaximander still believed the stars to be below the Sun and Moon, as lunar occultations of stars had not yet been observed. Still, some progress was made; Anaxagoras introduced the order of celestial bodies that was long to remain standard: "The Sun is placed highest of all, after it the Moon and under them the fixed stars and the planets" (Aetius s.d., see Heath 1932, 7), while Anaximenes constructed another classical device, the "stars fixed like nails in the crystalline vault" (Freeman 1983b, 70). This last arrangement was to achieve long-lasting success: the need for some crystalline stuff as supporting medium for both fixed stars and orbiting planets was still felt inescapable four centuries ago; and for the propagation of light, barely one!

Even from their poor geometry, Ionians began to unravel eclipses. Herodotus writes that during a battle between Lydians and Medes "… after they had joined battle, the day suddenly turned into night… [which] had been foretold to the Ionians by Thales of Miletus, who fixed as the limit of time this very year…"[5] By itself, the story does not prove that Thales understood the eclipse mechanism, merely that he had some notion of the involved periodicities, perhaps from Chaldean or Egyptian lore; anyway, the prediction of a total solar eclipse at a given place and time remained altogether beyond mathematical astronomy up to our seventeenth century. Still, Aetius definitely says that Thales was the first to provide a correct explanation for solar eclipses, and Stobeus affirms the same for lunar ones (Dreyer 1905, 14).

At this point, the reader probably feels that such a meagre collection of results does not bring great credit to those much-vaunted Ionians. However he is now free to ask our central question: What are the celestial bodies made of? and this is where the Ionian contribution becomes more tangible.

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[4] Herodotus s.d., III, 104: "As it grows to the afternoon, the sun of India has the power of the morning sun in other lands."

[5] Herodotus s.d. I, 74, see Laertius (s.d., I, p. 25) does not refer to any specific eclipse, but confirms that Thales "was the first to predict eclipses of the Sun… which gained him the admiration of Xenophanes and Herodotus." This eclipse has been mentioned by Pliny and identified by Stephenson (*Journal for the History of Astronomy*, 28, 279, 1997); the date is May 28, 585 BC (i.e., −584 as reckoned by astronomers), and the track of totality covers Northern Greece and Asia Minor. I thank Patrick Rocher of the *Bureau des Longitudes* for providing me with a precise map: the track center passed exactly over Byzantium, and the time was less than an hour before sunset; both Medes and Lydians must have been impressed indeed. Thales, who was in his prime at the time and lived in Miletus, may have seen the eclipse himself but missed totality. Thanks to these modern studies, we know far more about that eclipse and battle timing than either Herodotus or Pliny.

Anaximenes may have been first at least to publicize his speculations: "the Sun, the Moon and the other heavenly bodies are of a fiery nature… the stars give no heat because of the greatness of their distance." (through Hippolytus, Heath 1932, 10). For Anaximander, "the stars are compressed portions of air, in the shape of wheels filled with fire, and they emit flames at some point from small openings" (through Aetius, Heath 1932, 5–6); for Anaxagoras, they are (just like the Sun himself) "stones on fire carried round by the revolution of the æther." His most remarkable guess: "the Moon is of Earthy nature, and has in it plains and ravines" (through Hippolytus, Heath 1932, 26, 2), a view to be fully developed by Plutarch much later.

Let us stop after these few characteristic quotations; many more are available, because the Ionians were obviously fascinated by the subject. The concept of earthy Sun and Moon was an extremely bold one, and it is remarkable that it appeared so early and still acquired so little credibility for so many centuries. "Earthy" here means similar to Earth soil, while "fiery" just means hot, or compounded of fire as we know it in our daily experience. Those earthy and fiery matters should be contrasted with the Peripatetic quintessence and the Stoic fire[6] (see chapter 2), two ingredients that, for a very long time, were to prove far more popular for explaining the Heavens. To make the central Ionian concept more intelligible to the twentieth century mind, earthy might be translated as material, or more accurately rendered by some periphrasis: built of commonplace matter.

The approach of the Ionians ultimately meant that methods of enquiry that do work down here should be tried to solve the heavenly puzzle, a process that took an extremely long time to develop. However, one must grant that such an approach rested on a very flimsy base: Ionians did not possess any hard data unavailable to their opponents. The earthy composition of both Sun and Moon was merely deducted from their monist view of Nature: there could not be any essential difference between Earth and celestial bodies, because in that case, the World would not have been One. Still, Ionians must also have made observations of some kind, and we feel much frustrated to know nothing about them except in a spectacular case: the fall of a large meteorite on the banks of the Aegos Potamos, a river flowing into Hellespontus; this is reported by Laertius in his chapter on Anaxagoras (Laertius s.d. I, 139) and by Plutarch in his *Life of Lysander* (Plutarch s.d., vol. IV). For most Greeks, the meaning of that heavenly stone was clear: it was an obvious portent of the great naval disaster, which soon afterwards terminated the Peloponesian war when the entire Athenian fleet was captured. However, the event also played an important role in the thinking of Anaxagoras: that large chunk of matter provided a key argument for whoever wanted to prove that Earth and sky were one. In a rather similar way and intellectual context, another unexpected celestial happening was to start a similar controversy in the Renaissance epoch: the famous 1572 new star, or supernova in modern jargon. The consequence was that, since the Heavens admitted

[6]The Peripatetics are the followers of Aristotle, and the Stoics those of Zeno of Citium (3rd century BC).

change, they could not be different from Earth in essence; simultaneously, that star was also to be endowed with considerable astrological significance.

While the Plutarch account is most readable, it is too lengthy to be given in full. We are told that

> Anaxagoras is said to have predicted that if the heavenly bodies should be loosened by some slip or shake, one of them might be torn away, and might plunge and fall down to Earth… being of stone and heavy their shining light is caused by friction with the revolving æther, and they are forced along in fixed orbits by the whirling impulse which gave them their circular rotation. (Plutarch s.d., vol. IV).

The mention of an actual prediction is sheer nonsense, but might well be the kind of fable public imagination would construct from Anaxagoras professing not to be surprised by the stone; actually, it just fitted well with his cosmology. The Plutarch story, written five hundred years after the event, is half-popular fancy anyway, but clearly based on an actual large meteorite fall; as to the stone, it was still to be seen in his own days. The Anaxagoras concept of meteorites must be connected to his view of stars, and note the use of centrifugal force: "… the strength of the whirling motion tore away stones from the Earth, and setting them on fire, kindled them into stars." (through Aetius s.d., Heath 1932, 16). The extraterrestrial origin of meteorites was to be disbelieved by most serious thinkers up to the careful study of the meteorite fall at Laigle (in Normandy) by Jean-Baptiste Biot in 1804; a clear historical mistake of scientists which provides present-day saucerologists with their one argument worth a serious discussion. Seen against the Peripatetic concepts that were to prevail up to the Renaissance, i.e. quintessential and incorruptible Heavens, the core of the Anaxagoras model appears a fairly good first approximation of the modern view: that stone truly was a celestial body, and the Sun is made up of hot matter indeed.

A conceptual revolution has taken place indeed, and Athenians made no mistake about it; as already seen, Anaxagoras carried the approach to its logical conclusion and went as far as teaching that "there were dwellings on the Moon, and moreover hills and ravines." (through Laertius s.d., I, 137–9). Athenians officials were not amused: it was politically correct to conceive gods with beards and goddesses with rosy cheeks, but lunar dwellings in pleasant rolling countryside were not acceptable. The result was the banishment of Anaxagoras, despite his friendship with Pericles, and the trial has often been compared to those of Bruno and Galileo. Actually, we know very little about it, and the accounts are contradictory, or even in the case of Laertius somewhat self-contradictory (Laertius s.d., I, 137–9; for a more coherent account, see Freeman 1983b, 263). Anaxagoras may well have been simultaneously tried for "medism", i.e. treason for the benefit of the Medes; modern equivalents under various climates would be heresy, popery, bolchevism or deviationism of the Right or Left. Which is no bar to the analogy between the two trials: the actual charges against Bruno are poorly known, while Galileo definitely stood accused of having meddled in religious matters; judges in such suits generally find a way of avoiding indictments too obviously lying beyond their ken. But the central issue is perfectly clear, just the same: "The people could not endure those philosophers who treated natural phenomena, then called Meteorologists, … because they attributed what pertains merely to the Gods to some natural reasonable causes, and to powers which operate not by Providence or decision of will, but by natural force and constraint…" (Plutarch s.d., Vol. XLII). The Aristophanes comedies give a lively account of popular feelings at the time: in *The Clouds*, it is Socrates who is openly ridiculed, hanging from the roof in his basket, but some of the barbs must have been aimed at Anaxagoras (Santillana 1970, 169 & 184).

Another theme is that of strictly hypothetical Other Worlds, which take two different forms, not always easy to disentangle. The first involves complete systems including both planets and stars, i.e. what we have called *External Plurality*. Thales may have already entertained the thought (Freeman 1983b, 56); for Anaximander, we find a somewhat cryptic sentence: "Those who assumed that the Worlds are infinite in number, as did Anaximander, Leucippus, Democritus, and in later days Epicurus, assumed that they also came into being and passed away ad infinitum…" (through Simplicius, Heath 1932, 5). From the context of everything known about Anaximander, it appears more likely that he was referring to a succession in time of identical worlds rather than to a juxtaposition in space; there is also a Cicero report according to which he had believed "that there are worlds countless in number" (Cicero 45 BC, I, 25 p. 29), which is of no great help. With Anaxagoras, the picture becomes far more precise: "Men have been formed and the other animals which have life; the men, too, have inhabited cities and cultivated fields as with us, and their Earth produces for them many things of various kinds, the best of which they gather together in their dwellings and live upon." (Heath 1932, 29). However, the actual location of these Other Worlds remained quite indefinite, and we still do not know whether they are must be looked for in some foreign space or in long-past times.

The second concept is that of invisible dark bodies somewhere in between Sun, stars and planets; the hypothesis, while just as arbitrary as the first for Ionians, was to prove vastly more fruitful through history, and we still have much use for it today. Anaximenes writes: "The stars are composed of fire… There were also bodies of earthy substance in the region of the stars, revolving along with them" (through Hippolytus, see Heath 1932, 10). We do not know how he reached this conclusion: it may have been some false observation, as in the case of Anaxagoras discussed below; but he may have used pure deduction in the line of: The World is One, with Air as universal generating principle; Air has produced (by compression) the Earth, an obscure body; therefore dark bodies must exist everywhere. Bertrand Russell writes of him "Whenever he is original, he is scientific and rationalistic" (Russell 1946). In the next chapter, we shall meet Pythagoreans also introducing invisible planets, but from altogether different and strictly numerological premises.

With Xenophanes, whose thought is so modern in other respects, we find a rather strange kind of Plurality forming through a curious delusion: "The setting of the Sun happens by way of extinguishment, and another Sun appears at its rising again. There are many Suns and Moons according to the regions, divisions and zones of the Earth" (through Aetius, see Heath 1932, 14). Such a belief is a natural consequence of strict reliance on sensation: since we do not see with our own eyes what happens to the Sun at night, the idea that the same one is indeed seen day after day has the character of an unnecessary hypothesis. Not surprisingly, we shall find the same theme recurring in Epicurus and Lucretius, but this attitude has little to commend itself today.

The Anaxagoras approach is different. While he understood the overall mechanism of lunar and solar eclipses, he still had to account for the greater frequency of the latter, and did it by postulating unknown nearby objects: "The Moon was also sometimes eclipsed by the interposition of the bodies below the Moon" (through Aetius, see Heath 1932, 27). While such an hypothesis is quite unwarranted in this particular case, the method of explanation proves rational: today we have large numbers of stars called "eclipse variables" around which we are pretty certain that a "dark companion" is orbiting. About this invisible object we know nothing whatsoever beyond what is deducted from the light curve of the eclipsed star; happily, this means far more than what the non-specialist might think.

Our third and last concern is the cosmogony of the early Greeks, and their notions about the origin of life. These themes are today totally unconnected, and our specialists of the first question are mostly ignorant of the other. The history of these two subjects might easily deserve full separate studies in their own right; but in order to understand the development of Plurality, one has to know something about both, and both shall be followed here albeit in a superficial manner. About the Thales ideas nothing at all has survived, but those of his followers are known, and they appear staggeringly modern: the concept of slow elaboration by natural processes (particularly mechanical ones), starting from an initial undifferentiated state, is present right at the dawn of recorded thought. Empedocles introduced the four classical elements together with their original separation; he "held that the elements were four: fire, water, æther [i.e. air?] and earth. And Love and Strife are the causes of these. From the first mixture of the elements air was separated out and was spread round in a circle. After the air, fire, running out and finding no other place, ran out upwards under the solid enclosing the air" (through Pseudo-Plutarch, see Heath 1932, 21). Almost simultaneously appeared the vortices. The first descriptions of vortices are distinctly confused; for instance, Parmenides "held that there are certain wreaths (or bands) twined round one another; one sort is made of the rarefied element, the other of the condensed; and between these are others consisting of light and darkness in combination" (through Aetius, see Heath 1932, 19). Today, the crystal spheres have long been shelved and seem pretty unlikely to make any sort of comeback; but the association of chaos and vortices (more exactly, vortices putting chaos into some semblance of order), are still with us thanks to the Atomists, Descartes, Kant, Laplace, von Weiszäcker and to various kinds of astronomical objects. How did the Ionians hit upon that extraordinarily fortunate device?

From the meager available texts, we are reduced to pure guesses. While numberless mythological accounts of the origin of the World have survived, a primordial chaos is one of the few logical possibilities if a materialistic picture is insisted upon. As to the vortex, it may have been a mere lucky choice, but it was an understandable one: however crude the accepted system of the world is (and the Ionian one was passing crude indeed), it is clear that the Heavens are continually revolving, and that several different rotation velocities are simultaneously obvious. Within the sublunary world, apart from human artefacts, there are no clear examples of continuous rotation apart from fluid vortices, and each vortex presents a wide range of speeds as a function of radial distance. Hence, if the celestial World is elaborated not by a Grand Artificer, but by natural forces, vortices stand a fair chance of being taken as tools. However, the Ionian cosmogonical mechanisms remained fully as primitive as their cosmological ones; here is a sample: "Anaximander says that that which is capable of begetting the heat and the cold out of the *apeiron* was separated off … from this was produced a sort of sphere of flame which grew round the air about the Earth as the bark round a tree; then this sphere was torn off and became enclosed in circles or rings, and thus were formed the Sun, the Moon and the stars" (through Pseudo-Plutarch, see Heath 1932, 5).

The Ionian view of the origin of life is far more remarkable than their cosmogony, and deserves extensive quotations from Diodorus of Sicily. At first, the Earth was all wet mud; then

> as the sun's fire shone upon the land, it first of all became firm… portions of the wet swelled up… pustules covered with delicate membranes made their appearance. Such a phenomenon can be seen yet in swamps…While the wet was being impregnated with life by reason of the warmth… by night the living things received their nourishment from the mist… Finally when the embryos had attained their full development and the membranes had been thoroughly heated and broken open, there was produced every form of animal life… Such as had partaken of the most warmth became winged, such as retained an earthy consistence… [became] creeping things, while those whose composition partook the most of the wet element… [became] water animals. And since the earth constantly grew more solid through the action of the sun's fire and of the winds, it was finally no longer able to generate any of the larger animals, but each kind of living creatures was now begotten by breeding with one another.[7]

In short, primitive life grew out of physico-chemical processes, in the presence of water and thanks to incident solar energy, but all of that no longer works today, hence we do not watch spontaneous generation. Diodorus does not refer to any specific Ionian; we may suppose these views originated with Anaximander, because Aetius attributes to him a rather similar mechanism: "The first living creatures came into existence in moist element and had prickly coverings, but, as they advanced in age, they moved of to the drier part; and when the covering peeled off, they survived in their changed state." (see Heath 1932, 8). Some confirmation is available: Anaxagoras believed that "animals were produced from moisture, heat and an earthy substance; later the species were propagated by generation from one another" (Laertius s.d., I, 139) and Xenophanes that "we all have our origin from earth and water." (see Freeman 1983a, 24).

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[7] Diodorus s.d., I, 27. Is it possible to trust him for these surprisingly precise descriptions? Writing that sort of history is most difficult: Diodorus is believed to be quoting from Hecateus of Milesius (contemporary of Anaximenes, early Greek historian, whose works are lost), and Aetius from Theophrastus as usual. However, the views reported here are so close to those held by Epicurus and Lucretius that one fears the Diodorus-Aetius accounts may have become contaminated: Diodorus wrote a few years after Lucretius.

How did Ionians arrive at these remarkable insights? For once, we know the answer: just as we do. Xenophanes definitely understood fossils, and he may not have been the first to do so. He noticed that "shells are found on dry land, and even on mountains, while in several places, such as the quarries at Syracuse imprints of fish and seals have been found…. made long ago and then dried in the mud." (through Hippolytus, Freeman 1983b, 103; see also Dreyer 1905, 19). While never totally forgotten, this interpretation of fossils was to be long emphatically rejected as incompatible with both the Peripatetic and Biblical pictures, and to become widely admitted only during our eighteenth century. Again, the precise mechanisms, those prickly coverings etc.… fancied by the Ionians have not stood the test of time; but the overall direction of their search for explanations is exactly ours. The anticipation of Hutton-Lyell uniformitarianism, i.e. the build-up of the Earth surface in terms of slow action by still-observable forces, is striking: "Someone asked [Anaxagoras] if the hills at Lampsacus would ever become sea, and he replied "Yes, it only needs time."[8] In the next chapter, Aristotle will be seen similarly believing that land would turn into sea and vice-versa: however, for him, this was not a natural and observable process, but a mysterious automatic mechanism which he made no attempt to unravel.

No better way of concluding this account can be found than by presenting the Ionian view on our own origins. First, that of Man himself:

> Anaximander says that at the beginning, Man was born from other species of animals; this he inferred from the fact that while other animals quickly manage to find food for themselves, man alone needs long nursing. If he had been what he is now, he could not possibly have survived. (through Pseudo-Plutarch, Heath 1932, 8).

Next, language:

> Though the sounds which they made were at first unintelligible, yet gradually they came to give articulation to their speech… and made known the significance to be attached to each term. (Diodorus s.d. I, 29).

Last, civilization:

> The first men… led a wretched existence, having no clothing, knowing not the use of dwelling and fire, and also being totally ignorant of cultivated food… large numbers of them perished in the winters. Little by little, however, experience taught them both to take to the caves in winter and to store such fruits as could be preserved. (Diodorus s.d., I, 31).

Now these surprising men that Anaxagoras had located in unspecified Worlds, become more understandable, and may be seen as close brothers of our present-day intelligent aliens; of course without alluding to the flying-saucer craze, but to the serious modern hypothesis first formulated in a precise manner by Huygens, and shared by many sober-minded scientists of today. The Ionians had conceived the universe as One, with a single common principle at work everywhere, and vortices

[8] Laertius s.d., I, 141. Herodotus (s.d. II, 10), in his description of Egypt invokes similar mechanisms: the Nile delta (and also the country around Ilion, Ephesius and the Meander plain) is just alluvial soil.

organizing chaos into Worlds like our own. Life was arising out of dead matter, humans out of animals, and civilized peoples out of primitive ones, solely through the play of natural forces. Then, the inescapable consequence was: that grand experiment cannot have succeeded only once, and Man cannot be alone! Two and half millennia later, we have not found any truly novel argument; and no escape nor confirmation either.

The Atomists: Leucippus and Democritus

Extremely little is known about Leucippus, first of the Atomists; it comes as a shock to learn that, hardly more than a century later, Epicurus did not believe in his existence at all, and even Laertius devotes but a few lines to him. Democritus of Abdera is less hazy; nevertheless, while he wrote encyclopædically, the remains of his work are few: mainly aphorisms, some of them quite popular, but seldom dealing with the physical world. Hence we must again resort to the same unsatisfactory sources through which we followed the Ionians; even so, we are lucky because his near-contemporary Plato, for whom Democritus was the archenemy, did not quite succeed in burning all his books, which he is reported to have attempted (Laertius s.d., II, 449).

A discussion of the Atomists at this place is logical because their view of Plurality, indeed their entire cosmology, is very similar to the Ionian one, only far more articulate, and slightly better preserved. Furthermore, it may be said to have acquired a scientific basis: for Anaxagoras & Co., Plurality had remained (somewhat paradoxically) a consequence of Monism, a purely philosophical position, but for Atomists it becomes a part of Atomist physics, which (to a modest extent) anticipates modern atomic theory. Still, a word of caution: ancient atomism, as pioneered by Leucippus, developed by Democritus, adopted by Epicurus and most extensively transmitted by Lucretius, does not derive solely from Ionian thought. In order to understand the genesis of atomism itself, all Greek science of the sixth and fifth centuries BC would have to be followed; in particular that of the Eleatic and Pythagorean schools. Pythagoras and his followers will be discussed in the next chapter, but merely for their views about Plurality, which had no perceptible influence on the Atomists, even if Democritus did write a book on Pythagoras (Santillana 1970, 147). Hence we will grant Atomism with only a summary description, and pass on to Plurality.

Democritus writes that he was “a young man in the old age of Anaxagoras”, and in Athens, he must also have met Socrates, ten years older than himself (Freeman 1963, 92; Santillana 1970, 142). He was one of the most universal minds of the antique world, and his lost works (at least as listed by Laertius) cover not only mathematics, physics, astronomy, biology, medicine and some technologies, but also music and morals. For him the sovereign good was *euthymia,* a clear forerunner of Epicurean *ataraxia,* i.e. utter peace of mind; nevertheless he held the domains of morals and physics as totally separate: “Law is an invention of men, while atoms and the void exist according to Nature."[9] Hence his view of that said Nature was free to remain as purely causal and materialistic as that of the Ionians, who had been unconcerned with morals. Moreover, one priceless fragment makes him say that he would "rather discover one cause than gain the kingdom of Persia." (Freeman 1983a, 104). Nobody ever found a better formula for describing the true scientist.

Geometry had much progressed since the time of Thales, and Democritus himself seems to have been no mean mathematician: Archimedes will attribute to him the discovery of the volume of cone and pyramid, but the demonstrations were only given by Euclid. Clearly, the influence of developing geometry, and of the Eleatic paradoxes about motion, was of prime importance in the birth of the atom-plus-void concept; still, just as with Thales and his followers, Democritean astronomy remained surprisingly non-geometrical. Indeed, it was a close kin of the Ionian branch, with few Pythagorean influences.

Anaxagoras is sometimes described as having introduced a form of "qualitative atomism": matter indefinitely divisible into an infinite number of qualitatively different elements, coupled with a rejection of vacuum; but the Leucippus-Democritus brand of atomism is far closer to the modern view, all out of purely logical arguments: no sort of experimentation appears anywhere. Their world is made of a vacuum within which atoms are freely swimming; they are of finite size, because an infinite set of successive subdivisions of Being is taken as a logical absurdity. In modern parlance, the existence of quanta is postulated a priori, not as the result of any observation or experiment. Atoms are infinite in number, the World being unlimited; they differ by purely geometrical and quantitative characters: size, shape, and position. They do not yet have weight, an important feature added later by Epicurus. They move freely within a vacuum, apparently along straight lines, until they collide; associations of atoms are being formed or dissolved all the time.

Everything reduces to atoms, and (just as for Xenophanes), mere sensation is not a guide to knowledge. Democritus: "Sweet exists by convention, bitter by convention, color by convention; atoms and the void [alone] exist in reality." (Freeman 1963, 104). The sole governing force is Chance, by which is meant absence of intelligent planning, not lack of immediate causes: the Atomist Chance is basically anti-finalist but not anti-determinist, and anti-theological, but not anti-rationalist. Almost the only surviving Leucippus fragment (from a treatise *On Mind*) is "Nothing happens at random; everything happens out of reason and by necessity",[10] while for Democritus: "All things happen by virtue of necessity, the vortex being the cause of the creation of all things."[11] Their Universe stands in no need of any theological

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[9] From the French translation of Laertius by R. Genaille (1933, classiques Garnier, Paris), chapter *Démocrite*, 183. The Loeb English translation of R.D. Hicks is less striking "The qualities of things exist merely by convention; in nature there is nothing but atoms and void spaces."

[10] Freeman (1983a), 91. B. Russell (1946) writes: "It was common in antiquity to reproach the Atomists with attributing everything to Chance. They were, on the contrary, strict determinists, who believed that everything happens in accordance with natural laws."

[11] Laertius (s.d.), II, 455. To understand the bases of Atomism, see Santillana (1970), Chapter 9: *Atoms and the Void*. On Democritus, see the presentation in Freeman (1983b), 289–322.

explanation, as vacuum, atoms and motion are eternal. A key belief: “Naught exists just as much as Aught” (Democritus, see Freeman 1983a, 104); for context, one has to remember the categorical rejection of vacuum by the Eleatics, for whom a perfect void was a logical absurdity (it will remain one even for Descartes!), since non-Being may not exist; consequently, neither does motion, which is impossible without a vacuum to move within. For the Atomists, the four elements together with all the phenomena, forms and qualities present in the Universe have to be accounted for by motions and groupings of atoms; hence, they cannot allow any essential difference between Earth and Heavens. Their form of Plurality was not merely being taught but became an essential part of their doctrine because it was fully deducted from atomist physics. Scientists today follow their line of thought rather easily, since they construct their own picture of the Universe starting from their own atomic physics.

Let us adopt the same plan, and ask the same questions as for the Ionians. First, the system of the world remains dismally similar, and Atomism has been the source of no improvements. The Earth shape is for Leucippus “that of a tambourine” (Heath 1932, 36), while Democritus held it as “disk-like laterally, but hollowed out in the middle” (Heath 1932, 38); all of which is quite shocking, a full century after Pythagoras had taught the sphericity of the Earth. Did Leucippus really believe that “the Sun revolves in a larger circle round the Moon”, and also “the Earth rides steadily, being whirled about the center” (Laertius s.d. II, 441)? This last statement seems remarkable, but no confirmation is found anywhere, and the idea was not followed up by later Atomists; in any case, it might merely mean that one important Pythagorean novelty had finally percolated to Leucippus. If we believe Seneca (quoted by Dreyer 1905, 28, Note 6), Democritus did not even know the number of the planets, and merely described them as moving from east to west a bit slower than the stars. Nevertheless, he was first to explain correctly an obvious but mysterious feature of the Heavens: “Anaxagoras and Democritus held that the Milky Way is the light of certain stars.” (Aristotle 350BCb, A8, 345 p.25–31, quoted by Heath 1932, 28). Of course, this hypothesis was wholly *a priori*; no observations are quoted, and indeed none could be relevant before Galileo, with his primitive telescope, demonstrated the explanation that had been preserved by a small minority of thinkers. What the original Atomist reasoning had been is not reported, but we may at least make a guess: when the mind’s eye visualizes earthy matter as made up of discrete atoms, it is bound to resolve likewise that heavenly whitish stuff into stars. True, they are not individually perceived, but neither are atoms in a bowl of milk. Henceforward, one more important piece of the celestial puzzle had been located.

The nature of celestial bodies for the Atomists is about the same as for the Ionians. The Sun is again “a red-hot mass, or a stone on fire”, while “the Moon has the appearance of being earthy … it has hollows and valleys.” (Democritus through Aetius, Heath 1932, 38). This last view is not new, being inherited from Anaxagoras; it will become a central theme for Plutarch, and followed in our Chapter 3. Nevertheless, the conceptual gain is quite large: Moon and Sun are earthy because they are built from the very same atoms which make up our Earth, and which have been everywhere generated in the same way. That primordial sameness applies not merely to the Moon, but to all other Worlds, seen or unseen:

> Democritus said that there are Words infinite in number and differing in size. In some there is neither Sun nor Moon, in others there are more than one… Some are growing, others are at their prime, and others again declining, in one direction coming into being, in another ceasing to be… Their destruction comes about through collision with one another… Some Worlds are destitute of animal and plant life and all moisture. (Democritus through Hippolytus, Heath 1932, 38. See also Freeman 1983b, 302).

The picture of independent and uncorrelated time-development for all these Worlds is remarkably modern.

How did these multiple and more-or-less parallel Worlds come into being? According to the Leucippus account, it had all been the result of strict atomist mechanics:

> The All is unlimited… but of the All, part is full and part empty, and these he calls elements. Out of them arise the Worlds unlimited in number, and into them they are dissolved. This is how the Worlds are formed… many atoms of all manner and shapes are carried from the unlimited into the vast empty space. These collect together and form a single vortex, in which they jostle against each other… The atoms being so numerous that they can no longer revolve in equilibrium, the light ones pass into empty space as if they were being winnowed; the remainder keep together and, becoming entangled…form a primary spherical system… In this way the Earth is formed by portions brought to the center coalescing… The outer shell grows larger by the influx of atoms from outside… Some portions are locked together and form a mass at first damp and miry, but when they have dried… they afterwards take fire and form the substance of the stars… As the World is born, so too it grows, decays and perishes, in virtue of some necessity, the nature of which he does not specify. (Leucippus through Laertius s.d., II, 441–3).

That last comment was just Laertius complaining: as usual, he understands little of what he is reporting. Fortunately, Leucippus makes more sense for us than he did for him, and the reader may judge for himself the uncanny analogies with Kant-Laplace type theories: many of the essential features are present. Still, there is one marked difference: for the Atomists and their later followers, indeed for everybody up to Giordano Bruno, all fixed stars remain a constituent of our own "planetary system" (an anachronistic term of course), of which they merely form the boundary. Their Universe, being infinite, is filled *ad infinitum* by similar vortices, each of which generates a similar World. Here, "World" means a complete assorted package with full complement of Earth, planets (in the etymological sense, which includes Sun and Moon) and stars. Hence, these other hypothetical Worlds are not centered on any of the visible stars, since each star is a part of our own World, which encloses every single visible body. The existence of other Worlds is asserted with great confidence, but they are, by hypothesis, unobservable; this kind of belief is what we have called *External Plurality*.

That dogma had been gifted at birth with a serious vice: it could not be tested in any way, and we must deny to it the rank of a scientific hypothesis, despite some uncanny similarity with modern fancies, to be explored in our last chapter. Unsurprisingly, it had very little impact over the centuries, and most sensible thinkers were to find it unpalatable; other vices will become apparent with Epicurus and

Lucretius, and the Atomist version of Plurality largely ranks with Eternal Return, another vision to be discussed with Pythagorean contributions. Still, we have never been able to fully outgrow them; the picture of a hierachical order of the Universe recurring *ad infinitum* seems to recur *ad infinitum* in history, and we shall find the names of Lambert and Charlier associated with it in the modern epoch. What about the future? The possibility of multi-Universes outside ours is often discussed by cosmologists: here, we are back to Leucippus or even Anaximander, and just as free to speculate.

All these speculations may seem downright naive, as implying that ancient Greeks had found everything worth knowing. When *Internal Plurality* is concerned, this is very far from true: immense labor was to be required for transforming the theme into the present scientific hypothesis. On the way, it will acquire one indispensable adjunct, testability, but it will keep its central feature: others Earths, with full cargoes of intelligent beings, may indeed be cruising around, and not nearly as far as the Greeks had located them.

Epicurus and Lucretius

When Epicurus was born, Plato and Aristotle were already old men; however, as we do not follow strict chronological order, they will both be dealt with only in the next chapter. Epicurus wrote three hundred books, and all are lost; thankfully, Laertius transcribed his will (which dealt mostly with the famous Garden, located in the outskirts of Athens), three long *Letters* which he may or may not have written, and forty of his *Maxims*, famous throughout Antiquity. Since these texts summarize his thought, far more material is available than from the Atomists. Epicurus was to remain immensely popular, mostly as the founder of an important and long-lasting school[12]; moreover the extensive and well-preserved Lucretius poem *De Natura Rerum* (Lucretius, s.d.) mainly follows his teachings, although specialists debate many possible disparities.

The difference in starting point with Ionians and Atomists is radical: Ethics take the central place, and most Epicurean converts did not care a rap about physics or astronomy. The aim of all Epicurus teachings is the achievement of *αταραξια* (ataraxia), i.e. the utter peace of mind: all fundamental scientific research has no other justification! Maxims 1 and 12:

> If we had never been molested by alarms at celestial and atmospheric phenomena, nor by the misgivings that death somehow affects us, nor by neglect of the proper limits of pains

[12] Santillana (1970), 289: "The Garden was not only a school: it was a sort of retreat or religious community, in which women, even slave women, took part freely. The atmosphere was one of almost romantic friendship and tenderness, such as was not to occur again for centuries, until the Christian agape. Epicurus was treated by his disciples as the Deliverer, and every word he said as a doctrine of salvation." Hence, the immense and lasting success of Epicureanism was due in part to causes not unlike the ones that acted for Christianity, which was to treat it as archenemy.

> and desires, we should have no need to study natural science. It would be impossible to banish fear… if a man did not know the nature of the whole Universe, but lived in dread of what the legends tell us. (Epicurus through Laertius s.d., II, 667).

Clearly, the final goal is not knowledge, but comfort; while Democritus had been the prototype scientist, Epicurus does not qualify as one, and even stresses his hostility to disinterested scientific inquiry. Even so, what sort of science does he pick up? The Ionian-Atomist brand fitted the bill perfectly, since no other was so free of myths: remember Xenophanes. Hence Epicurus mostly adopts off-the-shelf Atomist physics and cosmology.

However, he does meddle with the method of science, and brings in important differences. One is that mathematics procures no pleasure at all, and that all geometry is false. As seen by Epicurus himself, pleasure, in the elevated Epicurean sense, is the true goal. Mere falsity proves no great drawback within any explanation, provided it stands as both plausible and non-mythical. In his *Letter to Pythocles*, mostly devoted to celestial phenomena, he stresses that "these phenomena admit, to the extent that one agrees with the appearances, several different possible explanations of their cause and of their nature." (Laertius s.d., II, 615; our translation from the French one by Genaille). Hence, several mutually incompatible theories of a given phenomenon may be simultaneously accepted and the more the better, since the goal is never absolute truth, but mere peace of mind. Some of his views on astronomy will be quoted later and illustrate well this Epicurean attitude, which a modern mind easily confuses with a caricature of skepticism. Actually, it is nothing of the kind, but merely *sensualism*[13] carried to the extreme: nothing must be trusted beyond direct sensation. While explanations are needed to achieve *ataraxia*, it is enough that, out of the many conceivable materialistic ones, some should save the phenomena. Seen in this light, the Epicurus contribution to the scientific method is not quite so negligible as often made out. Whenever we do not have the crucial data, we may only list in parallel all plausible hypotheses; that is invariably the situation for any problem at the frontiers of science, for instance the existence of *ETI*.

The most remarkable positive contribution of Epicurus to the method of science is a complete refusal of theological or teleological explanations. This attitude has never been better or more fully expressed than in the following quotation:

> … in the sky, revolutions, solstices, eclipses, risings and settings and the like, take place without the ministration and command, either now or in the future, of any being who at the same time enjoys perfect bliss along with immortality… Nor must we hold that things which are no more than globular masses of fire, being at the same time endowed with bliss, assume these motions at will… Phenomena invariably recurring… must be ascribed to the original interception and conglomeration of atoms whereby the World was formed." (*Letter to Herodotus*, Laertius s.d., II, 607).

The concept is stressed again and again; for instance, about the regularity of orbits: "The divine nature must not on any account be adduced to explain this… unless this be done, the whole study of celestial phenomena will be in vain." (*Letter*

[13] The proper but cumbersome philosophical term seems to be *sensationalism.*

to Pythocles, Laertius s.d., II, 625). We cannot help applauding; but, as discussed a little later, Epicurus notions about what risings, settings etc.… induce no enthusiasm today. However, his anti-finalist attitude is worth a few more quotations: during the greatest part of the present history, the theme of Plurality will flower under the guidance of unabashed teleologists, but it had been planted by a different breed of gardeners.

In the footsteps of his master Epicurus, Lucretius was to show best the simultaneous rejection of finality and anthropocentrism:

> Some people who know nothing of matter believe that nature without the guidance of the gods could not bring round the changing seasons in such perfect conformity to human needs, creating the crops and other blessings that mortals are led to enjoy… Obviously, in imagining that the gods established everything for the sake of men, they have stumbled in all respects far from the path of the truth. Even if I knew nothing of the atoms, I would venture to assert on the evidence of the celestial phenomena themselves… that the universe was certainly not created for us by divine power: it is so full of imperfections. (*De Natura Rerum*, 65). … Of what is covered by the wide sweep of the sky, part has been greedily seized by mountains and the woodland haunts of wild beasts. Part is covered by crags and desolate bogs and the sea that holds far asunder the shores of the lands. Almost two thirds are withheld from mankind by torrid heat and perennial deposits of frost. The little that is left of cultivable soil if the force of nature had its way, would be choked with briars, did not the force of man oppose it… (*De Natura Rerum*, 117).

Such is the background from which Lucretius extracted his belief in Plurality. The deep irony of it all is that their Christian archenemies were fated (in the very long run) to reach exactly the same conclusion as necessary to the manifest perfection of their God-designed Universe. Strange planet, indeed.

In the Epicurus and Lucretius writings, we find an exposition of Atomism far more complete than in the scant preserved texts from Democritus and Leucippus. The most striking passages give a description of atom behavior that sometimes reads as if extracted from some popular text on kinetic theory, complete with a description of Brownian motion. For once, Epicurean sensualism is shelved, and Lucretius even stresses all the reasons why we must believe in atoms even if we cannot see or feel them. It is a great pity that the Epicurean attitude about celestial bodies is not similar: here, strict sensualism is also adhered to, with disastrous results. All those brilliant Ionian or Pythagorean astronomical concepts are forgotten; and as for mathematics, if addition and subtraction had been unknown at the time, not one Lucretius verse would need changing. Within any straightforward history of astronomy, the *De Natura Rerum* may be skipped entirely. In its relation to Aristarchus, Hipparcus and Archimedes, it reads like a popular-science manual written by some surviving seventeenth-century Peripatetic unaware of Copernicus, Kepler and Galileo; not counting Descartes. What about the spherical Earth? In a few all-too-famous verses, Lucretius makes fun of those who believe

> the theory that everything tends towards what they call the center of the world… Whatever heavy bodies there may be under the Earth must then tend upwards and rest against the surface upside down, like the images of things which we see reflected in water. In the same way, they would have it that animals walk about topsy-turvy and cannot fall off the Earth

> into the nether quarters of the sky…But this is an idle fancy of fools who have got hold of the wrong end of the stick. (*De Natura Rerum*, 58).

All of this follows strict Epicurean principles: what happens beyond the horizon is not perceptible to the senses, hence why bother? However, more than plain sensualism is involved: nowhere is found any positive statement about the shape of the Earth; one feels nostalgic about the Ionian drums, columns or hollow disks… The reason is the Epicurean mistrust of geometry: it is not useful to present any geometrical description of the Earth, not even an analogy with any commonplace object; nor is any geometrical description of celestial motions attempted. Still, Epicurus cannot ignore plainly visible phenomena like risings and settings of celestial bodies, but shows characteristic indifference as to which explanation may be true:

> The rising and setting of the Sun, Moon and stars may be due to kindling and quenching… no fact testifies against this. Or the result might be produced by their coming forward above the Earth and again by its intervention to hide them. And their motions may be due to the rotation of the whole heaven, or the heaven may be at rest and they alone rotate. (*Letter to Pythocles*, Laertius s.d., II, 621).

The striking Empedocles discovery that Night is merely due to the shadow of Earth had been a great conquest of the mind; but the Lucretian account remains appallingly primitive, and multiple:

> The reason why the night shrouds the Earth in far-flung gloom may be that the Sun, exhausted by its long day's journey, has reached the utmost limits of the sky and puffed out its travel-spent fires enfeebled by excess of air. Alternatively, it may be driven to double back under the Earth by the same forces that guided its globe above the Earth…Or it may be that at the determined hour there is a concentration of fires, a confluence of many particles of heat which regularly causes the solar radiance to be born again. (*De Natura Rerum*, 191).

More analogies follow, all equally unfortunate; that laudable *a priori* belief in identity between celestial and terrestrial phenomena here goes wrong, and badly wrong indeed. There is far more in the same vein: "Next, as to the size of the sun's blazing disk: it cannot in fact be either much larger or much smaller than it appears to our senses…" (*De Natura Rerum*, 188), and Epicurus had said much the same thing. Both may have been remembering Heraclitus to whom we owe (out of many densely-foggy views) two clear statements: the already quoted one about Sun being the size of a human foot, and "The Sun is new each day." (Heraclitus, see Freeman 1983a, 25).

Next,

> What, then, about the Moon? It may be that it shines only when the Sun's rays fall upon it…It is equally possible that it rolls round with a lustre of its own and displays changing shapes of luminosity… Or perhaps the Moon is a rotating sphere of which one half is gilded with resplendent light… Lastly why should not a new Moon be created periodically with a definite sequence of determinate shapes… In the same way, you must understand that various causes may account for eclipses of the Sun, and the Moon's occultations. (*De Natura Rerum*, 192–3).

Lucretius does not even quote the Aristotle moon-mirror theory (to be described later), and never mentions the Moon markings at all; Epicurus had at least attempted multiple explanations: “The appearance of a face in the Moon may equally well arise from interchange of parts or from the interposition of something, or in any other way…” (*Letter to Pythocles*, Laertius s.d., II, 623). Lucretius strictly sticks to the apparent diameter: the Moon is not “of bulkier dimensions than those with which it appears to our eyes…” (*De Natura Rerum*, 188). Within such a Moon, there is no longer room for hills, valleys, shadows, dwellings, nor living creatures of any kind. Lastly, Lucretius does not mention planets anywhere, and Epicurus dismisses them in a few characteristic lines “That: certain stars are seen to be left behind by others may be because they travel more slowly…or… or…” (here, three perfectly incompatible accounts follow), since “to lay down a single explanation of these phenomena is worthy of those who seek to dazzle the multitude with marvels.” (*Letter to Pythocles*, Laertius s.d., II, 641).

The redeeming point is that Atomist theory applies everywhere, so celestial bodies should not differ from Earth in any essential way: “The Sun and the Moon and the stars were not of independent origin and later absorbed within our world… but began to take form by the accretions and whirling motions of certain substances of the finest texture of the nature of either wind or fire or both.” (Epicurus, *Letter to Pythocles*, Laertius, II, 619). However, this thought is never followed up, and remains purely theoretical. The Sun is no longer a hot rock, the Moon is not earthy; no interest is shown in meteorites. Conclusion: the observed celestial bodies are not possible abodes for life. Altogether, Epicureans rejected *Internal Plurality*, but for reasons which had nothing to do with those of the Peripatetic school, as we will see in the next chapter.

So far the contribution of Epicureans to astronomy in general, and to our Plurality problem in particular, appears null or negative. The picture becomes drastically different with their views of Space, and of yet-unseen Worlds. Here, they went far beyond their Platonist or Peripatetic adversaries, and outran mathematical astronomers, all similarly saddled with a spherical Universe, and stuck within crystal spheres of their own making. Actually, they did not progress so much beyond the conclusions of Ionian and Atomists, but the sheer volume of preserved material makes their argumentation much easier to follow. And mere arguments will be all we get, since no new observations will be forthcoming until Galileo appears on the scene.

Here is, from the Epicurus pen, the first actual demonstration of an infinite Universe:

> The Universe is boundless. For that which is bounded has an extreme point, and the extreme point is seen against something else… if on the one hand the void were boundless and the bodies limited in number, the bodies could not stay anywhere, but would be carried about and scattered through the infinite void, not having other bodies to support them in place by means of collisions. But if on the other hand the void were limited, the infinite bodies would not have room wherein to take their place. (translation by Santillana 1970, 228).

On this key point, Lucretius contributes a brilliant and famous thought-experiment of his own that has not aged in the least, the *Lucretian Arrow*:

> Suppose for a moment that that the whole of space were bounded, and that someone made his way to its outermost boundary and then threw a flying dart. Do you choose to suppose that the missile, hurled with its might and main would speed along the course on which it was aimed? Or do you think something would block the way and stop it? You must assume one alternative or the other. But neither of them leaves you a loophole. Both force you to admit that the Universe continues without end. Whether there is some obstacle lying on the boundary line that prevents the dart from going further on its course, or whether it flies on beyond, it cannot in fact have started from the boundary. With this argument, I will pursue you. Wherever you may place the ultimate limit of things, I will ask you: well, then, what does happen to the dart? (*De Natura Rerum*, 55).

Unavoidably, the absence of limits entails the absence of center. Lucretius again:

> [the Universe]…can have no limit and is accordingly without end or measure. It makes no odds in which part of it you may take your stand: whatever spot anyone may occupy, the Universe stretches away from him just the same in all directions without limit. (De Natura Rerum, 55).

Further automatic consequence: the Earth's position is unremarkable. In the very same passage where he has just derided that foolish sphericity of the Earth, Lucretius concludes:

> There can be no center in infinity. And, even if there were, nothing could stand fast there rather than flee from it… There is no place to which bodies can come where they lose the property of weight and stand still in the void. (*De Natura Rerum*, 58).

And in another page:

> It makes no odd in which part of [the Universe] you may take your stand: whatever spot anyone may occupy, the Universe stretches away from him in all directions without limit. (*De Natura Rerum*, 55).

This is our future Cosmological Principle, fated to be utterly forgotten and then rediscovered by Cardinal Nicolaus Cusanus starting from a diametrically opposite philosophy, since the Cusanian Universe operated under the care and watch of an all-powerful God.

This boundless Universe constitutes the only possible stage for the entrance of the hero, Plurality; here is the cue, as given by as Epicurus:

> … There is an infinite number of Worlds, some like this World, others unlike it. For the atoms by which a World might be formed have not all been expended in one World or a finite number, whether like or unlike this one. Hence there will be nothing to hinder infinity of Worlds. (*Letter to Herodotus*, Laertius s.d., II, 575).

Nothing hinders, indeed, and we are still stuck with the same argument today. How did they come to be? "All these [Worlds] have been separated off from conglomerations of atoms; and all things are again dissolved, some faster, some slower… Further, we must not suppose the Worlds have necessarily one and the same shape." Here Laertius interpolates some comments of his own "It is clear then that he also makes the Worlds perishable… [and their] shapes differ, some being spherical, some oval, others again of different shapes." (in Epicurus *Letter to Herodotus*, Laertius s.d., II, 603). Care is required: Worlds here again do not mean Earths, but packages equivalent to our complete celestial system, including stars: "A World is a circumscribed portion of the Universe which contains stars and Earth and all other visible things…[with a boundary] which may either revolve or be at rest, and be round or triangular or of any other shape whatever." The queer proposal of variegated shapes for these Worlds and their envelopes is merely regular Epicurean procedure: "all these alternatives are possible: they are contradicted by none of the facts in this World, in which an extremity can nowhere be discerned." The Epicurus stage instructions about their relative places are not of the clearest, as might be expected from such a non-geometric mind: "Such a World may arise in a World or in one of the *intermundia* (by which term we mean the spaces between the Worlds), and not, as some maintain, in a vast space perfectly clear and void." (*Letter to Herodotus*, Laertius s.d., II, 603). However, Descartes the expert geometer will also have to execute some contortions exploring the no man's land in between his Vortices.

Finer points of Epicurean atomist theory cannot be discussed here, but there are some differences with Democritus. The atoms are now gifted with weight, and also receive a "swerve" in their travels, i.e. a tendency to depart from linear motion through pure chance (here in the modern sense) and not from immediate causes; Epicurus seems to have believed this added feature necessary to preserve freedom. These additions entail a somewhat different mechanism from that used for the generation of Worlds (but, from our modern viewpoint, neither an improvement nor clarification). His criticism is here aimed at Democritus: "it is not enough that there should be an aggregation or vortex in an empty space… as one of the so-called physicists says", and his own solution requires that "certain suitable seeds rush in from a single World or intermundium, … and undergo waterings from appropriate sources until they are matured and firmly settled." (*Letter to Pythocles,* Laertius s.d., II, 619). In case you do not feel overly enthusiastic about the Epicurus mechanism, stop to think of how your own pet theory of planetary formation might look like in the year of grace 4000 AD.

Lucretius shares the Epicurus view of Plurality, but is far more explicit and easier to follow than his Master who, incidentally, he must have often found hard to swallow himself: "I am well aware that it is not easy to elucidate in Latin verse the obscure discoveries of the Greeks." (*De Natura Rerum*, 31). At first, some of his arguments are mere analogies:

> Nothing in the Universe is the only one of its kind, unique and solitary in his birth and growth. Turn your mind first to the animals. You will find the rule applies to the brutes that prowl the mountains, to the children of men, to the voiceless scaly fish and all the forms of flying things. So you must admit that the sky, Earth, Sun, Moon, sea and the rest are not solitary but rather numberless… (*De Natura Rerum,* 92).

He becomes more convincing when he shows that the generation of multiple Worlds is an automatic consequence of an infinite Universe plus atomism:

> Granted then that the empty space extends without limit in every direction, and that seeds innumerable in number are rushing on countless courses through an unfathomable universe under the impulse of perpetual motion, it is in the highest degree unlikely that this Earth and sky is the only one to have been created, and that all those particles of matter outside are accomplishing nothing. This follows from the fact that our world has been made by nature through the spontaneous and casual collision and the multifarious, accidental and purposeless congregation and coalescence of atoms whose suddenly formed combinations could serve on each occasion as the starting point of substantial fabrics, Earth, sea and sky and races of living creatures. (*De Natura Rerum*, 91).

The Lucretian process is strictly mechanical, and everywhere he stresses the absence of purpose; even so, we easily ferret out a hint of unconscious finality in his text, since those outside atoms are not allowed to "accomplish nothing": they must be of some use. Hence, some grand master plan must be hidden behind the scenery; but it would be quite easy to find similar lapses under the pen of some modern scientists.

And Lucretius carries the Plurality play to the *dénouement* we are all expecting:

> When there is plenty of matter in readiness, when…you have a store of atoms that could not be reckoned in full by the whole succession of living creatures [on Earth]. You have the same natural force to congregate them in any place, precisely as they have congregated here. You are bound to acknowledge that in other regions there are other Earths and various tribes of men and breeds of beasts. (*De Natura Rerum*, 91–2).

Altogether, a clear, concise and brilliant summary; does it imply that Lucretius or his disciples have solved the problem and must be blindly followed because they have evolved a Plurality model wholly free of final causes? Let us give voice to the modern philosopher L.W. Beck: "I suspect that deep-seated philosophical, religious and existential commitments which once availed themselves of the argument from design are still silently effective in guiding the Lucretian argument and keeping alive the archetypal idea that man is not alone." (Beck, in Regis 1985, 12). To this hostile but acute verdict we shall have to return *in fine*.

Lucretius, so far, does not seem to have proceeded beyond the ground already cleared by Ionians and Atomists; however, we will now show that his remarkable understanding of a continuous evolution as a natural process accounting for Worlds, life, intelligence, language, society and technology, puts his contribution in a different light. When he just stressed that in other Earths there are various tribes of men and breeds of beasts, he truly meant what he said, since he was able to account for their birth and growth. His research program had been inherited from Anaximander, but Lucretius reached far more striking conclusions than all predecessors. The last book of *De Natura Rerum* reads like the summaries (not merely the titles!) of any present *SETI* conference; when we follow his text, we meet all the factors that will appear in that famous Drake equation (see appendix of Chapter 13), and nearly in the same order.

First of all, what is Time? "Time by itself does not exist, but from things themselves there results a sense of what has already taken place, what is going on now, and what is to ensue." (*De Natura Rerum*, 40–1). Simple, straightforward and effective: the old Kronos, father of them all, lies fully debunked; demoted from divinity, he does not even rank as an entity. Theological and/or philosophical speculations are out, and we are freed to observe things as they evolve. At once, we are given a clear view of Uniformitarianism, already known to the Ionians:

> Again, in the course of many annual revolutions of the Sun, a ring is worn thin next to the finger with continual rubbing; dripping water hollows a stone. A curved ploughshare, iron though it is, dwindles imperceptibly in the furrow… Whatever is added to things gradually by nature…eludes the most attentive scrutiny of our eyes. Conversely, you cannot see what objects lose by the wastage of age: sheer sea cliffs for instance exposed to prolonged erosion by the mordant brine… (*De Natura Rerum*, 36–7).

This much for the operating principle; as to the raw material, it is still made of eternal, indestructible atoms in unchanging numbers:

> The supply of matter in the Universe was never more tightly packed than it is now, or more widely spaced out. For nothing is added to it or subtracted from it. It follows that the movement of atoms today is not different from what it was in bygone ages, and always will be. So the things that have regularly come into being will continue to come into being in the same manner; they will be and grow and flourish so far as each is allowed by the laws of nature. The sum of things cannot be changed by any force. (*De Natura Rerum,* 68–9).

In modern jargon this is a no-expansion cosmology, with the Cosmological Principle adopted in both its space and time forms. However, while the Lucretian universe is steady indeed, particular Worlds do evolve, all according to materialistic principles; out of many possible quotations, here are a few:

> Certainly the atoms did not post themselves in due order by an act of intelligence…they have experienced every variety of movement and conjunction till they have fallen into the particular pattern by which this World of ours is constituted.

Each of these Worlds lives a full but short life:

> This World is newly made; its origin is a recent event, not one of remote antiquity…Already, it is far past its prime …[The] whole substance of and structure of the World, upheld through many years, will crash…it may well be that force will be given to my arguments by the event itself; that your own eyes will see those violent earthquakes in a brief space dash the whole World to fragments. (*De Natura Rerum*, 57, 173, 181, 94, 174).

Hence, uniformitarianism does not apply to the birth and death of a World, but merely to its gradual changes; as to its violent demise, it may well be the outcome of a Democritean collision between Worlds, but we are not told. Again, analogy constitutes the argument:

> In the first place since the elements of which we see the world composed, solid earth and moisture, the light breath of air and torrid fire all consist of bodies that are neither birthless nor deathless, we must believe the same of the World as a whole. (*De Natura Rerum*, 178).

Even in translation, the Lucretius poetry is often appealing; sadly shortened, here is the picture of the World's birth: at first there was

> … nothing but a hurricane raging in a newly congregated mass of atoms of every sort…From this medley they started to sort themselves out, like combining with like, and to rough out the main features of a world composed of distinct parts: they began in fact to separate the heights of heaven from the earth…All the particles of earth, because they were heavy and intertangled, collected in the middle…The more closely they cohered and clung together, the more they squeezed out the atoms that went to the making of sea and stars, Sun and Moons, and the outer walls of this great World… The first element to break out of the Earth… was æther, generator of fire… We may compare a sight one often sees when the sun's golden rays glow with the first flush of dawn among the dew spangled herbage: the lakes and perennial watercourses exhale a vapor while we see the earth itself steaming… (*De Natura Rerum*, 184–5).

For the origin of this World, terrestrial analogues from daily experience are given, since birth had not been a catastrophic event:

> So the Earth by its weight and the coalescing of its substance came to rest. All the sediment of the world, because it was heavy drifted downwards together, and settled at the bottom like dregs. Then, sea and air and fiery æther itself were each in turn left unalloyed in their elemental purity, one being lighter than the other. Æther, as the clearest and lightest, floats upon gusty air… (*De Natura Rerum*, 186).

Anticipating, the separation between the elements is similar to the Aristotelian scheme, except that the sphere of fire is lacking.

The stage is now set for the apparition of life which took shape and developed in those days when Earth and æther were young…Then, because there must be an end to such parturition the Earth ceased to bear, like a woman worn out with age.

> The new born Earth first flung up herbs and shrubs. Next in order it engendered the various breeds of mortal creatures, manifold in mode of origin as in form… Even now, multitudes of animals are formed out of the earth with the aid of showers and the sun's genial warmth. So it is not surprising if more and bigger. (*De Natura Rerum*, 195–6).

We will find nineteenth-century geologists and biologists arguing about much the same points, albeit far less poetically. A most remarkable Lucretian anticipation is the role of natural selection:

> In those days again, many species must have died out altogether, and failed to reproduce their kind. Every species that you now see drawing the breath of life has been protected and preserved from the beginning of the world either by cunning or by prowess or by speed. In addition, there are many that survive under human protection because their usefulness has commended them to our care… But those that were gifted with none of these natural assets, unable to live on their own resources or to make any contribution to human welfare were fair game and an easy prey for others till nature brought their race to extinction. (*De Natura Rerum*, 197).

While the analogy between artificial and natural selections is perfectly adequate, no anticipation of Darwinism should be seen here, as there is no hint that species might be modified by selection; for Lucretius, they still spring out from the soil fully formed.[14]

The next act narrates the emergence of Man. Lucretius, unlike Democritus, does not stress a continuity between animals and men, but describes with great relish the evolution of society from rough beginnings in terms we find amazingly modern. No myth of any sort is involved, and neither a pagan Golden Age nor a Christian Lost Paradise are required:

> The human beings that peopled these fields were far tougher than the men of today, as became the offspring of tough earth…They lived their lives in the fashion of wild beasts roaming at large…No one knew how to cleave the earth with iron or to plant young saplings in the soil… Their hearts were well content to accept as a free gift what the sun and showers had given and the earth had produced unsolicited… They did not know as yet how to enlist the aid of fire, or make use of skins…They could have no thought of common good, no notion of the moral restraint of morals and laws… They hunted the woodland beasts by hurling stones and wielding ponderous clubs… As time went on, men began to build huts, and to use skins and fire … The agent by which fire was brought down to earth was lightning… There is also another possible source: when a branching tree, tossed by the wind, is swaying and surging to and fro, and stooping to touch the branches of another tree, the

[14] Equally well known is the Lucretian anticipation of modern genetics: "It may also happen at times that children take after their grandparents, or recall the features of their great-grandparents. This is because the parent's bodies often preserve a quantity of latent seeds, grouped in many combinations, which derive from an ancestral stock handed down from generation to generation. From these, Venus evokes a random assortment of characters, reproducing ancestral traits of expression, voice or hair; for these characters are determined by specific seeds no less than our faces and bodily members." (*De Natura Rerum*, 168).

violent friction squeezes out seeds of fire…Either of these occurrences may have given fire to mortals. (*De Natura Rerum*, 201–5).

About the origin of language, Epicurus had already given a first account:

The names of things were not originally due to convention, but… primitive man uttered special cries. The air thus emitted was molded by their individual feelings differently according to the difference of the regions which the tribes inhabited. (*Letter to Herodotus*, Laertius s.d., II, 605).

In *De Natura Rerum* the theme is more fully developed, and analogy with animals stressed:

Even dumb cattle and wild beasts utter distinct and various sounds when they are gripped by fear and pain or when joy wells up within them… [many examples given]. If the animals, dumb though they be, are impelled by different feelings to utter different cries, how much more reason to suppose that men in those days had the power of distinguishing between one thing and another by distinctive utterances. (*De Natura Rerum*, 203–4).

Next on our *SETI Conference* agenda: society, civilization and technology:

Male and female learnt to live together in stable union and to watch over their joint progeny…then neighbors began to form mutual alliances…Kings began to found cities and establish citadels… They parceled out cattle and lands… Next the discovery of copper, gold iron, weighty silver, serviceable lead…A fierce conflagration, roaring balefully, had devoured a forest down to the roots and roasted the earth with penetrative fire. Out of the melted ruins there would flow into the hollows of the Earth's surface a convergent stream of silver and gold, copper and lead. Afterwards, when men saw these lying solidified on the Earth and flashing with resplendent colors, they would be tempted by their attractive lustre and polish to pick them up. They would notice that each lump was molded into a shape like that from the bed from which it had been lifted… (*De Natura Rerum*, 209).

Unavoidably, the very first fruits of civilization are weapons of war:

The earliest weapons were hands, nails and teeth. Next came stones and branches wrenched from trees, and fire and flames as soon as these were discovered. Then, men learned to use tough iron and copper; actually the use of copper was discovered before that of iron because it is more easily handled and in more plentiful supply…then by slow degrees the iron sword came to the fore… So tragic discord gave birth to one invention after another for the intimidation of nations' fighting men, and added daily increments to the horrors of war… (*De Natura Rerum*, 211).

One invention after the other, and daily increments indeed: we are still stuck at exactly the same point.

Emergence of religion comes not far behind that of weapons:

Let us now consider why reverence for the gods is widespread among the nations… the explanation is nor far to seek. Already, in those early days, men had visions when their minds were awake, and more clearly in sleep, of divine figures… To these figures they attributed sentience … credited them with eternal life… pictured their lot as far superior to that of the mortals because they saw them in dreams perform all sorts of miracles without the slightest effort. Again men noticed the orderly succession of celestial phenomena and the round of seasons, and were at a loss to account for them. So they took refuge in handling over everything to the gods…chose the sky to be the home and headquarter of the gods… Poor humanity, to saddle the gods with such responsibilities… (*De Natura Rerum*, 207).

A belief in the similarity of Life evolution aboard other Worlds seems implicit in all these passages, and it does become explicit at least once: while expatiating on the miseries of war, Lucretius describes with great gusto some ancient horrendous attempts at using bulls, boars and lions within human battles; still, he holds doubts about the historicity of the event, and ends by stating that "it would be safer to assert that this has happened somewhere in the Universe, somewhere in the multiplicity of diversely formed Worlds, than in any specific globe." (*De Natura Rerum*, 212).

Our point in giving these extensive quotations of *De Natura Rerum* is of course to bring out its incredible modernity. Any of the present-day scientists making earnest (but feeble) attempts at listing or studying all the factors involved in the generation of intelligent, civilized and technically-minded creatures anywhere within these other Worlds, is bound to feel a close descendant of Lucretius. And all those who puzzle about the essential difficulty of *SETI* will sympathize with the Roman poet who deplored that between all those Worlds "…there is a limitless abyss of space such as even the dazzling flashes of the lightning cannot traverse it in their course, racing through an interminable tract of time." (*De Natura Rerum*, 56). A frightening abyss indeed, and even more so in time than in space.

The Lucretian view of Nature was, in his own words, to prove "…unpalatable to those who have not sampled it, and the multitude shrinks from it." (*De Natura Rerum*, 130). Which is just as true today, and from it the multitude still shrinks. Explanations of the Universe that do not start from intelligent design do not spontaneously appeal to intelligent beings; materialistic Nature has been an extremely slow and laborious conquest of the mind, and clearly remains a minority view among humans.[15] The altogether different systems of thought to be described in the next chapter were later found to fit fairly well within the Christian doctrine, thanks to workable adjustments, and Epicureanism vanished as a system. One single manuscript of De *Natura Rerum* survived, to be rediscovered only in 1417 and printed in 1470; even so, humanists valued Lucretius mostly as a poet. When Plurality became fashionable again in the seventeenth century, the Epicurean revival by Gassendi came too late; by then, Greek atomism was obsolete indeed, and mathematics, pleasurable or not, had been found most useful for making sense of this World of ours; not counting putative others.

Long before, in the late Middle-Ages, Dante had provided fairly decent accommodations in Limbo for all antique pagan philosophers, except for the hated Epicurus who alone was packed to Hell.[16] There he languished in a wide-open sepulcher, not to be sealed until the Last Trump, surrounded by heretics, alchemists, forgers, counterfeiters and diviners. His case proved worse: he had attempted to operate Nature without help from the gods; nor from God himself.

[15] For a rationalistic and illuminating discussion by a scientist of the origin and achievements of religion, see Isaacs (1966).

[16] "The cemetery on this part obtain, / With Epicurus, all his followers, / Who with the body make the spirit die." Dante Alighieri (1321?) Canto 10, Verses 14–16.

Chapter 2
Pythagoras, Plato and Ptolemy: Unicity by Design

To the end that this World may be like the complete Living Creature in respect of its uniqueness, for that reason its Maker did not make two Worlds nor an indefinite number, but this Heaven has come to be, and is and shall be hereafter one and unique.

Plato, *Timaeus* (Plato, ca 360 BC)

(left) Pythagoras and Philolaos testing music instruments, from Franchino Gaffurio, *Theorica musicae* (1492). Wikimedia Commons
(right) Platon holding his Timaeus (left) and Aristotle with his Ethics (right) from Raphael's School of Athens (1508–1512), Vatican. Wikimedia Commons

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Pythagoreans

The life of Pythagoras himself has become so overlaid with myth that it is impossible to disentangle his contribution from that of his followers. Laertius transcribes a probably apocryphal letter from him to Anaximenes, and writes that his school lasted for seven or ten generations; thus, it may have become extinct at about the time of the death of Aristotle, who himself usually refers the opinions he writes about to "the Pythagoreans." Furthermore, the school believed in secrecy, which makes the historian's job even more risky than usual. In several instances, the much later compilers differ and attribute the origin of important concepts either to Pythagoras or to Parmenides, the first of the Eleatics; the explanation may be that Pythagoras conceived, but Parmenides was first to teach openly.

The plan will be the same as in the preceding chapter: first an account of the central Pythagorean creeds, then enough of their system of the World to make their view of Plurality intelligible. Laertius gives the starting point: "The principle of all things is the monad or unit; arising from this monad, the undefined dyad …[then] spring numbers; from numbers, points…lines…plane figures…solid figures; from solid figures, sensible bodies."[1] Actually, the emphasis is put on various dualities, and that poor monad is soon forgotten about; oppositions between odd and even, limited and unlimited, hot and cold etc… take its place. Pythagoreans were the first to contrast corruptible matter and quintessence; after embellishments by Aristotle, these two protagonists were to stay on stage up to the Renaissance. And we are by no means through with another basic Pythagorean duality: "Soul is distinct from Life; it is immortal since that from which it is detached is immortal." (Laertius s.d., II, 345).

The opposition to the Ionian view of Nature is radical: morals and mathematics are brought in together at the base of the edifice. From today's viewpoint, the introduction of morals has been a basic flaw that nearly wrecked the Science building; but out of mathematics the distant followers of Pythagoras have erected the walls, with the roof nowhere in sight. Any account of the rise of science is bound to show morals and mathematics making a strange couple, but their union did last through most of history; it is merely over the very last few centuries that morals-within-science have been waning (and mathematics waxing) to the present point of utter divorce. Our modern view of Nature is born out of the subsequent pairing of Ionian materialism with Pythagorean mathematics, but such a marriage would have been considered nonsensical in the fifth century BC Greece: there could be no reason at all to use mathematics for a description of Nature except a moral one. Up to quite recent times, we shall find the Ionian outlook nearly forgotten about, and acceptance or rejection of Plurality governed by moral and/or religious arguments.

For Pythagoreans, numbers do not just describe things: they are things themselves, and come before all other entities, as Laertius has just shown. However, their

[1] Laertius s.d., II, 341–3. These basic teachings are given within a typical Laertius hodgepodge, right after the far more famous precept: "abstain from beans because they are flatulent and partake most of the breath of life."

use of numbers is far closer to magical practices than to any quantitative study of Nature; outside pure geometry, nearly all Pythagorean numerological “discoveries” are simply wrong. The pitch of the sound given by an anvil is not proportional to the dropped weight; the distances of celestial bodies are not in simple harmonic proportions, and they do not produce musical sounds as they move; the Earth is not a perfect sphere, nor do planets run in exact circles. In merely one case did Pythagoras, or some follower, hit upon an actual fact: there is indeed a simple relation between the length of a vibrating string and the pitch of the emitted sound. Somebody has written that Pythagoras had been first to use arithmetic beyond the needs of commerce; that contribution has proved enough, in the long run, to set mathematicians in the business of unraveling Nature, and we are not through with them either.

The geometrical starting-point of Pythagoreans, and their quest for simplicity and harmony, led to an immediate improvement in their picture of the World compared to the extremely fuzzy Ionian one. From bizarre premises, they reached a solid and durable conclusion: “The Universe is animate, intelligent, spherical with the Earth at its center, the Earth itself being spherical and inhabited round about. There are also antipodes and our “down” is their “up.” (Laertius s.d., II, 343). This quotation shows both a great Pythagorean discovery, and its sorry consequences. From now on, the World will be far more accurately described; however, precisely because it becomes geometrical, a great mental difficulty will arise about its shape and limits, thus about what lies outside. Ionian fancy had lightly flown to infinity and never met any bounds on the way.

How did Pythagoreans find out that the Earth was spherical? Quite possibly they had no argument beyond their belief that “the most beautiful figure is the sphere among solids, and the circle among plane figures.” (Laertius s.d., II, 343). That particular Pythagorean *a priori* was to become much later a great hindrance, but at the time it proved a sizeable progress: the sky vault may be conveniently treated as a sphere until a great degree of sophistication is required. All celestial motions are well described by merely plotting them on a sphere, and we still do it much of the time.

For understanding Plurality, the sphericity of the Earth and existence of antipodes are crucial steps, which make the lack of recorded arguments even more frustrating. What is certain is the Pythagoreans willingness to hypothesize that familiar conditions extend beyond the sensible horizon. They had broken the first psychological barrier on the way to the Cosmological Principle, by discovering that there was nothing singular about the position of Greece on the surface of the Earth. And carried by the same impetus, they went through the second one, introducing another equally remarkable novelty: the motion of the Earth. Their system of the World had been first designed, or at least, made public, by Philolaos of Crotone (perhaps Tarentum?), to whom Laertius devotes but a few lines: “He was the first to declare that the Earth moves in a circle, though some say that it was Hiketos of Syracuse.”[2] Fuller descriptions of the Pythagorean system are only summarized here; to the

[2] Laertius (s.d.), II, 399. Fullest descriptions of the Pythagorean world-model are by Aristotle (360BCa) *De Caelo*, and Simplicius; both given by Heath (1932), 30–32. About most astronomical views of the Pythagorean School, see Dreyer (1905), Chapter II.

modern mind, the main assumptions look both arbitrary and unnecessary. They postulate a central fire, hearth of the Universe, watchtower of Zeus, around which the Earth orbits along a circle in 24 hours, prudently keeping the antipodes of Greece toward that fire; hence it never becomes visible. All other celestial bodies also orbit the central fire along circles, the Sun taking a full year; such a system roughly accounts both for diurnal rotation of the fixed stars and for the solar yearly motion, no mean achievement. The gross travels of planets are also explained, but not their irregularities which had not yet been studied, at least by the Greeks; even so, Pythagoreans proceeded further than anyone else, and realized that planets move (approximately) along a great circle inclined relative to the Equator; that description will remain good enough for Plato. Also, Pythagoras "first declared that the Evening and Morning Stars are the same, as Parmenides maintains."[3]

The strangest of all Philolaos features is the addition of the *antichton* (counter-earth) which also fiendishly escaped detection by sitting halfway between Earth and central fire. According to Aristotle (who may be making fun of them), "regarding a they do the number ten as perfect… they say that the bodies moving in Heaven are also ten in number, and as those which we see are only nine, they make the antichton the tenth."[4] However, a belief in the existence of invisible bodies based on more sensible reasons next appeared; Pythagoreans hypothesized "a number of such [invisible] bodies carried round the center…This serves them as a reason why eclipses of the Moon are more frequent than those of the Sun…" (Aristotle 350BCa, II, XIII, 221). Here, the explanation is wrong, but the mode of reasoning is correct; it is still much used, and at the origin of many discoveries in astronomy. Note that the idea is the same one found in Anaximenes and Anaxagoras, and possibly borrowed from them.

Remarkably, the Earth is already taken as one of these celestial bodies. Why? To make up their count of ten, Pythagoreans had to include Sun, Moon, five observed planets, the fixed stars (taken as a single body), the *antichton*, and to add the Earth. As to the fact that the Earth moves, it appears a great innovation, but the Philolaos design remained geometrically incorrect and anticipated neither Aristarchus nor Copernicus. Nevertheless, Pythagoreans must have found answers of their own to the very potent common-sense arguments against any motion of the ground we tread upon. In the act, they erased the main conceptual difference between the said ground and all those things we see moving around up in the Heavens, thus paving

[3] Laertius (s.d.) II, 333. One of the Pythagoreans, Hiketos of Syracuse transferred the central fire to the center of the Earth. That operation had several advantages: it not only explained why this fire was so well hidden, but also the cause of volcanic eruptions as a bonus. Since Earth then rotated around an internal axis, still in 24 hours, the system became identical with that of Heracleides. Invisibility of both central-fire and counter-earth became hard to believe after Alexander reached India in the east, and the Hanno voyage in the west, and this part of the doctrine was sensibly dropped.

[4] Aristotle (s.d.), *Metaphysics* A 5, 986 a1; Heath (1932) 34. The Pythagorean obsession with Number Ten is expressed in a preserved Philolaos fragment: "… The Decad (Ten-ness) is great, complete, all achieving, and the origin of divine and human life and its Leader… Without this, all things are unlimited, obscure and indiscernible." (Freeman 1983a, 75).

the way for Plurality; in the very long run however, because their immediate successors did not follow the lead. Still, both Ionians and Atomists had, in a sense, gone even farther: in their acentric systems the Earth was free to move at random, but the question of relative motion had never been answered, nor even asked. The clear Pythagorean contribution is the concept that any observed motion may be only apparent and becomes better explained by another one, real but less obvious.

What is the nature of celestial bodies according to Pythagoreans? Information is meager; still, they had no need for supporting devices like the Thales water, the Anaximenes air and his crystalline stellar sphere, nor for the huge Anaximander wheels: all had been made obsolete at one stroke by the primordial perfection of the circle, since geometry came first, far in front of applied or even theoretical mechanics. However, the need of stage props was to be felt again later, and the machinery of crystal spheres was bound to reappear, with fancy improvements.

Not merely the celestial outlook, but the philosophical one are very different from that of the Ionians: "The Sun, the Moon and the other stars are gods; for, in them, there is a preponderance of heat, and heat is the cause of Life." (Laertius s.d., II, 343). Hence, few speculations about the actual substance of these bodies are found; still, the initial duality soon expanded to the four "classical" elements: earth, water, air and fire. As we have seen, these are usually credited to Empedocles, who combined orthodox Pythagorean notions with Eleatic and even Ionian features, but had no personal concern with celestial systems. Moreover, the four material elements were soon felt inadequate: "The bodies [physical elements] of the Sphere are five: the Fire in the Sphere, and the Water, and Earth and Air, and the vehicle [or hull?] of the Sphere." (Philolaos, from Freeman 1983a, 75). In this puzzling hull-vehicle (an avatar of the dodecahedron? the matter is arduous, see Dreyer 1905, 85; Santillana 1970, 69), we have the germ of Peripatetic quintessence, promised to a long carrier.

Was any part of the Universe habitable? The picture is highly confused. Pythagoreans seem to have been first to establish a distinction between the Heavens (*Ouranos*), a region that stood below the Moon, and admitted change, and the *Cosmos* above where only regular and eternal motions were allowed; the sphere of fixed stars was also sometimes called *Olympos*. Beyond was an "outer fire" the necessity of which is even less obvious than for the central one (Simplicius, in Heath 1932, 33; Dreyer 1905, 43). Apparently all celestial bodies were made of fire, except for the Sun and Moon; the Sun received its light from the central fire, and also perhaps from the external one; descriptions through Aetius make it transparent and glossy, and for Stobeus the Sun is a flat disk (Dreyer 1905, 40, 46).

About the Moon several opinions were held, and whether simultaneously or successively is hard to say. Phases and eclipses seem to have been correctly understood; the earthshine on the Moon may have been taken as illumination from the central fire. To Philolaos, the Moon seems to be a body comparable to the Earth with plants and animals fifteen times greater than ours, obviously because the lunar day is fifteen times longer (Aetius in Freeman 1983b, 226; see also Dreyer 1905, 46). If that remarkable opinion was held at all, this may be the result of Ionian influence; still, it appears contradictory with some basic Pythagorean creeds: a Moon within the

Cosmos would harbor neither birth nor death. Perhaps the *Cosmos-Ouranos* boundary was originally located below both the Moon and the Counter-Earth? Also, according to Philolaos "those who inhabit the antichton cannot be seen by us." (Pseudo-Plutarch, quoted by Mac Colley 1936, 386). There is no other report of the *antichton* being actually habitable, and anyway it was soon quietly shelved; as to the Earth-like Moon, it was not transmitted to the successors of the school. Moreover, at least some Pythagoreans already held the Moon to be a polished mirror that reflected the Earth (Aetius, quoted by Dreyer 1905, 38, and Stobeus, quoted by Dreyer, 47), a very strange explanation of lunar markings. After adoption by Peripatetics, this belief was to prove durable because, despite the optical absurdities involved, it fitted comfortably within quintessential Heavens.

Altogether, and despite these discordant views about Counter-Earth and Moon inhabited or not, most Pythagoreans seem to have rejected Internal Plurality. They certainly refused the External brand: their Universe was coincident with the visible Cosmos, and nothing was allowed to exist outside. In this rejection, they were followed by Plato, Aristotle, Neo-Platonists, Stoics and Christians alike, that is by all schools except Epicureans, who were to vanish anyway. Not until the Scholastic era shall we find the notion of invisible external Worlds reintroduced, and through an unexpected twist: they became necessary to the omnipotence of the Christian God.

However Pythagoreans were the first (in the West anyway) to introduce a different notion, to be called here *Time Plurality* in order to mark the conceptual analogy with our two spatial Pluralities. Actually, the concept was to take several forms and to be designated by different names, such as palingenesis (periodic rebirth of the Universe), or Eternal Return; such fancies were connected with the so-called Great Year, a universal period of time affecting all phenomena. This other Pythagorean innovation won durable success, and was to be adopted by all those schools listed above; except for the Christians, and even for them the official rejection did not come before our thirteenth century, precisely at the instant when Spatial Plurality was to become compulsory! Time Plurality is obviously a separate and very different notion from the space variety; still, the connecting bridges are many, and it is best to treat both whenever met. On the one hand, we shall see Space Plurality growing in a somewhat hesitant manner, then blossoming out from the Renaissance to the present day; on the other, Time Plurality remained a rather barren scheme that went into a lengthy eclipse, to be resurrected only in recent years in the Oscillating Universe form.

A second glance is needed to see the point of a brief historical account. The Renaissance episode, during which Internal Plurality became credible thanks to the Galileo discoveries, led only to a static form, in which the time element was absent. However, in the present modern context, Time has been reintroduced, and plays an essential role. The passage from static to dynamic took place only in the nineteenth century, with the advent of evolutionary theories, first within the biological world, and later in cosmology. Of course, this was not done by reinventing palingenesis: neither did Dalton have to read Democritus before producing his law of partial pressure. The present view of *ETI* is that at random scattered places in the Galaxy or galaxies, and at random times a similar scenario is played again and again. Stars condense, planets form, temperature drops, life arises, intelligence and civilization follow, elaborate technology develops, many people start writing papers about Plurality, some even read them and, ultimately, a happy few try do some checking. The separation in time between such Galactic civilizations may well be the most formidable barrier before actual verification of that grand scheme, far more so than the distances involved, which are not an obstacle for the latest breed of receivers and radiotelescopes. All this will be discussed in the last chapter of this book.

Hence, we shall treat this strange and totally *a priori* belief in a periodic universe whenever we find some traces. Two forms are found almost from the start: the strict one, to which the Eternal Return trademark specifically applies, with all events and individuals recurring in the most precise manner; and a looser form, within which only general conditions repeat periodically. The first is a fruit of pure metaphysics; the second does seek some scientific justification, as will be seen with Aristotle, but both start from the same Pythagorean stock.

We know little about the Pythagoreans' cosmogony, and nothing about their explanations for the origin of life, beyond a very sensible statement: "Living creatures are reproduced from one another by germination; there is no such thing as spontaneous generation from earth." (Laertius s.d., II, 345). It is the belief in transmigration of souls that introduced palingenesis: featureless eternity would have been too boring for those poor souls, hence it had to be filled in some way. Pythagoras "was first to declare that the soul, bound now in this creature, now in that, goes on a round ordained by necessity." As to himself, "in the course of time his soul entered into Euphorbus and he was wounded by Menelaus" (Laertius s.d., II, 325, 333), and Laertius delightedly fills a page with his next avatars. However, strictly periodic repetitions of a given-individual's life became more appealing to minds obsessed by circles and circular motion; their solution was a periodic rebirth of the Universe with a well-defined common period, the Great Year.

Classical Greeks were not the first to launch such speculations. Around 260 BC, Berosius, a Chaldean priest, translated to Greek many old Babylonian documents, and fragments of his work have been preserved through Seneca:

> The Flood of water or fire takes place when God wants to create a better World and finish with the old one … Berosius … attributes these revolutions to celestial bodies in such an affirmative manner that he gives the date of both fire and flood. He says that the globe will burn when all bodies which now have such different courses will meet in Cancer and place under each other so that a straight line could go through all centers. The Flood will happen when all similarly meet in Capricorn. The first of these constellations rules the summer solstice, the second the winter one… (Seneca, III, 28–9, quoted by Duhem 1959, I, 70).

This is our first glimpse of the cataclysmic Great Summer and Great Winter, components of the Great Year, and of these grand celestial periodicities. The theme will recur again and again, and acquire great astrological significance; while a full history of astrology would be out of place here, it cannot be wholly left out because astrology has always dealt with connections between the celestial and earthly worlds. We no longer hold these as real, but many of the thinkers who grasped for arguments for or against Plurality were also active astrologers.

Hindu philosophers also toyed with these concepts, and produced definite figures for the Great Year, out of purely numerological arguments; we know of their results through Arabic writers of the tenth-eleventh centuries. Let us quote Duhem (1959, I, 68–9):

> Some Hindus believe that after certain periods life starts again; after this interval has run, the World reaches again the state it has started from. A new race [of men] appears in the Universe, water runs again within the Earth, the soil gets covered with grass, animals start moving and zephyrs breathe life into the air. Most of them picture the various revolutions undergone by the world as circles; the interval is 36,000 years multiplied by 12 000. Another count gives 4,320,000,000 and this is called a kalpa… [i.e.] a day of Brahma, or a day of Nature… Life of Brahma will be one hundred years made of such days.

Hindus must have been helped by their invention of the (so-called) Arabic numerals: simply by struggling to write down such figures with letters (preferably on wax tablets), one understands why Greeks remained more conservative in their numerical estimates; but the spirit was the same, and the concept became more precise. To start with, there had been no clear opposition between Ionians and Pythagoreans; but the notion of exact periodicity could not evolve with the first, whose thought was non-mathematical, and who held no interest in circles nor circular motion. They certainly did not pass any definite period to the Atomists, for whom Worlds were randomly dissolving all the time, and identical ones did not succeed each other. Pythagoreans were to prove far more specific, and presented the fanciful theory in astronomical context:

> The Great Year is accomplished when [Sun and Moon] return to their original places. Some make it eight years, others nineteen, others use a longer interval and still others take 59 years; among these are Oenopides and Pythagoras. Others yet consider the Great Year to be the Principle of Time *(χεφαλη του χρονου)*; this principle is marked by the meeting of the seven errant bodies… [This Great Year] Heraclites takes as containing 18,000 solar years; Diogenes the Stoic uses 365 years, each as long as the Heraclitean one. (Stobeus, cited by Duhem 1959, I, 72).

A bewildering diversity of Great Years was to be used not only by Pythagoreans, but by all the later Greeks who adopted the notion; most had no factual basis, but some were built up starting from Meto's cycle of 19 years, a luni-solar periodicity that was already used to predict eclipses. Within this definite time frame, the Chaldean idea of periodic cataclysms was preserved. Aristotle, who himself is all for a Steady-State Universe, attributes to Empedocles and Heracleides the belief that the World "alternates, being at one time as it is now, and at another time changing and perishing, and this process continues unremittingly." (Aristotle 350BCa, I, X, 97). About the operation of these cycles we know little; still "Philolaos says that destruction takes place in two different manners, sometimes because the fire of Heaven comes down, sometimes because lunar water flows into the atmosphere" (Philolaos through Stobeus, cited by Duhem 1959, I, 77); the association of Moon and water is an ancient one, obviously arising from observations of the tides. Philolaos had already established a distinction that will rise to prominence with Aristotle: the part of the Universe above Heavens, the one that shows obvious periodic motions, is eternal and unchanging, and it rules periodic catastrophes affecting only the unfortunate Earth.

How much did these successive Worlds have in common with each other? Two possibilities were considered: "Empedocles taught that what has been newly engendered is not identical to what has been destroyed, except insofar as the species is concerned." (Simplicius, cited by Duhem 1959, I, 76). We may understand: the successive Worlds merely obeyed the same laws (i.e., were statistically identical), which agrees not too badly with our present view of Plurality. However, Pythagoreans soon evolved more precise requirements, and their obsession with exact numbers was bound to show: they.

> taught that again and again (*παλιν και παλιν*) beings were engendered who were numerically the same as those who had come before… The same things, numerically identical, must reproduce again; I shall tell you again the same fables, holding in my hands this same staff, and you will be again sitting as you are now… All these things will be identical, and Time itself will be identical too. (Simplicius, cited by Duhem 1959, I, 80).

The concept of numerical identity of individuals past, present or future, is a distinct Pythagorean contribution that will be adopted by their mathematically-inclined successors, first of all Plato.

As to the notion of a cyclical Universe, it will be pursued to its logical conclusion: Time itself becomes Number, with the Great Year used as a sort of natural unit.

> Time is the number of a certain motion, or again in a general way, the interval pertaining to the nature of the Universe… If Archytas declares that Time, cause of generation, is the number proceeding from the motion of the Soul taken as a unit, it is also clear that he has considered this motion as standard (monas) of Time… (Simplicius, cited by Duhem 1959, I, 81, 83).

Time being one rare commodity upon which we have not yet dared to impose a quantum, we feel overwhelmed by the daring of these fancies, from the very beginnings of recorded philosophical thought.

Plato

From all thinkers so far discussed, except Lucretius, we had only small fragments, but from Plato's own pen extensive texts have been preserved. Only a few are devoted to the study of Nature and in particular to astronomy: all of the *Timaeus* (Plato c. 360 BC), plus brief passages of the *Phaedo* and the *Republic*. However, *Timaeus* always carried great weight, and was never forgotten about through the Dark ages, thanks to extant Latin translations; it is the book Raphael places under Plato's arm in his *School of Athens*, where Plato (somehow resembling Leonardo) looks up to Heavens while Aristotle points down to Earth. We shall not follow the learned controversies about the actual paternity of the theories developed in the Platonic *Dialogues*; let us merely take Socrates as Plato's main mouthpiece. Another difficulty is more serious: exposition of the Platonic world system is so much mixed up with allegory that it is often a problem to decide when to take a passage seriously, as representing what the Master believed in actual fact. Apparently, his students themselves were often none too sure, and we feel great sympathy with their plight considering the sort of textbooks they had to learn from.

Platonic astronomy introduces only one technical novelty: geocentrism; otherwise it is largely derived from Pythagoreans, and was to be quickly superseded by the systems of Eudoxus and Aristotle. In any standard history of astronomy, Plato plays but a modest role; nevertheless, he deserves to be discussed here in full, because he was led to condemn Plurality in categorical terms, and this exclusion was to have lasting consequences long after his own astronomical edifice had crumbled to pieces. Strangely enough, one also finds him at the origin of the so-called Principle of Plenitude, which was to be used in the distant future to provide Plurality with a rational basis; an operation Plato himself would have emphatically disowned. Hence, we shall present here those Platonic notions that have proved relevant to our problem, often considerably later. The route may take us far from science, but the detour is unavoidable: adoption or rejection of Other Worlds has ever been a largely metaphysical issue.

Being an astronomer of the observing breed, I am inclined to take Plato with a sizeable grain of salt after hearing Socrates advise: "So, if we mean to study astronomy in a way which makes proper use of the soul's inborn intellect, we shall proceed as we do in geometry, working at mathematical problems, and not waste time observing the Heavens." (Plato, *The Republic,* 530c, quoted in Toolmin 1961, 83). How far behind already is the time when an Anaximander could invent the gnomon and draw the first geographical map! Socrates and his disciple may rest easy; rain or shine, a large fraction of my past (or even present?) learned colleagues have ever since most exquisitely implemented the Socratic program; admittedly not without some notable successes.

The Pythagorean order, simplicity and harmony are fully preserved and even elaborated upon by Plato. The shape of the Earth is not treated in Plato's *Timaeus,* but (rather surprisingly) in *Phaedo*: just before downing that fatal cup, Socrates pronounces his.

> … conviction is that the Earth is a round body in the center of heavens, and therefore has no need of air or any similar force to be a support, but is kept there, and hindered from falling or inclining anyway by the equality of the surrounding heaven, and by her own equipoise… Also I believe that the Earth is very vast, and that we who dwell in the region extending from the river Phasis to the Pillars of Heracles inhabit a small portion only about the sea, like ants or frogs about a marsh, and that there are other inhabitants of many other like places… (*Phaedo,* in Plato s.d., 130).

A clear statement, but applying only to the Earth itself. Happily, Socrates is still given enough time for drifting into a favorite Platonic theme: the Heavens we see are not the real thing. We are convinced to be living on the surface of the Earth, but we are actually dwelling in a kind of air-filled hollow, and.

> …if any man could arrive at the exterior limit, or take the wings of a bird and come to the top, then like a fish who puts his head out of the water and sees this World, he would see a World beyond… and he would acknowledge that this other World was the place of true Heaven, and the true light, and the true Earth…" (*Phaedo* in Plato s.d., 149).

Here follows a lengthy description of a Paradise-like place (truly an anticipation of the Christian model), but one that has nothing to do with our main theme. Sure, that world Plato discovers with the mind's eye is real enough: actually, it is the only real one, and the place we live in is merely a wretched copy. Unfortunately, the Master used up all the available space by locating this True World of his so close at hand. Maybe his picture was mostly allegory; just the same, he never found room for complete additional Worlds, or even invisible dark bodies, within or without the bounds of our own.

The Platonic system is geometric, and geometry had made much progress since the days of Thales and Pythagoras: Euclid was born at about the time of Plato's demise. Nevertheless, it is Eudoxus, contemporary and younger disciple of Plato, who was to present a working system, clearly stated in simple geometrical terms and not buried under layers of myth. Eudoxus was first to attempt accounting for all observational niceties, such as planetary retrogradations; his devices will be discussed later. By comparison, the Platonic model had been very crude, and merely accounted for gross planetary progress along the ecliptic. And not through any oversight: Plato was well aware of those irregularities, but they were not worth studying. Socrates again:

> Those intricate traceries in the sky are no doubt the loveliest and most perfect of material things, but they are still part of the visible world, and therefore fall short of the true realities. The true movements in the ideal world of numbers and geometrical figures are responsible for these rotations. Those, you will agree, have to be worked out by reason and thought, and cannot be observed." (Plato, *The Republic*, quoted in Toolmin 1961, 82).

And so they do, and the dilemma is an eternal one: which of these tiny wriggles my pen recorder is busily scratching on the paper chart are truly significant, and which are just noise, thus unworthy of notice? I still have to apply reason and thought to reach the true reality.

The main progress from Philolaos to Plato is that he drops both the central fire and the *antichton,* and fixes the Earth in the center. His system becomes far less arbitrary, but also less susceptible of improvement; geocentrism, once introduced, will prove a solid psychological stumbling block. Plato and Eudoxus have lost these promising degrees of freedom Pythagoreans had kept available with their moving Earth. Stellar and planetary motions are again circular and uniform; however, they are no longer self-explanatory, and an actual mechanism (the first in a long line) is described in *The Republic* to account for them. Still, it remains more-than-half mythical, and the blueprint should not be passed directly to any workshop; by contrast, the Eudoxus and Aristotle devices will be truly mechanical. The lengthy description starts with an axle, adamantine shafts and hooks, a set of tops and rims; however:

> … the axle turned on the knees of Necessity. Upon each of the circles was a siren who was carried round with its movements and gave out a single sound of constant pitch so that all eight of them made up a single scale. Round about, at equal distances, the three daughters of Necessity were seated on thrones, robed in white with garlands on their heads. They were

> Lachesis, Clotho and Atropos, and they chanted to the music of the Sirens: Lachesis of the things past, Clotho of the present, and Atropos of the things to come…”.[5]

Actually, these three elegant singing *Parcae* are not merely invited sopranos: they play a highly-technical role by preserving the eternity of the mechanism (we often call in vain for a similar help). Mathematics also come in, and planetary distances to Earth are given in *Timaeus*; they are constructed by mixing the geometrical progressions 1,2,4,8 and 1,3,9,27, the Moon’s distance being 1 and that of Saturn 27.

Next come the usual questions about the substance of celestial bodies and the concept of Plurality. Plato will not bother about practical details; still, some account is needed of all these celestial objects that, even if part of a mere copy-world, are plainly visible. Just as was the case for the Atomists, the Platonic astrophysics is grounded in physics; however, his own is still Pythagorean, only more elaborate. Plato is able to deduce from geometrical arguments all four elements, plus a fifth which seems necessary to make the world complete. Socrates to Timaeus:

> Now, that which comes to be must be bodily, and so, visible and tangible, and nothing can be visible without fire or tangible without earth. Hence the God, when he began to put together the body of the Universe set about making it of fire and earth. But two things alone cannot be satisfactorily united without a third, for there must be some bond between them… (*Timaeus*, cited by Munitz 1957, 71).

Plato goes far beyond Pythagoras in making Nature geometrical: he demonstrates that two intermediaries (fire and water) are needed in a three-dimensional world, while a single one would be enough within two dimensions. A correspondence is found between earth, water, air and fire and the first four regular “Platonic” solids. Unfortunately, it had just been shown that five regular solids existed, and five only; this remarkable discovery was already considered of great portent, and its full demonstration has ever since been taken as a striking achievement of the young science of Geometry. So the four elements left one unused solid; in a fully teleological universe, such an oversight was inexcusable. Hence “…seeing that there still remained one other compound figure, the fifth [i.e. the dodecahedron], God used it up for the Universe in his decoration thereof.” (Timaeus, cited by Munitz 1957, 135). While all five elements are now in place, the scheme is not equivalent to the better-known Aristotelian one, and the difference is important for both Internal and External Pluralities: in Plato there is not yet any radical distinction between the Earth and the celestial bodies. The four elements are not uniformly distributed across the visible world, and the stars contain both earth and fire. Does Plato mean that stars are both visible and tangible? As to the Moon, closest to Earth, it is mostly of earthy nature; still, its markings are altogether below Plato’s

[5] Plato, *The Republic*, quoted in Toolmin (1961), 86. Plato has to account for eight motions: Sun, Moon, five planets, and the star vault. Happily for him, the figure eight also fits the musical scale.

notice, and he never stoops to propose any explanation. These confused shadows were just not geometrical enough; his reaction would have been quite different if some planetesimal had implanted on the Moon's face a nice round impact crater large enough for naked-eye view.

Two Platonic opinions seem to imply no singularity in the nature of the Earth. First, the differences between elements are not primordial, and transmutations remain allowed; fire, air etc.… are the names of qualities, not of substances. The second point is more direct: all celestial bodies are Gods, and so is the Earth. The argument is frankly metaphysical, at least from our viewpoint, but it occupies a central place in Plato's system of the world. Socrates explains to Timaeus that the Creator has made three kinds of living creatures adapted to life on land, air or water, plus

> the heavenly race of gods …The form of divine kind he made for the most part of fire that it might be most bright and fair to see, and after the likeness of the Universe he gave them well-rounded shapes and set them in the intelligence of the supreme to keep company with it, distributing them all round the Heavens…. [we have] all the un-wandering stars, living beings divine and everlasting, which abide for ever revolving uniformly upon themselves; while those stars [i.e. our planets] that have turnings and in that sense wander, came to be in the manner already described. And the Earth he designed to be at once our nurse as she winds round that axis that stretches right through, the guardian and maker of night and day, first and most venerable of the gods that are within the heaven.[6]

Altogether, Plato never specifically excluded celestial bodies as possible places for life, and he even spoke of "the souls of the beings which live in the various cosmical bodies…" (*Timaeus,* quoted by Dreyer 1905, 79). Who are the owners of these souls: mortals, immortals or deceased mortals? There is no way to believe that Plato packed creatures more or less like ourselves aboard stars or planets; at most, he did not openly reject the possibility, and Timaeus never asked Socrates the question outright.

However, the multiplicity of Worlds, adopted by Atomists and Epicureans, is rejected by Plato in the strongest terms:

> … The God wishing to make this World most nearly like that intelligible thing which is best and in every way complete, fashioned it as a single visible living creature … Have we, then, been right to call it one Heaven? or would it have been true rather to speak of many? One we must call it if we are to hold that it was made according to its pattern. For that which embraces all the intelligible living creatures that there are, cannot be one of a pair; for then there would have been to be yet another Living Creature embracing those two… thus our world would be more truly described as a likeness, not of them but of that other which would embrace them. Accordingly, to the end that this World may be like the complete Living Creature in respect of its uniqueness, for that reason its maker did not make two Worlds nor an indefinite number; but this Heaven has come to be and is and shall be hereafter one and unique… (*Timaeus*, 70; translation, 57–59).

[6] *Timaeus,* cited by Munitz (1957), 80. A controversy has arisen about Plato's alleged rotation of the Earth, but it all boils down to the translation of one word; the Earth either "winds" around her own axis, or is simply "packed" around the axis of the Heavens (Dreyer 1905, 71–72)

Although the text is difficult to understand, the chain of reasoning is both solid and clear: God is good, he wants to make the World in his own image, he is unique, therefore the World is unique. This rejection of multiple Worlds was to be of great historical importance; to make it understandable, a cursory examination of Plato's cosmogonical beliefs is in order.

To start with, Plato introduces a considerable novelty with a long future of its own: Creation. The Ionians had never fancied any kind of Grand Beginning was needed at all. Plato badly wants one, and having a suitable Creator handy, finds no trouble in supplying particulars. To start with, he needs Chaos:

> Before that, all these kinds were without proportion or measure. Fire, water, earth and air possessed indeed some vestiges of their own nature, but were altogether in such a condition as we should expect anything when deity is absent from it. … From such constituents, four in number, the body of the Universe was brought into being, coming into concord by means of proportion… (*Timaeus*, cited by Munitz 1957, 88).

Harmony and geometry are the Creator's specific contribution; primordial chaos, not requiring any kind of intelligent design, is left free to have pre-existed eternally, and Plato is happy without any hint of the Judeo-Christian *ex-nihilo* process. His *δημιουργοσ (demiourgos)* merely puts things in decent order; in its prime meaning, the word designates some kind of artisan exerting a manual profession. The Creation was not for Plato a historically datable event, it took place within an indefinite past, and at least as far back as the war with Atlantis which he sets at 9000 years before his own time. The account is at least more self-consistent than the Biblical one, in which (through a momentous slip of the divine pen as wielded by Moses), the Sun materializes on the Third Day. For Plato "there were no days and nights, months and years before the Heaven came into being, but [the Creator] planned they should now come to be at the same time that the Heaven was formed…".[7]

As to this World of ours, it was complete and perfect from the beginning,

> nothing being left over out of which such another might come into being; and moreover it might be free of age and sickness; for [the Creator] perceived that if a body be composite, when hot and cold things… attack it from without they bring it to untimely dissolution, and cause it to waste away… (*Timaeus*, cited by Munitz 1957, 72).

Hence, while Unicity, needed for perfection, is reaffirmed, any opportunity for change is ruled out for either life, intelligence or society. The order of Nature and the laws of morals or politics are similarly eternal. The Ionian-Atomist understanding of Change and evolution is lost, to be preserved only by rare Epicureans. No wonder that Plato wanted to burn all the Democritus writings; nor that two millennia later, Dante sent Epicurus to Hell.

Nevertheless, the Universe cannot be unchanging in any strict sense because it is actually periodic; here some inconsistency appears in Plato's thought. He adopts the

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[7] *Timaeus,* cited by Munitz (1957), 77–78; see Lovejoy (1976), 51. The *Genesis* inconsistency about these sunless First Days was deeply felt by Augustine: "We cannot understand what happened as it is presented to us; and yet we must believe it without hesitation." (Augustine 414, XI, 7, p. 436). The voluminous subsequent hermeneutics does not seem to have solved the puzzle.

idea of Eternal Return so fully that later ages spoke of a Platonic Great Year, not a Pythagorean one. For him, absence of change applies merely to perceptible events: we must no more look for evidence of that Great Year on Earth than for traces permitting to date Creation. Do we live during the first cycle of the Universe, or within some later one? Plato never tells; his starting point, an obsession with periodicities, is fully Pythagorean. If God had created diverse celestial bodies, it is largely in order to teach us arithmetic:

> God kindled the Sun to the end that it might shine, so far as possible, throughout the whole Heavens, and that all the living creatures might participate in Number… In this wise and for these reasons were generated Night and Day… and Month, every time the Moon overtakes the Sun; and Year, as often as the Sun has completed his own orbit. Of the other stars [i.e. planets], the revolutions have not yet been discovered by men." (*Timaeus*, 81, see Duhem 1959, I, 65).

We applaud Plato's beliefs about the role of observed celestial periodicities in the development of mathematical thought. Still, none of these pedestrian periods satisfied him, and he looked for The Period: "The complete number of Time fulfills the complete Year when all the eight circuits, with their relative speeds, finish together and come to a head." (*Timaeus*, 83). Tantalizingly, Plato never provided the exact figure of his perfect number, making later generations curious. Exegetes have rushed into the breach, with diverging results; for Duhem it is 40,000 times Meto's cycle, i.e. 760,000 years.

Neither did Plato explain whether he adopted strict Eternal Return, but later commentators clearly state that he did; why settle for anything less than rigorous periodicity? Here is the Plutarch comment on *Timaeus:*

> Within this determined grasp of time…all things will be re-established according to their ancient state… Let us suppose that it is because of a celestial influence that I am presently writing these lines, and that you are doing presently whatever you do; when the same cause appears again, with it the same effects will be repeated, and all of us shall appear again to repeat the same actions. And similarly for all men…" (Plutarch, *De Fato,* quoted by Duhem 1957, I, 288).

Plutarch himself disbelieved these notions, and opposed all forms of astrological fatalism, very popular in his own time. Another late critic, Augustine, was also to attribute the idea of Eternal Return to Plato, and blasted the concept as incompatible with Revelation; in this path he was not followed by fellow Christians without serious difficulties.

It is often said that a history of Philosophy is but a set of footnotes to Plato. This timeworn aphorism will be found to fit the history of Plurality just as well, except for the very latest episode of the modern period, during which the Ionian materialism has been back in fashion. Up to that time, countless variations on the Platonic theme will be found, but very few hard facts. Hence, we have to understand Plato's reasons, when he took such a categorical position against multiple Worlds. Was this outcome unavoidable starting from his core beliefs?

Plato's main interest is not merely morals but politics, and science is not an end in itself. This attitude implies that the true causes operating in Nature are the final ones; the efficient causes the Ionians had been happy with, are never of real importance. Let us hear Socrates speaking to Cebes in *Phaedo*; the point is of recurring importance throughout the present History, hence the lengthy quotation:

> Then I heard someone reading from a book of Anaxagoras that the Mind [*animo*] was the disposer and cause of all, and I was delighted at this notion which appeared quite admirable… I rejoiced to think that I had found in Anaxagoras a teacher of the causes of existence such as I desired, and he would tell me first whether the Earth is flat or round; and whichever was true, he would proceed to explain the cause and the necessity of this being so … if he said that the Earth was in the center, he would further explain that this position was the best, and I … should not want any other sort of cause. And I would then go and ask him about the Sun and Moon and stars, and that he would explain to me …their comparative swiftness and returnings, and how all of them were for the best… How grievously was I disappointed! … I found my philosopher altogether forsaking Mind or any other principle of order, but having recourse to air, and æther and water and other eccentricities…. [all of which is like pretending] that I sit here because my body is made up of bones and muscles… and he would have a similar explanation of my talking to you, which he would attribute to sound and air… There is surely a strange confusion of causes and conditions in all this… It may be said indeed that without bones and muscles… I cannot execute my purposes. But to say that I do as I do because of them…is a very careless and idle mode of speaking. I wonder if they cannot distinguish the cause from the condition… And thus one man makes a vortex all round, and steadies the Earth by the Heavens; another gives the air as support to the Earth which is in a sort of broad trough. Any power which in arranging them as they are, arranges them for the best, never enters their minds; and instead of finding any other superior strength in it, they rather expect to discover another Atlas of the world who is stronger and more everlasting than the Good… (*Phaedo* in Plato s.d., 129–132).

All through these Socratic ramblings, the key word is "the Good"; and likewise, throughout most of history, the Platonic idea of "the Good" shall appear as *ultima ratio* in explanations of Nature. The argumentation is quite solid if the premise of Nature as one large animal is accepted. Unfortunately, as well put by Giorgio de Santillana, "the Good is a dangerously simple idea" (Santillana 1970, 213); hylozoism has accumulated nothing but failures, and today teleology is on the wane even when living creatures are concerned.

Is it possible to find a flaw within the argument of Goodness entailing Unicity itself, not just in the premises? Might later thinkers, as fully convinced of the Universe essential Goodness as Plato himself, find an escape clause? For the Master, there was none, the connection was straightforward, and the *Cosmos* had to be both spherical and unique, with no handles attached. Literally so; Socrates speaking to Timaeus:

> …accordingly, [the Creator] turned its shape rounded and spherical, equidistant every way from center to extremity, a figure the most perfect and uniform of all for he judged uniformity to be immensely better than its opposite. And all round on the outside he made it perfectly smooth for several reasons. It had no need of eyes, for nothing visible was left outside; nor of hearing, for there was nothing outside to be heard…it had no need of hands to grasp with or to defend itself, nor yet of feet… (*Timaeus* cited by Munitz 1957, 72).

At this point, we rebel: does Plato believe circularity to be the best shape for an argument also? His round and smooth Universe needs nothing on the outside because nothing exists outside. Is that type of construction all for the best in the best possible World? Not necessarily so, and the Infinite Goodness might choose to exert itself in a diametrically opposite manner. The Creator could erect a wholly full Universe instead of one empty apart from that well-polished bubble. The trouble is that the corresponding *Principle of Plenitude* may also be traced back to Plato himself, which points to a sizeable lacuna in his cosmological thought. This will cause anxiety for many of his distant followers in the Christian era, when the Unlimited Divine Power finally replaced the Platonic Good. The analysis, and the very name of the *Principle of Plenitude,* are found in A. Lovejoy's 1976 classical work *The Great Chain of Being.* His definition is "fullness of the realization of conceptual possibility in actuality", with some helpful comments:

> The assumption that no genuine potentiality of being can remain unfulfilled, that the extent of creation must be as great as the possibility of existence, and commensurate with the productive capacity of a perfect and inexhaustible Source, and that the World is better the more things it contains. (Lovejoy 1976, 52).

The Principle itself, never explicitly stated by Plato, seems implicit behind many of his arguments. For instance, it must not.

> … be thought that the World was made in the likeness of any Idea that is merely partial, for nothing incomplete is beautiful. We must suppose rather that it is the perfect image of the whole of which all animals, both individuals and species, are parts. For the pattern of the Universe contains within itself the intelligible forms of all beings just as this world comprehends all other visible creatures. (*Timaeus*, 57; given as quoted in Lovejoy 1976*,* 50).

In this passage, the accent has been on the living world; indeed, the most important application of the Principle, as traced by Lovejoy, is that *Great Chain of Being* scheme which, starting from Aristotle, was to attain maximum popularity during our eighteenth century.

Another and less well-known application of Plenitude has been to the theme of Plurality, as much of the present history is bound to show. The concept of a Universe which is the best possible one, hence contains many Worlds in order to be full, was to flower in modern times; however, by then, the meaning of "Worlds" had been changed to signify planetary systems. In the thought of Plato himself, there was no inconsistency; paraphrasing Lovejoy, it is because the universe is a replica of the monolithic world of ideas, that Plato says there can be only one Creation, leaving nothing from which a second World might be fashioned. Much later, very different consequences will often be drawn: what about all that wasted room outside our own bubble? Why did the Creator stop and rest after such a paltry job? Even granting that Good and Best are the ultimate criteria for existence, why should outside smoothness prove any better than overall fullness? However, such a trend of thought was to become predominant only after Galileo had demonstrated the old Democritus view of the Milky Way, and shown the Universe to be much fuller than so far believed. Now and then, in astronomy, observational discoveries stand out and even the most Platonic minded cosmologists are bound to wake up and take notice.

At which point the reader probably feels tired out of metaphysical discussions, and eager to proceed to more modern views. Not so fast! The aim of this history is precisely to show that we shall never meet an abrupt transition to the modern concept of Plurality. For instance, we will see that before the end of the eighteenth century, astronomers had built up cosmological models much like our present ones, as far as features relevant to our theme seem concerned: multiple planetary systems (Huygens) and galaxies (Kant). However, the philosophical atmosphere was still very different from ours: for them, the Best of possible Worlds was still the guide with Plenitude as a docile attendant. Today, the Platonic Good is as dead as mutton as principle of explanation in physics; we have found this new Atlas that Socrates was deriding, and he is Chance, helper of the hated Democritus. Have we equally got rid of the Principle of Plenitude? Or, could it be alive and well, thinly disguised under the cloak of our Cosmological Principle? No attempt at a final answer will be made now, and the point is stressed merely to show that suffering through a few more pages of half-metaphysical stuff might be worthwhile.

Aristotle

From Aristotle's pen we have voluminous and well-preserved works; it matters little if nearly all of these are probably lecture notes taken and more or less edited by eager students. Like Democritus, he had an encyclopædic mind, and he wrote on Ethics, Politics, Economics and Poetics. Within what we would call his scientific output, the largest fraction concerns the living world, his central interest; but the most relevant book for our purpose is the *De Caelo* (*On the Heavens*, Aristotle 350BCa).

A brief summary of Aristotle's overall view of Nature is needed first. Clearly, he refuses autonomous existence to Numbers, and to Plato's Ideas; furthermore, he makes almost no use of mathematics. Hence, within any general history of scientific thought, nobody would place him within a chain starting at Pythagoras and ending with the later mathematical astronomers. However, for the present purpose he fits well at this particular place because of his precise and carefully argued rejection of both internal and external Space Pluralities, coupled with acceptance of Time Plurality. On these counts he follows Plato, and will be followed himself by the astronomers who, like Ptolemy, will construct similar but fully mathematical world systems.

For Aristotle, the starting point of all knowledge is sensation plus observation, and he proved a universal and fairly often correct observer; which is enough to make him far more readable than Plato to scientists of all ages.[8] Starting from observations, he proceeds by extensive and painstaking use of logic, but his arguments and deductions remain nearly always qualitative; furthermore, he sees no need for experimentation, which would produce only artifacts, hence is no way of

[8] Some help from Bertrand Russell's *History of Western Philosophy* (Russell 1946): Aristotle is "…Plato diluted by common sense. He is difficult because Plato and common sense do not mix easily" (p. 175); "…common sense prejudice pedantically expressed" (p. 176); "Plato was mathematical, Aristotle biological; this accounts for the differences in their religions" (p. 182).

understanding Nature. On some philosophical counts, Aristotle nevertheless remains a good Platonist: his Universe is a well-ordered place, within which the Good is still the central explanation. While he details his four classical types of causes (material, efficient, formal and final), in actual practice they generally boil down to efficient and final, of which the last are clearly to be preferred: "God and Nature create nothing that does not serve a purpose." (*De Caelo*, I, IV, p. 31). As a logical consequence, his world system will merely be a branch from the Pythagorean-Platonic trunk. Epicurus (merely one generation younger), who carried reliance on sensation and distrust of mathematics even further, nevertheless was to reach totally different conclusions about the nature of things. Indeed, the budding mathematics of the time were able to provide very few solid explanations within the physical world, and whether you were willing to use them or not did not make a great deal of practical difference.

In the same vein, Aristotle systematically adopts hylozoism (a doctrine which states that the world and matter have a proper life), and uses it with all the added strength derived from his vast knowledge of the animal word. Hylozoic explanations come in front of geometrical ones; here is a sample. Pythagoreans attribute the properties of Right and Left to the Heavens; are they correct?

> This is something which has been worked out in the treatises on the movement of animals… It is natural that what is present in the lowest stage of animal life is also present in [the Heavens]… Above and below, the front and its opposite, and right and left… may reasonably be supposed to be possessed by all complete bodies." (*De Caelo*, II, II, p. 139).

A most sensible lesson in elementary geometry, noting that "complete bodies" means three-dimensional solids, but the starting point had been analogy with animals. Aristotle applies similar principles to other problems: for instance, he confesses some puzzlement concerning the complexity of celestial motions, being at least aware of planetary irregularities; our error "is that we are inclined to think the stars as mere bodies or units… completely lifeless; whereas we ought to think of them as partaking of life and initiative. Once we do this, the events will no longer seem surprising." (*De Caelo*, II, XII, p. 207).

A serious account of Aristotelian physics cannot be given here, which is a pity, because they are linked to his astrophysics more closely than for any of his predecessors. Indeed, the appealing coherence of his system is what made its overthrow so difficult; ultimately, both the Galileo celestial observations and his renewed terrestrial mechanics were to be needed. Still, let us recall the most relevant points. Aristotle fully endorses and develops the four-elements-plus-one theory, which is closely linked to his own view of motion; he has use for two simple kinds, straight and circular, plus mixtures of the two. Similarly, there are four simple bodies (or elements): earth and water whose natural motion is straight and down, plus air and fire to which he attributes straight and up. Compound bodies move according to their predominant element. Whenever simple bodies do not obey these rules, their motion is forced, hence much less deserving study; again, he has no place for experimentation.

However, circular motion is of supreme interest (just as it had been for Pythagoreans) and it will lead to the invention of what was called later quintessence. The tricky argumentation must be followed step by step:

> Circular motion must be primary… the circle is a complete figure whereas no straight line can be so… Circular motion is prior to rectilinear; rectilinear motion is the motion of the simple bodies (e.g. as fire moves in a straight line upwards and earthy bodies move down to the center), then circular motion must of necessity be the motion of some simple body…. From these premises it follows that there exists some primary substance besides the four in our sublunary world… more divine than, and prior to all these… it cannot have either weight or lightness… We may regard it as ungenerated and indestructible, susceptible neither to growth nor alteration. (*De Caelo*, I, II, p. 15 and I, III p. 21).

At which point, religion has to be brought in, to rescue mere observation and logic: "All men have a conception of gods, both barbarians and Hellenes … If then there is something divine, what we have said about the primary bodily substance is well said." Lastly, that substance deserves a name for which he credits the ancients who "gave the name æther to the uppermost region." (*De Caelo*, I, III, p. 25). Aristotle proceeds farther than Plato by demonstrating that this æther (or quintessence) is not just necessary but also sufficient: a fifth element is able to account for observed circular motions, and nothing else may do the trick. Forced motion cannot be eternal, thus "if fire be the body carried round [within Heavens] as some say, this motion will be no less unnatural to it…natural motion of fire is a straight line away from the center." (*De Caelo*, I, II, p. 17). A further reason (and a rather sensible one too) for banishing Fire from the Heavens is given elsewhere: fire would not last, since there can be no fire without something being consumed (*De Partibus Animalium*, II, 2, and *Meteorologica,* I, 3, quoted by Dreyer 1905, 120). We shall meet some late-19th Century astrophysicists gravely demonstrating that a solid-coal Sun could not possibly burn for long either.

Altogether, the last vestige of terrestriality has been banished from the Heavens; fire at least had been the stuff the children of men could play with.[9] All those thinkers who had kept some fire or earth inside celestial bodies, including Plato, had been badly wrong. At one stroke, Aristotle banished Plurality to the hell of disproved theories.

The Aristotelian world system, with its full complement of crystal spheres, is not described in *De Caelo* at all, but (rather strangely) in Aristotle's *Metaphysica*; some befuddled half-dumb student must be responsible, or perhaps, not so dumb after all? The precise organization is only of moderate interest here, and as it came chronologically after that of Eudoxus, it will be summarized later together with those of the mathematical astronomers. Here we shall be concerned more specifically with the nature of Earth and celestial bodies as seen by Aristotle; this is needed to understand his categorical rejection of Internal Plurality.

[9] Through most of history, fire has not been considered as incompatible with life; see 17th Century discussions, and in the last chapter Herschel's and Arago's view of an inhabited Sun.

Sphericity of the Earth is not merely stated, but demonstrated from observations:

> It is also possible to demonstrate the sphericity of the Earth from the phenomena visible to the senses. If one were to suppose the Earth not spherical, the eclipses of the Moon would not present the shapes they do present in the [actual] state of things… the line which terminates them is always curved… Furthermore, from the appearance of celestial bodies, it is obvious not merely that the Earth is round but that it is not very large, because it is enough to go a small way north or south to change the circle of the horizon…. Some stars are visible in Egypt or Cyprus, and not in northern countries. Hence, when we make the assumption that the country around the Pillars of Herakles rejoins India, and that there is only one Ocean this supposition does not appear to me incredible. One also gives another proof, elephants, the species of which is found at both these extremities. And mathematicians who have tried to measure the length of the circumference estimate it at forty times ten thousand stades [18 000 km].[10]

These arguments have become classical, except for the intervention of elephants; Eudoxus must be responsible for the Earth-circumference figure, and the order of magnitude is correct. Aristotle also gives for the shape of the Earth a physical argument that has not aged in the least:

> the shape must …of all necessity be spherical; since all the parts have weight down to the center, and the lightest parts being pushed by the heaviest, it cannot be irregularly lifted like waves of the sea, but it is rather compressed and one part gives before another until pressure reaches the center… This motion comes because any body having weight goes naturally to the center… hence all bodies tried to reach the center with equal intensity… and necessarily the extremity of the surface came everywhere at equal distance from the center; this is precisely the shape of the sphere.[11]

Similarly, we say that all celestial bodies (of sufficiently large mass to have melted) initially took a spherical shape out of self-gravity. However, Aristotle's tendency to the center is not the result of an attraction, but of an intrinsic property of heavies seeking their natural place; and that place is the only one in the Universe. Thus, his demonstration is valid for the Earth only, and not for any other celestial body. The strict uniqueness of the natural places of heavies will play the central role in the Aristotelian rejection of Plurality.

After the shape of the Earth, what about any possible motion? Aristotle starts from an understanding of the Earth itself far more impressive than the one achieved by Atomists or Epicureans, hence his categorical affirmation of the Earth's immobility was fated to carry great weight for a long time; it introduces one more radical difference between the Earth and everything else. First, he refutes the opinions of his predecessors, which is most fortunate, since in the process he preserves some of them! With the greatest ease, he sinks the Thalesian Earth floating in water, or the arbitrariness of the Pythagorean system, and mocks the humming of the spheres, which he finds most ingenious but quite impossible. He shows more respect for Anaximander who "pretended the Earth kept at rest by virtue of being in

[10] *De Caelo,* II, XIV, p. 255; Note *a* of the translator, W.K.C. Guthrie, compares the Aristotle, Archimedes, Erastothenes and Hipparchus figures; all are distinctly too small and were to influence Columbus, and even Magellan.

[11] *De Caelo,* II, XIV, p. 247–9. A summary of the ancient views about the shape of the Earth is given by Copernicus in his first chapter, found e.g. in Munitz (1957), 156.

equilibrium; according to him, there is no reason why a body placed in the center and equidistant from the extremities should move up, down or obliquely." (*De Caelo*, II, XIII, p. 235). He has a better explanation, and demonstrates with one master stroke both Earth immobility and universal geocentrism, starting from his own mechanics and applying impeccable logics:

> If the Earth moves, whether at the center or at a distance from it, its movement must be enforced: it is not the motion of the Earth itself, for otherwise each of its parts would have the same motion, but as it is their motion is invariably in a straight line towards the center. The motion therefore being enforced and unnatural, could not be eternal; but the order of the world is eternal. (*De Caelo*, II, XIV, p. 241).

In other terms, Aristotle starts from his primordial law of mechanics, the centripetal fall of heavies, just as we would start from the law of inertia. The spherical Earth is for him a compound body in which earth and water predominate; hence, it cannot have naturally any other motion than centripetal. Furthermore, this is a universal property:

> The natural motion of the Earth as a whole, like that of its parts, is towards the center of the Universe; that is the reason why it is now lying at the center. It might be asked, since the center of both is at the same point, in which capacity the natural motion of heavy bodies or parts of the Earth is directed towards it; whether as center of the Universe or of Earth. But it must be towards the center of the Universe that they move, seeing that light bodies like fire whose motion is contrary to that of the heavy, move to the extremity of the region that surrounds the center. It so happens that the Earth and the Universe have the same center, for the heavy bodies do move also towards the center of the Earth, yet only incidentally because it has its center at the center of the Universe… (*De Caelo*, II, XIV, p. 243).

In brief: the very first law of mechanics is centripetal motion (or centrifugal for "light" bodies). There is one and only one center in the Universe, with unique properties; we would speak here of a space singularity. The Earth happens to be centered at this point because it is predominantly heavy. Gravity is not a property of the Earth as such, and still cannot be felt at any other place; no celestial body is allowed a center of its own nor local gravity. None is comparable to Earth in this sense; thus none can harbor life.

The Platonic gravity described in *Timaeus* had been very different:

> When we isolate a piece of earth, and carry it in the middle of air, which is unlike earth, we have to use violence, and act against nature because a portion of earth and a volume of air both stick to bodies of the same family. In any place, only one rule holds: one calls gravity the tendency that carries a body like earth when placed in the middle of air towards bodies of the same family while it moves, and inferior place the place towards which this body is moving. (*Timaeus*, 62.3).

Hence, Plato's starting point had been that the like attracts the like (the concept of attraction is perfectly fitting here), a process that may happen in any place. There is no unique and singular center of the Universe; heavies are free to congregate anywhere. Platonic gravity might have been developed to explain how terrestrial-type materials could be permanently maintained at many places within Heavens; and, two millennia later, it was. No such escape remained open for Aristotle, who set the Earth farther apart from the rest of the World than anybody had done before.

He has little to say about the actual nature of celestial bodies. Stars cannot be made of fire, and the reason why they look like fire comes from their rapid motion: “The heat and light which they emit are engendered as the air is chafed by their movement. It is in the nature of movement to ignite even wood and stone and iron” (*De Caelo*, II, VII, p. 179), as happens to flying missiles. Here, Aristotle misses the opportunity to propose the same explanation for shooting stars, because they are treated in the *Meteorologica* (Aristotle 350BCb, I, VI, p. 39–69) together with auroras, comets and the Milky Way: all are similarly due to hot exhalations from Earth, but the last two rise so high that they pass through the sphere of air and reach the sphere of fire marking the frontier of the sublunary world, hence they participate in the universal diurnal rotation.

Pythagoras and Plato had denied the gift of existence to other Worlds; with Aristotle this conviction gathers great weight from the joined powers of observation and logic, and what is wrong with such a procedure? With him, the uniqueness of our World becomes a truly scientific theory; unfortunately, a wrong one.

To start with, he presents a very thorough rejection of infinity. Nothing may be infinite, neither (1) bodies, nor (2) geometrical figures, nor (3) weight, nor (4) space itself. The order in which these four cases are tackled may seem strange, but it is Aristotle’s own. Arguments are many, and laborious to follow; they will be much shortened here, and only those most easy to grasp for the modern scientific mind will be given, maybe at the cost of some distortion in the Master’s thought. First of all “every body must be either simple or composite… if the simple bodies are finite any composite body must be finite too…” (*De Caelo*, I, V, p. 35). And since the simple bodies (i.e., the elements) we can manipulate down here are all patently finite in size, only the fifth element seems worth considering; but it is also finite. The only convincing demonstration makes use of Time: we know that celestial objects are circularly moved; if they were at infinite distances, they would make infinite displacements in a finite time, which is absurd. He also shows that the weight of a body cannot be infinite either, and the demonstration is again grounded on his mechanics: since speed of fall is proportional to weight, the impossibility of infinite speed entails that of infinite weight. Last, Aristotle proceeds to show that there is no such thing as infinite Space; his full demonstration, by now all logic and zero observation, is tricky and hard to follow: it appears to rest on eternity of natural laws, but the clear conclusion is nothing less than a full abolition of space outside the perceptible world. The last argument is frankly hylozoic: if it existed, that Space should participate in the universal rotation, for which it would require a motor; then: “What is it which moves the infinite? If it moves itself, it must be alive. How could there be an infinite animal?” (*De Caelo,* I, VII, p. 65). Aristotle also disproves vacuum out of very similar arguments.

What are we to make of the Aristotelian disproof of infinity? The central argumentation itself is faultless: no cosmology coherent with physics (any physics) may indeed accommodate an infinite revolving sky vault; it is just unfortunate that the said sky had not been revolving after all, while that vault itself was mere fiction. Today, we still believe that no velocity may become infinite, but we draw no conclusion as to definite limits of Space. However, Aristotle will now leave behind the Infinity conundrum, and proceed to answer those who believe in “other Worlds being formed similarly to the one around us, many, though not infinite in number.” (*De Caelo*, I, VI, p. 53). Here we are at the heart of our subject and Aristotle has to be followed in full.

The problem has never been delineated in clearer terms: “We must now explain why there cannot even be more than one World.” (*De Caelo*, I, VIII, p. 69). The essence of the Aristotelian demonstration is again perfectly sound, as based on the belief that physics should be the same everywhere:

> All the Worlds must be composed of the same bodies, being similar in nature… if the bodies in another World resemble our own in name only, and not in virtue of having the same form, then it would be in name only that they could be pronounced a World. (*De Caelo*, I, VIII, p. 71).

In brief: a Plurality of Worlds should not be just a plethora of words. The technical demonstration, based on Aristotelian gravity, is again a masterpiece of logic, but despite all his wriggles, the Master never deduces anything beyond his basic premise: there is only one center in the Universe**:**

> It must be natural for the particles of earth in another World to move towards the center of this one [i.e., our own World] also, and for the fire in that World to move towards the circumference of [our own]; and similarly earth from our own World would have to move naturally away from [our] center as it made its way to the center of the other [etc…, etc….] and this means that there cannot be more Worlds than one. (*De Caelo*, I, VIII, p. 73).

Aristotle has convincingly shown that any form of our Cosmological Principle (the Universe the same everywhere) is incompatible with his own model, endowed with centripetal attraction to a single center. He is never conscious of the crude anthropocentrism behind his whole argument. In plain terms: since every sort of heavy stuff I throw up invariably falls down, these permanently suspended luminous bodies I see above my head have to be of a different essence. We applaud to his conviction that the laws of Nature are universal; but his physics, built on observation without experimentation, are simply too naive for our taste.

The Peripatic view was to remain that of most thinkers up to the Renaissance, but we have already seen that such naivety was not universal in the antique world, and more examples will follow. The Lucretian arrow was to pierce the Plato-Aristotle bubble, and the Plutarch Moon (with its built-in gravity) will soon lightly escape from the grasp of the Aristotelian singularity, and all without the benefit of telescopic observations.

The Aristotle view of Time will now be followed. The Master adopts the main Platonic creeds, but with some important differences: the World happily remains eternal, and does even better since eternity is extended to both directions of Time, Creation being altogether dispensed with. Cyclical variations and the Platonic Great Year are both preserved, but restricted to the sublunary world, while the Heavens above gain unrestricted permanence. Simultaneously, the hidden but obligatory connection between heavenly and terrestrial doings becomes a precisely spelled-out dogma. These Aristotle innovations will cause considerable difficulties during the Scholastic era, when the time will come to fit Peripatetism within Christianity, and will be discussed at length in Chapter 5.

In his *De Caelo*, and immediately after disposing of all these other Worlds, the Stagyrite comes to grip with Creation; as usual, the problem is posed with great clarity: "Let us next decide whether the World has been from all time or has had a beginning, and whether it is indestructible or destructible. First, let us run over the theories of others…" (*De Caelo*, I, X, p. 95). He mentions ancient sages, but singles out Plato for attack: **"**in the *Timaeus*, he says that the World has been generated but nevertheless will last for all future time." (*De Caelo*, I, X, p. 103). Characteristically, Aristotle establishes his own theory through logical arguments, starting with precise definitions of what he means by created, uncreated, eternal etc.…; for instance, he proves that some combinations, like created and non-perishable, are absurd. We shall not follow him, merely noting that one of his demonstrations is connected with his rejection of spatial Plurality: a unique World could not possibly have been created all out of nothing, nor could it be totally destroyed in the future "though if there are an infinite number of Worlds, it is more feasible." (*De Caelo*, I, X, p. 101).

This argument alludes to the Atomists who had separate Worlds in the process of being assembled or destroyed all the time. He will hit the nail again and again, stressing immobility and eternity of the Heavens or of its putative substance, æther. He will even give a rather questionable etymology for the word *αιθερ*; according to him, the Ancients had believed that this so-called æther "always ran" (*αει θειν*) (*De Caelo*, I, III, p. 25). His logic leaves us cold; still, once (and once only) he brings in the argument of historical data: "Throughout all past time, according to the records handed down from generation to generation, we find no trace of change either in the whole of the outermost Heaven or in any of its proper parts." (*De Caelo*, I, III, p. 25 and note a). Historical records were more relevant to the problem than appears at first glance. Greeks, rather careless about their own calendar or chronologies, had conceived intense admiration for those of some Barbarians; Simplicius asserts somewhere that they believed Egyptian chronology to be reliable for 630,000 years, and that of the Babylonians for 1,440,000 years (see Duhem 1959, I, X, p. 65–85).

Despite this reference to observation, the Aristotelian concept of Time is mostly metaphysical, and his God, ever responsible for all extraterrestrial happenings, manipulates all through final causes. In the Heavenly theatre, the Platonic Grand Artificer had been both author and machinist; the Peripatetic Prime Mover behaves merely as director. He coexists with the World, and is not allowed to exert himself in Creation, being too perfect to have any need for such exercise. And how could He? For Aristotle, Necessity, by which he means the power of Logic (his own, anyway), comes first. Creation, having just been syllogized out, God had better conform. Future generations of medieval theologians were to make a full (but uncomfortable) living by fighting these Peripatetic constraints; and it is precisely through this fight that they will achieve the Christian reintroduction of Spatial Plurality, as told in our *Scholastics* chapter 5.

As to Time Plurality, Aristotle adopts the Pythagoras-Plato concept, again with one important proviso: cyclical cataclysms cannot affect anything within Heavens, since he has just demonstrated the total incorruptibility of celestial matter. When he treats uniform circular motion as perfect, he means it to the letter: any interruption would be a bar to perfection, thus Time Plurality could not apply to the whole

World, Heavens included (see Duhem 1959 I, 234). Hence, all periodic changes can only affect the Earth; however, he places these under far more precise celestial control than any of his predecessors. In a famous passage of *Meteorologica,* Aristotle provides the "scientific" basis of astrology: "This World down here is somehow connected, and in a necessary manner, to the local motions of the Upper World, in such a way that the power residing in our World is controlled by such motions." (*Meteorologica,* from the translation to French by Duhem 1959, I, 134) This "necessary manner" renders but weakly the $\varepsilon\xi$ $\alpha\upsilon\alpha\gamma\kappa\eta\sigma$ (out of Necessity) with which many similar passages will be punctuated. Even so, neither Aristotle nor his immediate followers were to practice astrology themselves, and his authority in this respect was not to be quoted until much later. He showed no interest in actual prediction of specific events, nor did he provide a figure for the Great Year any more than Plato had done; he merely recalled in *De Caelo* that Heraclitus and Empedocles had held that our World "alternates, being at one time as it is now, at another time changing and perishing and that this process continues unremittingly." (*De Caelo*, I, X, p. 97).

Aristotle's views are far closer to observation (and more sensible!) than those of older thinkers. A total destruction of Earth does not fit within his plan, more fully explained in *Meteorologica,* as he favors limited changes: "The same parts of the Earth are not always moist or dry… mainland and sea change places, and one area does not remain earth, another sea, for all time." Which appears an almost modern view of geology; but for him such changes are bound to be periodic: "This process must, however, be supposed to take place in an orderly cycle", while the mechanism itself is largely hylozoic: "The originating cause is that the interior parts of the Earth, like the bodies of animals or plants, have their maturity and age." Astronomical causes are not altogether forgotten: "Cold and heat increase or decrease owing to the Sun's course", and some processes are well described: "The sea too must change; wherever it has encroached on the land because the rivers have pushed it out, it leaves behind dry land; while wherever it has been filled and silted up by the rivers and formed dry land, this must again be flooded." This is inferred rather than directly observed, because "it takes place by slow degrees over periods of time which are vast compared to the length of life, and whole people are destroyed and perish before they can record the process." (*Meteorologica*, I, XIV, p. 107–9). And the overall Conclusion proves more than sensible as it reaches the status of an eternal truth: Do not put faith in any simplistic extrapolation to the very distant past of present observations. In his own terms: "Let us not pretend that such changes are due to the fact that the World has had a beginning. It is ridiculous to invoke a change in the whole Universe in order to explain small things, with no more weight than a mere feather." (*Meteorologica*, I, XIV, from the translation by Duhem 1959). Despite our laborious unveiling of a few more facts of Nature, over and beyond silting rivers, we are still stuck at the same point, are we not?

What about that trifling matter, the fate of humanity? Aristotle has no interest in palingenesis or metempsychosis; he is not obsessed by the splendor of any strict periodicity, and fancies no inborn supremacy of integers over any other numbers, in the sublunary world anyway. Hence, while believing in some sort of cycles operating under the influence of celestial bodies, he does not endorse the Pythagorean strict identity between individuals living in these successive cycles; at most "the same opinions recur in rotation, not once or twice or occasionally, but infinitely often." (*Meteorologica*, I, III, p. 13). On the one hand, all sublunary things are subject to corruption and generation, but "generation is necessarily [*διο αναγκη*] cyclical… All of which conforms to Reason, since the heavenly motion appears to be periodic and eternal; then, necessarily, all the effects generated by that motion will be equally periodic and eternal." (Aristotle, *De Generatione et Corruptione*, I, II, from the translation by Duhem 1959, I, 164). So far, this seems to fit the Platonic Great Year; but on the other hand "believing that men who get born are for ever numerically identical is a blunder; a better opinion is that they are conserved merely as a species" (Aristotle, *Problemata*, XVII, 3, from the translation by Duhem 1959, 168); today, we might express the thought better by "statistically conserved." This broader view does not save him from the belief that history repeats itself, and he has to speculate on the meaning of the words "before" and "after": if indeed the Trojan war keeps repeating, then it is permitted to say that we live before that great event…

Altogether, for Aristotle just as for Plato, there is still a succession of closely, if not rigorously, similar Worlds following each other: that Plurality which he utterly refuses to allow in Space, he adopts in Time. Such was the outcome of the first grand attempt to understand Nature by fitting logic to observation; it was to last far longer than any other, but very little of it remains today.

Mathematical Astronomers

We are reaching the end of two fat chapters, and the history of ancient astronomy has not even been sketched. The reason is that Eudoxus, Aristarchus, Eratosthenes, Hipparcus and Ptolemy contributed almost nothing to the theme of Plurality, having merely adopted the Plato-Aristotle world picture; none of them introduced new arguments of any relevance. However, a summary of their discoveries and of the systems they erected is needed: when Plurality will at last be reintroduced during the Renaissance, it will be constructed not from the naive and fuzzy picture of the Atomists and Epicureans, but using the geometrical model inherited from Ptolemy and other mathematical astronomers.

Eudoxus of Cnidus studied under Plato, and was a first-rank geometer; the fifth book of Euclides appears to be mostly his contribution. He also studied Egyptian astronomical records on the spot. He was well acquainted with those baffling irregularities in planetary motions that Plato had not found worth bothering about (Figure 2.1), and he will be the first to explain these through a geometrical model. His works are all lost, and his system, known through a brief reference in Aristotle's *Metaphysica* and a comment by Simplicius, was only understood and reconstructed a mere century ago by Schiaparelli. The main assumption is geocentrism; each body is carried on the equator of a uniformly revolving sphere, the poles of which are carried by a second larger one with different poles and rotation period, and so on.

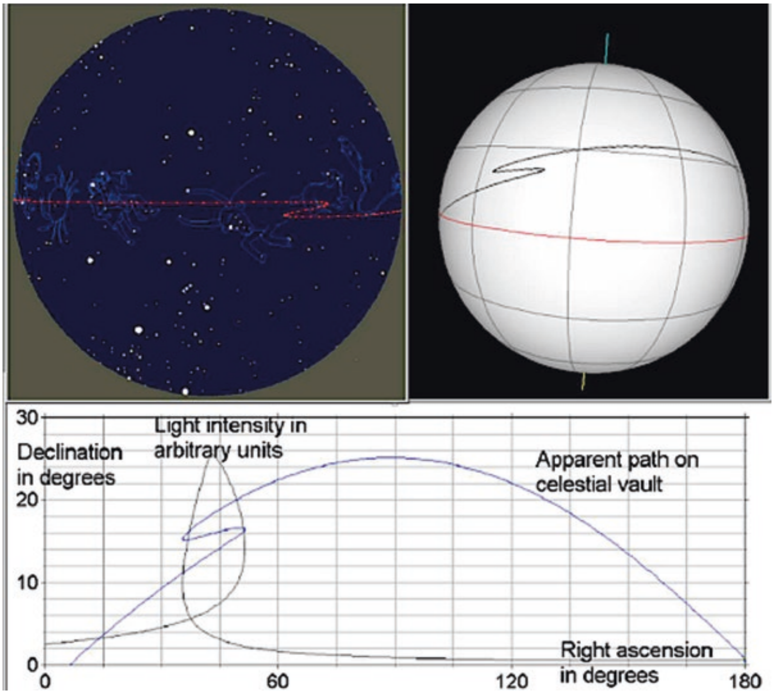


Figure 2.1 Planetary paths passing from raw data to scientific presentation. Above, left: a direct naked-eye view showing those "intricate traceries in the sky", condemned by Plato (and ignored by Scripture), but well known to antique astronomers. The figure shows the apparent path of Mars among fixed stars; most striking is the retrogradation, which takes place every 26 months precisely when Mars is closest to Earth. Right: Mars path drawn on a solid celestial-sphere: a first level of elaboration, but one accessible to any sculptor. The Mars path (and light-curve on the Cartesian graph) presented here is that for 2005–6, but the date does not matters, as that show is repeating itself without change. I thank Fr. Dalaudier for plotting the first two figures. Below: presentation in Cartesian coordinates, never used before our 17th century. Also plotted is the intensity of the light received on Earth; the variation (particularly large and obvious in the Mars case) was well known and understood in Antiquity as due to varying distance, a mostly correct view

Three spheres are adequate for the Sun and the Moon, four are needed for each of the five planets, and one for the fixed stars; the total is 27. The fit to observations was already felt inadequate in Eudoxus time, particularly for Mars (ever a most tricky planet), and his disciple Kalippus added six more spheres; all are concentric and nesting within each other. Their diameters were chosen from numerological Pythagorean-type arguments; for instance the Sun was exactly 9 times farther than the Moon. The most appealing feature of the system is its beautiful simplicity and the fact that planetary motions are now fully separated from stellar ones; so far, all Greeks had taken planets as carried by the stellar sphere but somehow dragging a little behind.

Eudoxus himself operated purely as a geometer and did not worry about the physical reality of his model. This is where Aristotle stepped in; his own system followed closely the Eudoxus-Kalippus one, and he was not concerned with a better fit to the observations. However, precisely because he was not a mathematician but a student of Nature, he insisted on a model that would truly work. The Eudoxus one did not: his mechanism might have been built like a set of Chinese balls, but it would not have functioned. Aristotle, unworried by budgetary constraints, added three or four counter-rotating spheres in between each planet and replaced geometric axes by mechanical axles. Altogether, he required 55 spheres, all fashioned out of pure æther, like the stars themselves, but somehow made transparent (he never says how). There was no vacant space anywhere; the core of the system was occupied by the four concentric spheres of earth, water, air and fire. The lunar sphere was found just beyond, and the last sphere made one full revolution per day. The overall construction seemed fully coherent, and apparently accounted for everything; which explains why it proved dangerous to tamper with for such a long time.

However, since all geocentric distances were constant, it did not account at all for the brightness changes easily seen with the naked eye by comparison with fixed stars, and particularly conspicuous for Venus and Mars. No Peripatetic wanted to admit intrinsic brightness variations, which would have implied unpleasant changes in the supralunar realm. Hence, distances had to vary, but nobody wanted to give up circular motion either, so the epicylic theory was invented later to provide the solution.

Let us now follow what occurred after Aristotle, in rough chronological order, stressing not merely systems but also improvements in observations, and their interpretation. No writings by Aristotle's almost contemporary Heracleides of Pontus have survived, and he is known mostly through Laertius and others doxographers. He studied under Plato, Aristotle and some late Pythagoreans; his interests were encyclopedic, but he is best remembered for having openly taught that the Earth rotated in 24 hours around an internal axis, thus accounting for heavenly rotation. In this choice, he may have been preceded by two Pythagoreans from Syracuse, Hiketos and Ekphantus, who shelved both the central fire and the counter-earth (Dreyer 1905, 51). The Heracleides theory seems to have remained unknown to Aristotle who never mentioned it; which was most fortunate for him, since it blasted to pieces his main argument against an infinite Heavens. Heracleides may also have held that Mercury and Venus circled the Sun; indeed for these two planets, which never wander far from the Sun, the idea could be grasped more easily than for the others. Moreover, he stands practically alone in having taught that "each of the stars constitutes a World, that it consists of an Earth surrounded by air and that the whole is swimming in illimitable æther."[12] With this concept, obviously built from both the

[12] Johannes Stobaeus, *Eclogarum Physicorum*, chapter 24, as quoted by Crombie (1959), II, 46. Not mentioned by Heath (1932) in his *Greek Astronomy*, but in his *Aristarchus* (Heath 1913, 254). Thus, the only trace left of this remarkable anticipation comes through a very-late doxographer (5th C. AD). Dreyer (1905), 123, believes that Heracleides may have been referring to planets, not to stars.

Ionian and Pythagorean traditions, Heracleides easily ranks as one of the most prescient minds of antiquity; nevertheless, Cicero will lightly dismiss him as having merely "filled volume after volume of childish fictions" (Cicero 45 BC, 37), mostly because of his disrespectful (and un-ciceronian) opinions about the gods.

Aristarchus of Samos (see the classical work by Heath 1913) achieved great fame in his days, but definitely not through his heliocentric system in which both diurnal and annual motions of the Earth were correctly introduced; at the time, this appeared just as one more arbitrary geometrical construction with no particular advantages. The corresponding book is lost, and the hypothesis known through only two brief quotations, none of which takes it seriously. The first, by Plutarch in his *De Facie,* will be given in Chapter 3; the other is from Heracleides' younger contemporary Archimedes of Syracusa in his *Arenarius* (Archimedes s.d.). For Archimedes, heliocentrism is a side issue; what he truly wants is to compute the number of grains of sand (hence the name of the work) that might be used to fill the Universe, merely to show that there is no arithmetic impossibility involved. Today, in exactly the same spirit, we ask students to compute, with their pocket calculator (limited to 10^{99}), the number of nucleons in the Universe. Archimedes takes the problem very seriously; first he fills the standard Plato-Aristotle bubble with sand; next he mentions that in the Aristarchus system, the distance of fixed stars has to be much greater because no annual apparent motion of stars is seen from the Earth. We would say now that the parallax of stars is negligibly small, to the naked eye anyway; this correct deduction will achieve great importance in later chapters. Since the Plutarch account is even shorter, this is all that remains of one of the most prescient guesses of antique science (Dreyer 1905, 139).

However, another book of Aristarchus, *On the Distances of the Sun and Moon,* has been preserved. So far, the Pythagorean application of geometry to the cosmos had used pure numerology for distances and sizes, and the Ionian estimates had been equally fanciful. Now, at last, a geometrically sound technique is proposed to compute the ratio of Sun and Moon distances: when the Moon is exactly at first quarter, measure the Moon-Earth-Sun angle (i.e. the angular distance between Sun and Moon); next, solve the triangle. Unfortunately, the proposal is an armchair scientist's dream (the first of many), as it relies on checking that the lunar terminator is seen as a straight line; even today, and with telescopes, it cannot be done with sufficient accuracy. Hence, the actual Aristarchus result, a 19/1 ratio, is grossly wrong; the true figure is 390/1; even worse, Aristarchus still had only a poor figure for the Earth size, and none for the lunar distance. Soon afterwards, a method both correct and accurate for measuring the diameter of the Earth was described and used by the geographer Eratosthenes of Alexandria, with results very close to the modern figure. In essence, he measured the zenith distance of the Sun on the same day at noon from two Egyptian cities separated by about 7° in latitude, plus their linear distance on the ground. Next, Hipparchus of Rhodes obtained a remarkably accurate mean distance of the Moon: 59.1 Earth radii (the modern figure is 60.3). His elegant method involved measuring the time taken by the Moon to cross the Earth's shadow during a central lunar eclipse.

These results mark a milestone not only in astronomy, but also in all of scientific methodology; for these problems (and through all epochs and chapters), we shall follow the invaluable *Measuring the Universe* of Albert Van Helden (van Helden 1985). Within the present history, such achievements are pivotal: the Moon diameter became accurately known. As far as size was concerned, the Moon proved to be a somewhat smaller Earth and one key component of the Plurality concept was passing into the realm of exact science. Still, when Hipparchus tried to estimate the solar distance, his result was far too small: the problem was much more difficult, and his method, correct in theory, was hopelessly inadequate in practice. He seems to have been content with giving a lower bound for that distance, but his successors proved less cautious, and first of them, Ptolemy. Using the same technique, he decided the Sun was 1210 earth-radii away, which is 20 times too small; consequently, the sizes of the Sun and of the entire planetary system were to be similarly underestimated, an error not to be corrected until 1672, using telescopes and micrometers. A second independent error was that all apparent diameters of stars and planets were grossly overestimated, and nobody produced even roughly correct figures for the sizes of the planets before the telescopic era; the question will be followed in Chapter 10. Altogether, from Antiquity to Renaissance, the only celestial body for which the size was known is the Moon.

Hipparchus was also responsible for the first Greek stellar catalogue, and from his interest in accurate stellar positions, discovered precession; of course he interpreted this new effect as one more stellar motion, not an Earthly one. Precession would not concern the present book at all, except for the strange impact it had on Time Plurality, to be studied a little later. Next, Hipparchus played an important role developing the epicyclic theory, in which the first step had been taken by Apollonius of Perga, best remembered for his treatise on conic sections. The final and most historically important form of that theory is to be found in the great Ptolemy synthesis. By then, Alexandria had become the center of the learned world, and thanks to the Museum and the Library, astronomers were enjoying State support to a degree so far unknown in Greece or in Rome for that matter. Is it a coincidence that simultaneously they grew far more cautious in their enquiries, and seem to have suffered some loss of curiosity?

Aristarchus and Hipparcus seem to have acted merely as geometers and observers, and made no speculations about the nature of celestial bodies, but relatively little of their writings is known, while Ptolemy's great work, the *Almagest (*Ptolemy c. 150), has been fully preserved. Here the new attitude becomes unmistakable, and from the very first page:

> Those who have been true philosophers, Syrus, seem to me to have wisely separated the theoretical part of philosophy from the practical…Aristotle quite properly also divides the theoretical into three immediate genera: the physical, the mathematical, the theological… If we should seek out in its simplicity the first cause of the first movement of the Universe, one would find God, invisible and unchanging. And the kind of science that looks after him is the theological…The kind of science which traces through the material and ever moving quality, and has to do with the white, the hot, the sweet, the soft and such things would be called physical; and such an essence…is to be found only in corruptible things and below the lunar sphere. And the kind of science…seeking figures, number and magnitude, and

> also place, time and similar things, would be defined as mathematical… And therefore, meditating that the [first] two genera would be expounded in terms of conjecture rather than in terms of scientific understanding… meditating that only the mathematical… would give its practitioner certain and trustworthy knowledge with demonstration both arithmetic and geometric resulting from indisputable procedure, we were led to cultivate most particularly… this theoretical discipline… especially in respect to divine and heavenly things. (*Almagest*, I, 5 as cited by Munitz 1957).

Hence, both theology and physics are thrown out of astronomy together, and only mathematics is left. Still, Ptolemy believes in Aristotelian physics and occasionally refers to the æther, and also to the divine nature of celestial bodies, but he is not really concerned. He contributes very little to the Aristotle demonstrations on the nature of all things celestial; the system he builds is a triumph of advanced geometry, but cannot any longer be illustrated by a working model. Epicycles, excentrics, equants and the spheres themselves are pure computing devices and not mechanical tools. Only one physical point remains a matter of dogma, the immobility of the Earth, and Ptolemy adds a powerful mechanical argument that was only implicit in Aristotle; if the Earth had any kind of motion "… the animals and other weights would be left hanging in the air, and the Earth would very quickly fall out of the Heavens. Merely to conceive of such things makes them appear ridiculous …" More specifically, rotation is absurd since "…all those things that were not at rest on the Earth would seem to have a movement contrary to it, and never would a cloud be seen to move towards the east, nor anything that flew or was thrown into the air…" (*Almagest*, 11, as cited by Munitz 1957).

Apart from this primordial certainty, anything goes. The geometrical devices must save the phenomena, and here Ptolemy is more painstaking than any of his predecessors, but he is not bothered by any lack of internal consistency. Each planet is treated separately, and some require more complex gearing than the others; moreover, two different and mutually incompatible explanations may be resorted to simultaneously, and this attitude is explicit: "I do not profess to be able thus to account for all the motions at the same time, but I shall show that each by itself is well explained by its proper hypothesis." (quoted by Dreyer 1905, 201, from a minor Ptolemy work, *Hypotheses of Planets*). The case of the Moon is typical, and most shocking to the modern mind: in Ptolemy's time, the variation in apparent diameter was well known, since it is large (29′ to 33′), hence detectable with simple devices. Unfortunately, the particular set of eccentrics that best fitted the lunar motion (which is highly non-uniform), also produced a much too large variation in its apparent diameter: it should have reached nearly one degree at perigee, a glaring discrepancy with even the crudest naked-eye observations. Neither Hipparchus nor Ptolemy felt in the least bothered.

In any case, all these complicated meschanisms invented to account for the motion of the planets remained in the domain of specialists. The basic model of Ptolemy that was to be adopted for many centuries is very much simpler: the Earth at the center surrounded by air and fire, then the "orbs" of the Moon, the Sun and the planets, and finally the stellar firmament (Figure 2.2).

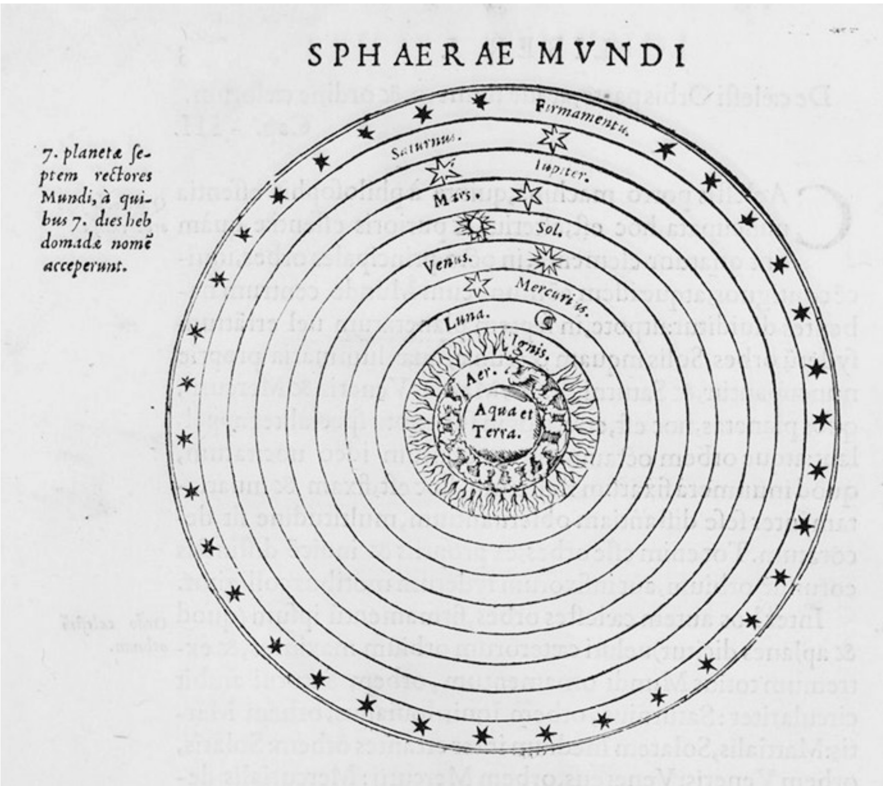


Figure 2.2 The World according to Ptolemy. This concept survived until the 17th century. Oronce Fine, who published in 1555 this engraving in his *De mundi sphæra sive cosmographia*, recalls that the seven “planets” that include the Sun and the Moon have given their name to the days of the week. © Bibliothèque de l’Observatoire de Paris

The ablest mathematical astronomers were sharing the attitude of the anti-mathematician Epicurus: indifference as to which hypothesis is physically true, as long as one or a few fit the appearances. Down the drain went the Spatial Plurality hypothesis, as simply irrelevant and explaining nothing of what was visible in the sky. The bold (often too bold) speculations of Ionians and Pythagoreans about unseen bodies or Worlds no longer had any place in Alexandria. Similarly gone was all concern about the actual nature of the Heavens, and there was no longer any point in discussing similarities with the Earth. Meteorites presumably kept falling, but went unreported; as to comets, they had been safely stuck by Aristotle within the sphere of fire, thus no longer concerned astronomers. Heavens had become a playground for mathematicians, and the Platonic program was implemented to the full.

The first consequence was a distinct boost to Time Plurality: mathematical astronomers had provided it with a new justification neither Pythagoras nor Plato had even dreamed about. A new celestial motion, with period immensely longer than all previously known, had been discovered: this was Precession, and it appeared just made to order.

As understood today, precession is a conical top-like rotation of the Earth's polar axis around another axis, perpendicular to the ecliptic, i.e. the plane of the Earth's orbit around the Sun. The period is the time taken by that axis to fully describe the cone, and it is equal to 25,725 years. The Earth's equatorial plane follows the motion, and its intersections with the ecliptic, the celestial equinoxes, similarly revolve around the zodiac in the same amount of time; hence the full name, *precession of the equinoxes.* Since the ecliptic itself does not move, stellar latitude (i.e. the angular distances to that ecliptic) does not change either; but the second stellar coordinate, longitude, is measured within the ecliptic plane, taking the spring equinox as origin; hence, all longitudes increase linearly with time.

Writing in 129 BC, Hipparchus compared his own observations with those of Timocharis two centuries before. He correctly deduced that celestial latitudes had not changed, but that longitudes had increased by about two degrees. One degree per century (thus a full revolution in 36,000 years) made a nice round figure; that estimate was generally adopted, in particular by Ptolemy, since numerology was by no means out; the difference between 36,000 and 25,725 years is unimportant for our own story.[13] Since the Earth had to be immobile, this novel motion was attributed to the sphere of the fixed stars (the so-called *primum mobile*), which was granted a second rotation; the first had been the diurnal one. Hence an additional sphere, wholly starless, had to be postulated as supporting device beyond visible stars. Again, Hipparchus contributions are known through Ptolemy, who in his *Hypotheses on Planets* explicitly postulates the existence of this precession sphere, since known as the ninth. In the epicyclic system, each body had been provided with only one sphere; hence, the Sun, Moon and five planets required seven, and the *Primum Mobile* was the eighth.

Hence, from now on, the Heavens could no longer present strictly the same configuration until 36,000 years, or some multiple of that period, had elapsed. Today, we understand that, in the absence of any physical connection between precession and all planetary motions, planets cannot ever return to the same exact places in our own sky. But in Ptolemy's time, the Creator could simply not have played such a nasty trick on poor mortals, and especially on astrologers; these periods had to be commensurable, and 36,000 years was that long-sought period of the Great Year, about which too much freedom had so far been left. The origin of this new fancy are unclear; it may have arisen amidst Indian astronomers, ever fascinated by the Great Year, when they heard about the Greek precession discovery. While explicitly mentioned only in Arab texts of the tenth century, it will acquire great significance during late medieval disputations about both Space and Time pluralities. In the meanwhile, the Great Year had never been more popular, but mostly for different

[13] We also leave aside a purely fancied motion, *trepidatio* (periodic modulation of the precession rate) since it does not seem to have interfered with the Great Year scheme.

reasons. Plato and Aristotle had adopted the scheme, but gave it only a subsidiary role in their own systems. Neither of them carried palingenesis to its inescapable conclusion, fatalism, which is surprising from such logicians; but the Stoics did.

So far, the Stoic school has not been discussed in these pages; in any history of ancient views of the physical world, the Porch ($\sigma\tau o\alpha$), unlike the Garden ($\kappa\eta\pi o\sigma$), does not play an important role. Stoics were much less concerned about explanations of Nature than Epicureans or Peripatetics; the didactic poem *Astronomica* of Marcus Manilius (Manilius ca 10), written under Augustus and Tiberius, while not without literary merit, remains far less interesting to the scientist than the Lucretius one.[14] While it begins with a description of the Heavens, and contains many refutations of *De Natura Rerum*, the central goal is clearly astrological. Altogether, Stoic cosmology is non-mathematical and mostly derived from Aristotle, but with some differences. As reported by Laertius in his *Life of Zeno,* Stoics reject æther as substance for celestial bodies, replacing it by fire; their Sun "is pure fire …The Moon is of a more earthy composition, since it is nearer to the Earth… [they] derive their nutriment, the Sun from the wide ocean… the Moon from fresh waters, with an admixture of air." (Laertius s.d., 249). The Stoics do not preserve an essential Peripatetic tenet, the total rejection of vacuum:

> The World is one and finite, having a spherical shape, such a shape being the most suitable for motion… Outside the World is diffused the infinite void, which is incorporeal. By incorporeal is meant that, though capable of being occupied by bodies, it is not so occupied. The World has no empty space within it…. The World is limited, the void is unlimited. (Laertius s.d., 245).

Hylozoic explanations remain prevalent; Chrysippus, disciple of Zeno, holds that

> The World is a living being, rational, animate, and intelligent… in the sense of an animate substance, endowed with sensation; for animal is better than non-animal, and nothing is better than the World, ergo the World is a living being. (Laertius s.d., 247).

However, these are mixed with some surprisingly sensible views, obviously inherited from the Ionians

> a shooting star is the sudden kindling of a mass of fire in rapid motion through the atmosphere, which leaves a trail presenting an appearance of length… Lightning is the kindling of clouds from being rubbed together… Rainbow is the reflection of the sun's rays from watery clouds. (Laertius s.d., 257).

Despite their adoption of an infinite empty space outside our World, Stoics remained uninterested in its potentialities; they clearly distrusted other invisible Worlds, or at least did not discuss them openly. Their central interest lay in unlimited Time and unmitigated fatality, as a natural consequence of harmony between terrestrial and celestial things. Pierre Duhem devotes very interesting pages to Stoics (and later, to astrology); let us quote him extensively (our translation). "By considering the Universe as a perfectly adjusted mechanism where the least motion

[14] For our few remarks on Stoics, we are indebted to the G.P. Goold *Preface* and *Introduction* in Manilius (ca 10). About Stoic astronomy, see Dreyer (1905), 157–161.

of any component entailed for each point of the machine an exactly determined displacement, [Stoics] have truly extracted from Peripatetism the consequence that the whole doctrine was calling for…"[15] Hence they adopted palingenesis, and gave it a central place in their philosophical system. For Stoics, the entire world periodically disappeared in a universal conflagration called *incendium*, after which it was born again. For Aristotle, the superlunary world had been exempted from any such disaster since heavenly perfection entailed eternity and ranked above any scheme of universal periodicity; but the Stoics made no such exceptions, and for them the links between Earth and Heavens were felt much tighter than ever before. The logical connection between fatalism and the Great Year scheme is clear; according to Stoics

> when each of the errant bodies returns exactly to the point where it was situated at the beginning, when the World was first created, these errant bodies set ablaze and destroy all beings. Next, when they start again on the same courses… every single thing which had happened during the first period happens again in exactly the same way. Socrates will live anew, and similarly Plato, and every single man, his friends and fellow citizens… (Nemesius, reporting on Cleanthes and Chrysippus, and as quoted by Duhem 1959, I, 289).

Not being mathematically-minded, Stoics did not worry about an exact figure for the Great Year, and provided no fresh estimates. Their school had many converts (for instance in Roman Empire governing circles), and was to make the Eternal Return scheme widely known.

Thus, one practical consequence of mathematical astronomy was the rise of astrology, and we are by no means through today. Belief in astrology was not limited to practicing Stoics; some sort of close connection between Earth and celestial bodies was almost universally felt at the time, and one of far greater importance for daily life than any the Ionians had ever dared: they claimed that if everything is fated to happen, no kind of prediction is worth the trouble. However, if celestial motions govern terrestrial change, they can be used for prediction of all that is of any concern to mortals. For discerning minds, there is here an absurdity that was very seldom felt; still, the astute Cicero once pointed it out: "What use is it for us to predict inevitable events?" (Cicero, *De Divinatione*, II 9, quoted by Duhem 1959, II, 291). A regular study is out of the question here, but astrology and Great Year are closely connected; as they will survive and thrive in the Christian context (see Chap. 4 and 5), a brief discussion is in order.

Ptolemy himself was largely responsible. His *Tetrabiblos*, a work that proved as important for astrology as the *Almagest* for astronomy, provided the "scientific" material, while the ground had been cleared by Aristotle:

> Suppose then a man knows accurately the movements of all the stars, the Sun and the Moon… and from these data is able to work out both by calculation and successful conjecture the distinctive effects which will result from the combined operation of all these factors; what could prevent him from telling how the atmosphere will be affected by these phenomena?… Why should he not in the same way, by considering the nature of the environment at the time of birth, work out for any individual man the general character which

[15] Duhem (1959), II, 297. For Stoics and the Great Year, see (I, 275–284), and for astrology (II, 270–390).

> his temperament will have, e.g. that he will have such and such bodily characteristics? (Ptolemy, *Tetrabiblos*, quoted by Toolmin 1961, 146).

A most vexing fact is that, due to the advance of geographical knowledge, Ptolemy was able to preach far more convincingly than Aristotle had done. Classical Greece had almost completely ignored tides; but Alexander's soldiers reached the mouth of the Indus, where (as told by Quintus Curtius) they got a bad fright from the periodic rise and fall of the sea. For Ptolemy, the correlation with lunar motion was unmistakable and firmly established:

> A force, emanating from the ethereal and eternal nature is transmitted to all things surrounding the Earth… The first elements under the Moon, fire and air, are surrounded and pushed by motions of æther; then in turn they surround and push in their agitation all bodies below, that is earth, water and all animals and vegetables born there… The Moon, being Earth's closest neighbor, acts in a manifest manner on all things terrestrial; most animate or inanimate beings agree with her in all their changes; rivers swell or get dry together with the Moon's light; according to whether it rises or sets the seas are pulled by contrary currents; either in whole or in part, vegetables and animals feel the effect of the Moon's waxing and waning. (Ptolemy, *Tetrabiblos*, quoted by Duhem 1959, II, 290).

Not all of Ptolemy's observations are correct, but there was to be no answer to the tide argument until Newton stepped in; and we shall see that in his utterly wrong theory of the tides, Galileo went to the illogical extreme of negating the Moon's influence altogether. As to Newton, he only killed "scientific" astrology while the popular brand remains alive and well. Altogether, those Indus tides have nastily delayed the progress of thought among humans.

The impetus had been given. Once those troublesome physicists had been thrown out of Heavens, astrology and mathematics could become the very best bedfellows. Worse, theology was free to move in, and form an unholy *ménage à trois* that was to remain stable for centuries; not however without some internal quarrels, as will be seen in the next chapters. Ptolemy in *Tetrabiblos* again:

> A sincere love of philosophy consists uniquely in the desire to know the Divinity better … Pure philosophy which depends solely on piety towards God should interest itself in other sciences only insofar as these… encourage to admire, adore and bless the craftsmanship and intelligence of God. To love God with a simple heart and soul, to revere the works of God and finally to show in one's life thankfulness for the Divine Will which alone is the fullness of the Good: that is the philosophy which is unspotted by any harmful curiosity of mind. (Ptolemy, *Tetrabiblos*, quoted by Toolmin 1961, 147).

Let us quote Bertrand Russell (1946, 56): "The combination of mathematics and theology, which began with Pythagoras, characterised religious philosophy in Greece, in the Middle Ages, and in modern times down to Kant." The Ptolemaic program, solidly grounded in the Good, and inherited as much from Plato as from Aristotle, anticipates Augustine; indeed, for all practical purposes, it is already Christian. But a never-ending trouble will arise from that too hastily dismissed curiosity of mind.

The system of the World starting from Pythagoras and developed on Platonic principles by the mathematical astronomers was to prove successful for a very long time, while Ionians, Atomists and Epicurus were largely forgotten about, together with their form of the Plurality of Worlds. Why?

The main reason is that Chaos, Chance and Plurality were to prove unpalatable to Christianity, at least in its early fundamentalist form, while the Order-Design-Unicity trinity inherited from Plato seemed just made to order. Still, the trouble with the materialism of Atomists was older, and much antedated the Christian era. In his *Life of Nicias,* right after narrating the Athenian mishaps of Anaxagoras, Plutarch proceeds to explain how Plato saved the situation by making Science theologically (and politically) correct:

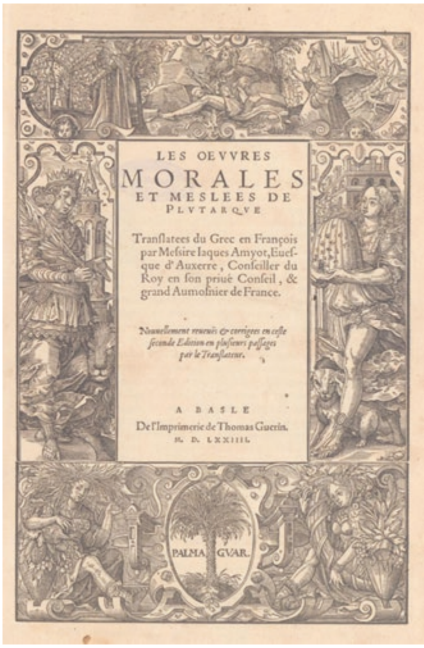
> In fine, the doctrine of Plato being received and liked, as well for his virtuous life as also for that he submitted the necessity of natural causes unto the controlment and disposition of divine power, as unto a more excellent and supreme cause, took away all the ill opinion which the people had of such disputations and gave open passage and free entry unto the mathematical sciences. (Plutarch s.d., III, 291; we reproduce here the 1579 translation by Thomas North, itself from Jacques Amyot's French one).

However, there had been a basic flaw within Plato's cosmological model: within it, uniqueness and the closed form of the World are consequences, not of a Creator-planned Order, but merely of crude anthropocentrism. Conversely, Plato's distant followers will be able to construct multiple Worlds on rational and even geometrical premises, all according to a grand master plan. Later, Plurality will become thoroughly Christianized from the efforts of many thinkers exploring these perilous possibilities open to the Platonic Artificer, which His prophet had simply neglected. When painting an Universe all wrapped-up within a finely-polished crystal ball, Plato believed himself making sole use "of the soul's inborn intellect"; but he had unconsciously been looking around, and with short-sighted eyes at that. As to his primordial Good, it has remained Man's exquisite piece of wishful thinking; and the most damning too.

Chapter 3
Plutarch's De Facie: The Moon Is Another Earth

Just as, assuming that we were unable to approach the sea or touch it, but only had a view from afar, and had the information that it is bitter, undrinkable and salty water, if someone said that it supports in its depths many large animals of multifarious shapes and is full of beasts that use the water for all the ends that we use air, his statements would seem to us like a tissue of myths and marvels, such appears to be our relation to the Moon… when we disbelieve that any men dwell there. Those men would be much more amazed at the Earth… obscurely visible in moisture, mists and clouds to think that it engenders and nourishes animate beings which partake of motion, breath and warmth.

Plutarch, *De Facie*, 179


LES OEVVRES
MORALES
ET MESLEES DE
PLVTARQVE

Tranſlatees du Grec en François par Meſsire Iaques Amyot, Eueſque d'Auxerre, Conſeiller du Roy en ſon priué Conſeil, & grand Aumoſnier de France.

A BASLE
De l'Imprimerie de Thomas Guerin.
M. D. LXXIIII.

(Left) Plutarch, in the *Nuremberg Chronicle* (1493). Wikimedia Commons
(Right) Front page of Plutarch's Moral works, second edition of the Amyot translation, published in 1474 by Thomas Guérin at Basel, Switzerland. The *De facie* is in this book. www.e-rara.ch

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
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Antique science ultimately turned out to be a failure, in the sense that it never led to the explosive growth that we Moderns have been witnessing from the Renaissance to the present day. There are different ways of accounting for this general slowdown of innovation. Here is one, not worse than most others: no synthesis was ever achieved between the rival currents of thought described in the two preceding chapters. The materialistic, broad-minded and remarkably modern Atomist-Epicurean approach remained anchored on mere sensation and wholly qualitative; while in the Pythagorean-Platonic system, the Universe was rational and even mathematical in principle, but actually operated by a plethora of Gods through hylozoic mechanisms, and grew more and more narrowly anthropocentric. No in-between path was explored, and the final convergence had to wait for almost two millennia.

However, as far as the Plurality problem is concerned, some minds came close to the future amalgam. This is best seen in the case of Plutarch because we have the nearly complete text of his little book, written in Greek but generally known under the Latin title *De Facie quae in orbe Lunæ apparet* (Concerning the Face which appears in the Orb of the Moon, Figure 3.1). This minor work has always remained far less famous than the *Parallel Lives*; while never completely lost, it seems to have carried little weight in antiquity, and remained unknown at least to astronomers throughout the Middle Ages; then, after being rediscovered during the Renaissance, *De Facie* went through several editions. Plutarch was no scientist, and did not write for scientists in particular; still, as will be seen, he was to be taken quite seriously by Copernicus, Kepler and Newton.

He was born in Beotia, at Chæronea, approximately in 50 AD; most of his works appear to have been written around the age of fifty, that is under the reigns of Emperors Domitian and Trajan. Enough remains of his philosophical books (well known in his own time) to show his attitude to be eclectic, borrowing from Pythagoreans, Stoics, Peripatetics and mostly from Plato; but he takes nothing directly from Epicureans, which makes his lunar concepts perhaps even more original. Unlike Lucretius, he shows good awareness of contemporary geography, optics and astronomy. His *De Facie* theme is presented through a common literary device, first used by Plato and still popular in Galileo's time: a conversation between half a

Figure 3.1 Amongst the depictions of a face on the Moon, that from Georges Méliès' movie *Voyage dans la Lune* (Travel to the Moon, 1902) is probably the most famous: a shell containing the travellers falls on the Moon. Wikimedia Commons

dozen sensible people interested in unraveling the true picture of the World. He does not deal with External Plurality, as the possibility of other unobserved Worlds is never discussed; however his treatment of the Moon is quite remarkable, because it shows how close to the true picture one could hit, from just the naked-eye observations available to all Ancients. The *De Facie* displays unity of purpose: it defends the idea that the Moon is another Earth, and as such is able to sustain forms of life either similar to or different from the terrestrial variety. There is no need to follow slavishly the not so dramatic and often confusing dialog, nor to credit each speaker for his personal contribution; it is better to present the main arguments from each of the schools represented: the Stoics (Plutarch's main targets), the Peripatetics, and the Academics whose outlook he seems in the whole to favor.

To make the Moon another Earth, four kinds of issues have to be settled. First, one must form an idea of how large the Moon is, which involves its distance; second, it has to possess gravity like that we experience on Earth; third, their material constitution and illumination must be comparable. Only at this point does it become possible to speculate on lunar life. The first question, distance and size, is linked to the adopted system of the World. Well aware of technical points, and without explicitly adopting one of the available models, Plutarch gives an invaluable reference to the most prescient and least-known of all, that of Aristarchus:

> … the Greeks ought to lay an action against Aristarchus the Samian on the ground that he was disturbing the hearth of the Universe because he sought to save the phenomena by assuming that the heaven is at rest while the Earth is revolving along the ecliptic, and at the same time rotating around its own axis. We [the Academics] express no opinion of our own now; but those [ourselves] who suppose the Moon is Earth, why do they, my dear sir, turn things upside down any more than you [Stoics] do who station the Earth suspended in the air? (*De Facie*, 55).

Plutarch himself does not seem to endorse the Aristarchus system but uses it to illustrate an important concept that we shall meet again and again: the equivalence of all vantage points within the Universe. He writes:

> After all, in what sense is Earth situated in the middle, and in the middle of what? The sum of things is infinite, and the infinite having neither beginning nor limit, cannot properly have a middle, for the middle is a kind of limit too, but infinity is a negation of limits…In fact, in the sum of things no middle has been left… it is without hearth and habitation, moving in infinite void to nothing of its own. (*De Facie*, 77).

However (and unlike for the Ionians and Epicureans) this unequivocal adoption of an infinite centerless Universe does not mean geometry is banished; on the contrary, the distances between celestial bodies can be determined, and the Moon situation is intermediate, hence peculiar:

> Dismiss the fixed stars and other planets, and consider the demonstrations of Aristarchus in his treatise *On Sizes and Distances* that "the distance of the Sun is more than 18 times and less than 20 times the distance of the Moon"… however the Moon's distance from Earth is said to be 56 times the radius of the Earth… according to the mean calculations, this radius is 40 000 stades.[1]

[1] Plutarch (*De Facie*), 75. Stating the exact value of the *stade* used here is difficult; estimates vary between 157 and 185 m.

The question of the Moon's size is considered next. In one place, Plutarch writes that "… the Earth casts a shadow which at its narrowest is three times as broad as the Moon" (De Facie, 57), a roughly correct estimate: Aristarchus and Hipparchus actually give 2 and 2.5 lunar diameters for the size of that shadow. In another paragraph, Plutarch mentions different estimates he had heard about, without referring to the method employed:

> In fact the Egyptians, I think, say that the Moon is one seventy-second part [of the Earth], and Anaxagoras that it is the size of Peloponesus; Aristarchus demonstrates that the ratio of [the Earth's diameter to] the diameter of the Moon is smaller than 60 to 19 and greater than 108 to 43. (*De Facie*, 121).

Each statement might warrant a full discussion (the last one is taken almost verbatim from Aristarchus), but there is little need, as Plutarch is mainly interested in the intermediate situation of the Moon: in between Earth and stars. Hence, this intermediate position is for Plutarch an argument for the earthy nature of the Moon. Modern minds feel unimpressed; today, the fashion is that our Moon is cold and stony because it is small, like the Earth, not because it is a near neighbor. Many times in the present history will actual truth be unveiled from wrong arguments; fortunately, Plutarch will present more solid ones a little later. The most important point is that he preserves the valid elements from the two opposing world pictures. His infinite, centerless universe is basically Ionian; but he keeps none of the Epicurean nonsense about a human-foot-size Sun being just as good an explanation as any other, nor the Lucretian flat Earth. His universe is geometric, just like the Platonic one; the astronomers are kept busy estimating the main parameters, and their results may be trusted.

So the two "theories" of the universe were not incompatible after all, a line of approach with a solid future. And it is precisely this path that leads Plutarch to his prophetic view of the nature of the Moon, to be presently discussed.

Let us tackle lunar gravity first. The extreme audacity of the concept has become somewhat difficult to grasp for a modern mind, so obvious being the case today. The Peripatetic view and the great strength it derived from agreement with rough common sense have already been stressed; as we all know, Aristotle was not to be refuted until Galileo appeared on the scene with unexpected tools. Still, Plutarch not only displays a clear understanding of gravity on the surface of the Moon, but also of a much wider issue: gravitation itself. For him, the balance between gravitational and centrifugal forces is present in all but name:

> … the Moon is saved from falling by its very motion and the rapidity of its revolution just as missiles placed in slings are kept from falling by being whirled around in a circle. For each thing is governed by its natural motion unless it be diverted by something else. That is why the Moon is not governed by its weight: the weight has its influence frustrated by the rotary motion. Nay, there would be more reason perhaps to wonder if she were absolutely unmoved and stationary like the Earth. (*De Facie*, 59).

This amazing text reads like some popular twentieth-century booklet on celestial mechanics, and worse written ones might easily be found. There no intimation yet of that "gravitation" being universal, since cases other than the Earth-Moon pair are not considered; even so, the picture of the Moon in free fall around the Earth is so startlingly modern that one feels tempted to mistrust any post-newtonian translation of the Greek text. Fortunately, we have at least two pre-newtonian ones: the first was given in 1587 by Jacques Amyot, who also made the *Parallel Lives* immensely popular in France, and the second is the Latin version of Kepler, written before 1630. In both cases, no serious difference is found with the modern English text just given. Thus, one key point of Newtonian mechanics had been anticipated[2]; Plutarch does not of course foresee the future importance of the concept, and gives no credit to anyone in particular; he merely puts it in the mouth of one Lucius, supporter of the Academy. We have already seen that, when narrating the fall of the Aegos Potamos meteorite in his *Life of Lysander*, he had attributed to Anaxagoras the notion that celestial "bodies having weight, and stony in nature… are maintained [in their positions] by the impetuosity and speed of the heavens circular motion…" (*De Facie*, 59; see also Laertius s.d., 106). While not as precisely worded as in the lunar case (and, of course, basically incorrect), the idea is clearly related; thus, what we call centrifugal force was already considered as playing a role in the Heavens.

Plutarch next explores the consequences of a spherical Earth plus centripetal gravity, both concepts being presented as a set of "paradoxes"; today, we would say thought experiments. To start with, consider the notion that

> …people live on the opposite hemisphere clinging to the Earth like woodworms or geckos turned bottom-side up, and that we ourselves in standing remain not at right angles but at an oblique angle leaning from the perpendicular like drunken men. (*De Facie*, 63).

All these up-and-down notions must be taken with a grain of salt:

> If a man should so coalesce with the Earth that its center is at his navel, the same person at the same time has his head up and his feet up too. Moreover, if he digs through the farther side, his bottom in emerging is up, and the man digging himself up is pulling himself down from above… (*De Facie,* 67).

Aristotle himself had been well aware of the convergence of verticals, but Plutarch proceeds far beyond mere geometry; we have more paradoxes if we fancy that:

> … incandescent masses of forty tons falling through the depth of the Earth stop when they arrive at the center, though nothing supports or encounters them; and in their downward motion the impetus should carry them past the center, they swing back again and return of themselves? And not that a turbulent stream of water, if flowing downwards, it should reach the middle point which they themselves call incorporeal, stops suspended or moves round about it oscillating in an incessant and perpetual see-saw?

[2] Anti-Newtonians will not fail to point out that Newton's great discovery was actually old hat; to viz., Huygens in his *Cosmotheoros*: "Plutarch in his Book of the Moon says that some of the Ancients were of opinion, that the reason of the Moon keeping her Orbit was, that the force of her Circular Motion was exactly equal to her Gravity, the one which pull'd her to, as much as the other forc'd off from the Center… Which Mr. *Isaac Newton* has more fully explained, with a great deals of pain and subtilty; and how from that cause proceeds the Ellipticity of the Orbs of the Planets, found out by Kepler." (Huygens 1698, 158).

Plutarch may have derived from volcanoes the picture of incandescent rocks falling through the Earth, and that of a subterranean waterfall from Plato's *Phaedo*. His indisputable contribution is that oscillation around an incorporeal center in perpetual free-fall. For his Stoic or Peripatetic opponents, one key difference between terrestrial and celestial motions had been that only the second could be eternal. Altogether, Plutarch came not too far from that most famous and fruitful of all the Newtonian *Gedankenexperimenten*: the artificial satellite, eternally orbiting the Earth after being vomited from the mouth of a gun.

The next step for Plutarch is a concept that might be called universal local gravity, by which his speculations are extended to other celestial bodies:

> …it is no more at the center of the sum of things than as a whole that the Earth would appropriate to herself the heavy bodies that are part of herself, and [the downward tendency] of falling bodies proves not that [the Earth] is in the center of the cosmos but that those bodies which, when thrust away from Earth fall back to her again, have some affinity and cohesion with her. For, as the sum attracts to itself the parts of which it consists, so the Earth too accepts as her own the stone that has properly a downward tendency, and consequently every such thing ultimately unites and coheres with her." (*De Facie*, 69).

No anticipation of mutual attraction as a universal property of matter is found here, but merely an application of the old hylozoic principle: the like attracts the like. Earth, Sun (and Moon, as will soon be seen) solely attract their own parts, thus Plutarch would have been unable to conceive Earth-Moon orbital transfer. However, this limitation makes no difference locally, and he is able to form a perfectly correct picture of conditions on the lunar surface:

> If there is a body, however, that was not originally allocated to Earth or detached from it, but has somewhere independently a constitution and nature of its own as … the Moon, what is to hinder it as from being permanently separate in its own place, compressed and bound together by its own parts? For it has not been proved that the Earth is the center of the sum of things, and the way in which things in our region press together and concentrate upon the Earth suggests how in all probability things in that region converge upon the Moon and remain there. (*De Facie*, 71).

The stage-machinery being adjusted, Plutarch is now able to explore the lunar matter and illumination. While the two problems are conceptually separate from a theoretician's viewpoint, they are not so for the observer. We infer what the Moon is made of from the light it reflects to Earth, and it is this light that we analyze to the best of our abilities; which was true for Plutarch, and has remained true up to *Apollo 11*. Hence lunar matter and lunar light are tackled simultaneously in *De Facie*, and no attempt should be made to separate the two studies. The phenomena Plutarch must account for are the spots, the phases and the appearance of the Moon during eclipses. The first of the two theories he has to counter is the Stoic one in which the Moon is a globe of fire and air shining mostly by its own light; the second is the Peripatetic, involving a sphere of crystalline matter with mirror-like polish. This last view, according to which lunar phases are explained by refraction of sunlight and spots by reflection of the Earth itself, is more familiar today because it was preserved up to the Renaissance by the considerable success of Aristotelian doctrine; but the Stoic explanation was deemed at least as important when De *Facie* was written.

Plutarch starts by stressing that the problem is pretty serious: the Moon's markings, whatever they are, cannot be mere optical delusions:

> To begin with, you see that it is absurd to call the figure seen in the Moon an affection of vision in its feebleness giving way to brilliance… this phenomenon should rather have occurred in relation to the Sun since the Sun lights upon us keen and violent… moreover [this would not] explain why dull and weak eyes discern no distinction of shape in the Moon… while those of keen and robust vision make out more precisely and distinctly the pattern of facial features…The contrary should have been the case if the image resulted from an affection of the eye when it is overpowered. (De Facie, 37).

The Stoic theory held the Moon to be

> a sphere of fire containing air dispersed about it here and there, and a sphere moreover that has neither clefts nor depths and hollows, such as are allowed by those who make it an earthly body, but has the air evidently resting upon its convex surface." (*De Facie*, 51).

From such inauspicious beginnings, any explanation of the spots was bound to prove arduous; the best that the Stoics had been able to contrive was that:

> …supposing the Moon to be a mixture of air and gentle fire… what appears to be a figure is a result of the blackening of the air as when, in a calm water, there runs a ripple under the surface…[3]

After rippling air, what about fire? Stoics

> … prove the Moon to be a star or fire since she is not entirely invisible in her eclipses but displays a color smoldering and grim which is peculiar to her…[she] has a faint and feeble light of her own. (*De Facie*, 131).

His own criticism: the Stoic model is quite unable to explain the markings of that Face:

> If the Moon is really fire, whence came so much air in it? … and if air did come to be there, why has it not come to be æther realized by the fire, and in this transformation disappeared but instead has been preserved as a housemate of fire this long time, as if nails had fixed it to the same spots and riveted it together? Air is tenuous and without configuration, so it naturally slips and does not stay in place; and it cannot have become solidified if it is commingled with fire… (*De Facie*, 49-51).

We agree with Plutarch that no lunar mixture of air and fire is a tenable model.

Plutarch does not explicit the Stoic treatment of lunar phases; he merely hints that it must have been quite laborious. His own argumentation proves rather diffuse, and gains in being much shortened:

> if the mass of the Moon that is illuminated by the Sun were æthereal or fiery, the Sun would not leave her an hemisphere… in shadow…; she should be saturated in her entirety and altered through and through by the light proceeding easily in all directions… in fact the circle … that divides her visible and invisible parts… conclusively demonstrates that her illumination is the result… not of a concentration of light within her, but of light shining upon her from without. In that she is not only illuminated herself however, but also transmits to us the semblance of her illumination she gives us all the more confidence in our theory of her substance…" (*De Facie*, 111-115).

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[3] Plutarch (*De Facie*), 51, see *Note a*. Strangely enough, that ripple explanation had already been expressed by Homer (*Iliad,* VII, 63–64). That Face in the Moon has a long history indeed.

Why is he trusting that he is able to guess the true nature of lunar substance, while his Stoic opponents cannot? Because he has made his own observations about the behavior of light and matter on Earth; or, as we would say, performed suitable optical laboratory experiments:

> There are no reflections from anything rarefied or tenuous in texture, and it is not easy even to imagine light rebounding from light or fire from fire; but whatever is to cause a repercussion or reflection must be solid… The same sunlight that the air lets pass without impediment or resistance is widely reflected and diffused from wood and stone and clothing exposed to its rays.

Such laboratory tests are bound to be applicable to the astronomical case:

> The Earth too we see illuminated by the Sun in this fashion. It does not let the light penetrate its depths as water does or pervade it through and through as air does; but such as is the circle of the Sun that moves around the Moon… just such a circle in turn moves around the Earth… Give me leave then to put it in geometric fashion in the manner of a proportion. Given three things approached by the light from the Sun: Earth, Moon, air; if we see that the Moon is illuminated, not as the air is but rather than as the Earth, the things upon which the same agent produces the same effect must be of a similar nature. (*De Facie*, 115-117).

Which is the core belief for implementing all astrophysics; the only difficulty is to follow properly these excellent guidelines. From our vantage point, the whole discussion seems too elementary; but one should remember that the mere fact that "night is the shadow of the Earth" (as Plutarch himself will write a little later, *De Facie*, 119), had been a considerable discovery: before Empedocles, darkness had been a substance in its own right, just as much as light itself. Hence he feels he has to hit the nail on the head again and again:

> the fact is that in setting the Sun is screened from our vision by the Earth and in eclipse by the Moon; both are cases of occultation… If the effect is similar, the agents are similar for it must be the same agents that cause the same things to happen to the same subject… (*De Facie*, 119-121).

The general description of eclipses that follows is not original with Plutarch, hence there is no need to follow it except insofar as the Stoic fire is concerned. Indeed, the true nature of that "grim smoldering color" seen during total eclipses of the Moon has proved a matter of considerable difficulty, and was not established before modern times. We know it is due to refraction plus selective absorption of sunlight grazing the Earth, and passing through its atmosphere: the eclipsed Moon is reddish from the same cause that reddens our sunsets. This phenomenon was for long to assume great astrological significance, as the intensity and hue vary randomly from one eclipse to the next, and were neither explainable nor predictable; even William Herschel will still feel compelled to invoke some faint lunar emission! (*De Facie*, 133, *note b* of translators). Thus, the complexity of the problem makes Plutarch's highly sensible discussion all the more interesting; for him, the main error is to treat the reddish color of the Moon as

> …if it were really her own. But it is not so … for as she is eclipsed she exhibits many changes of color…[Hence] it is a mistake to settle upon the smoldering color alone, the very one that might especially be called alien to her, and rather an admixture or remnant of the light shining round about through the shadow… Since here on Earth places near lakes and

> rivers open to the sun take on the color and brilliance of the purple and red awnings that shade them, what wonder… that the Moon takes the stain of different hues… A star or fire could not in shadow shine out black or glaucous or bluish; but over mountains, plains and seas flit many kinds of colors from the sun, and blended with the shadows and mists, his brilliance induces such tints as brilliance does when blended with a painter's pigments… (*De Facie*, 137-139).

Thus Plutarch came close to the explanation that was to elude astronomers for such a long time: while refraction by the Earth's atmosphere itself remained far beyond his ken, weak scattered sunlight, modified in color, is clearly invoked.

Plutarch next turns to refuting the Peripatetic doctrine. Obviously he believes it well known to his readers, and the account given by his various speakers is rather scanty; we are told only the essential points, which are immediately refuted. Peripatetics have to account for both the phases and the spots; eclipses seem to be of less concern. They start from a belief that the Moon is illuminated by "the sun shining through her in the manner of glass and ice" (*De Facie*, 101), which leads them "to assert that what is called the Face consists of mirrored likenesses, that is images of the great ocean reflected in the Moon… and the Moon is itself in uniformity and lustre the finest and clearest of all mirrors." (*De Facie*, 41). That theory achieved an incredibly durable success, being still current in Galileo's time. Peripatetic notions about mirrors were not of the clearest, since they also "think that the reflection of the visual ray to the Sun accounts for the appearance of the rainbow in a cloud…. [and also] that the outer ocean is seen in the Moon not in the place where it is but in the place where the visual ray has been deflected to the ocean…" (*De Facie*, 41).

The trouble lies not in operating that bizarre tool, the visual ray, which is legitimate, and no bar to correct geometrical optics; it was common at the time, and Plutarch also will wield the device whenever convenient; we still do, now and then. However, that comparison with the rainbow means that Peripatetics did not understand how images were formed by mirrors, and a study of reflection was in order. Plutarch's notions are interesting and sound in the whole, not always in details; but since they are not original, and do not go beyond Euclid's *Catoptrics*, there is no point in following them except when specifically applied to the lunar case. The law of reflection plays a central role, and we feel rather amused to learn that "… some people take direct issue with the mathematicians and maintain that they confute the equality of the angles of incidence and reflection by the very streams of light that flow from the Moon upon Earth, for they deem this fact to be much more credible than the theory." (*De Facie*, 109). In plain words: everybody knows the Moon to be a mirror showing an image of Earth; if geometers can't manage to agree with common sense, they better revise their theorems, and we will take them seriously afterwards.

Now, the Plutarch answer: what is wrong with the Aristotelian account of lunar spots? First, geography itself: an image of Earth would not in the least look like that Face we see

> … although the outer ocean is a single thing, a confluent and continuous sea, the dark spots in the Moon do not appear as one, but as having something like isthmuses between them… Therefore one must assume the existence of several outer oceans separated by isthmuses and mainlands which is absurd and false…

Next, optics is also invoked:

> …is it possible, though the inhabited world has length and breadth, that every visual ray when reflected from the Moon should in like manner reach the Ocean, even the visual rays of those who are sailing in the great Ocean itself, yes, and who dwell in it as the Britons do?

So far, the modern reader is not impressed: Plutarch's geography was inadequate, and by inverting the argument, his opponents would have discovered America! As to those unlucky *Βρεττανοι*, we know that they live swamped in fog, and just can't see a thing anyway. His optics are also faulty: the terrestrial image would not have looked different when observed from anywhere on Earth.

Plutarch's first purely optical objection is not convincing either: "How is it that the reflection of the ocean exists as a face only in the Moon and is seen in none of all the many other stars although reason requires that all or none of them should affect the visual ray in this fashion?" (*De Facie*, 47). The question is absurd: he should have understood that (in modern terms) the stellar apparent diameters were much too small; only the Sun could have shown the effect, but nobody had ever taken it to be a mirror. Thus, the difference in nature between Moon and stars is again a correct conclusion deduced for a wrong reason, but more solid arguments follow. That Peripatetic polished sphere, whether glass or ice, does not hold water:

> …were that true, we should see the Moon at the full on the first [day of the lunar] month if she does not conceal and obstruct the Sun but because of her subtlety lets his light through… Certainly her deviations [in latitude?] cannot be alleged as the cause of her invisibility when she is in conjunction…. Far from doing this, she is at that time invisible herself, and often has concealed and obliterated him… As for the explanation of Posidonius that the profundity of the Moon prevents the light of the Sun from passing through her to us, this is obviously refuted by the fact that the air, though it is boundless and has many times the profundity of the Moon, is in its entirety illuminated and filled with sunshine by the rays… (*De Facie*, 101-103).

Summarized: a transparent Moon plus any kind of sunlight refraction cannot account for the phases. And the concept of reflection from the surface is even more absurd: elementary tests show that whenever you look at the Sun in a mirror, you see an image of the Sun itself:

> Those who have placed themselves in the path of reflected rays see not only the object illuminated but also what illuminates it. For example, if when a ray of light rebounds from water to a wall, the eye is situated in the place that is itself illuminated by the reflection, the eye discerns all three things, the reflected ray, and the water that causes the reflection, and the Sun itself… [hence the beholder should be able] to point out in the Moon at night an appearance of the Sun such as there is in water by day when there is a reflection of the Sun from it. (*De Facie*, 149).

In short, a mirror-Moon should not show those diffuse markings, but a small and clear image of the Sun.

Today, the argument appears straightforward, clear, and final. Such was certainly not the view of Plutarch's contemporaries, and his demonstration was to lie mostly forgotten. In the sixteenth century Leonardo wrote up a similar one (Vinci s.d., II, 154–168), but his *Notebooks* were solely for his own use. Next, Galileo published a full treatment in the *Dialog of the two systems of the world*, under a more technical form that did not differ in essence. Only then did the Peripatetic Moon-mirror nonsense vanish, and not without a fight.

Plutarch is now ready to present his own lunar model. He starts precisely from the absence of specular reflection to demonstrate that lunar soil must be (in modern terms) a fairly good scatterer of light:

> Milk does not retain such mirrorings either to produce reflection of the visual ray back from herself in the way the smoother mirrors do…?[4]

And again and again (the point cannot be too much stressed)

> such a Moon [as I have in mind] ought to shatter and divert the visual ray so that reflection would be out of the question… reflection is likely to occur only in mirrors that have been polished to exact smoothness…the Moon is very uneven and rugged with the results that the rays …striking against considerable heights which receive reflections and diffusions of light from one another are multifariously reflected and intertwined…coming as it were to us from many mirrors. (*De Facie*, 111).

The modern term is multiple scattering.

Plutarch next presents his radical conclusion:

> Consequently let us not think it is an offence to suppose that [the Moon] is Earth… and just as our Earth has certain great gulfs, so that Earth yawns with great depths and clefts which contain water or murky air.

Unfortunately, he next goes awry on a point of some difficulty (which two millennia will be required to clear up) since he believes that "…in the interior of these [clefts] the light of the Sun does not plumb or even touch, but it fails and the reflection it sends back is discontinuous." (*De Facie*, 143). Which means, as the context shows, that the dark spots are explainable by local shadows. Actually they are not, as far as the naked eye full Moon is concerned, and the modern explanation is one of inconsiderable subtlety: the dark parts (the *maria*) are simply darker matter, and that's that. Still, he makes some good points: the shadows under some circumstances, would be far greater than the mountains themselves, and he gives a fitting terrestrial analogy: the shadow of Mount Atlas is known to reach a far as Lemnos! (*De Facie*, 145–7); failing, however, to see that this case could not apply to the full Moon. Never mind; the Moon is another Earth, and as such ready to receive Life.

Now is the proper time to stop for a few cautionary remarks. By careful pruning of the quotations, elimination of either wrong or irrelevant parts (and, alas, of the poetry also), and sorting the various points in an order more immediately apprehensible to the modern reader, we risk having made Plutarch more modern than he really is. Actually, his dialog does not read like the Galilean ones, and by a wide margin. The present account would be unfair if it failed to stress that despite many correct deductions, Plutarch still sees the Universe through a veil of Platonic mysticism. The point is made here not to belittle his contribution, but because the ultimate

[4] Plutarch (*De Facie*), 151. Unfortunately, Plutarch next weakens his case by adding unnecessary (and incorrect) explanations based on relative positions of Sun, Moon and Earth. There is no need to follow these; the important point is the correct deduction of roughness for the surface of the Moon.

compatibility of the Platonic outlook with Plurality will become of growing importance in the next chapters.

He presents his rational but fully hylozoic model of the cosmos in a rather tentative manner, within a discussion purporting to show that the notion of natural place, defended by his Peripatetic opponents, is in fact subjective. According to him, things are not located where they are because they are endowed with intrinsic weight or lightness, but because the Universe is planned to work in the best possible manner:

> …such is probably the case with the cosmos too if it is really a living being; in many places it has earth, and in many fire and water and breath as the results not of forcible expulsion but of rational arrangement. After all, the eye has its position in the body not because it was extended thither as a result of its lightness, and the heart is in the chest not because of its heaviness… but because it was better that each of them should be so located… The rational principle is in control, and that is why stars revolve fixed like radiant eyes… the Sun in the heart's capacity transmits …heat and light as it were blood and breath, and earth and sea naturally serve the cosmos to the ends that bowels and bladder do an animal… The Moon situated between Sun and Earth as the liver… is between heart and bowels, transmits hither the warmth from above and sends upwards the exhalation from our region… It is not clear to us whether her earthiness and solidity have any use suitable to other ends also. Nevertheless, in everything, the better has control of the necessary. (*De Facie*, 91-5).

Such hylozoic explanations will remain active up to the times of Descartes; and that Best possible World will be preserved as the central cause of Plurality for three centuries more. We find within another discussion: "The Moon herself, like the Sun, which is an animate being of fire many times as large as the Earth, is nourished by the moisture on the Earth as are the rest of the stars too…" (*De Facie*, 177–179) Furthermore (and this is pure Plato), Plutarch's earthiness itself is no bar to divinity:

> … the honorable repute of the Moon is surely not impaired nor is her divinity because she is held by men to be a celestial and holy Earth rather than, as the Stoics say, a fire turbid and dreggish… we are far from thinking that the Moon, because she is a celestial Earth, is a body without soul and mind…" (*De Facie*, 141-143).

Altogether, we have to take as a fact that the first quasi-scientific treatment of the Plurality theme in history rested on a philosophical basis we no longer share. There will be others.

The last part of the *De Facie* is devoted to Life on the Moon. Remarkably, it is easier to read than the first; ideas follow each other in logical order, the main points are clear and easily summarized. First, prudence is necessary, as life on the Moon can only be tackled as a reasonable hypothesis:

> … I should like to hear about the beings that are said to dwell on the Moon, not whether any really do inhabit it, but whether habitation there is possible.

Second, Plutarch searches for the Causes:

> If [habitation] is not possible, the assertion that the Moon is an Earth is itself absurd for she would then appear to have come into existence vainly and to no purpose, neither bringing forth fruit nor providing for men of some kind an origin, an abode and a means for life, the purposes for which this Earth of ours came into being, as we say with Plato "our muse, strict guardian and artificer of day and night. (*De Facie*, 157).

And Plutarch's answer was to remain the unique and complete answer as long as the slow and laborious incorporation of Ionian materialism within Science had not been completed. Not a single one of the Plurality converts we shall meet on the way will ever propose any other ground for his fancy before the nineteenth century. Nevertheless Plutarch displays far more subtlety in his manipulation of teleology than most of his later followers, since the following objection is made (by one Lamprias, his usual mouthpiece):

> If the Moon is not inhabited by men, it is not necessary that she have come to be in vain and to no purpose, for we see that this Earth of ours is not productive and inhabited throughout its whole extent either… some parts are desert and fruitless with winter storms and summer droughts and the most are sunk in the great sea… Yet it is by no means for nothing that these parts have come to be… Nothing prevents the Moon too, while destitute of living beings, from providing reflections for the light that is diffused about her…and digest the exhalations from the Earth and at the same time slacken the excessive torridity and harshness of the sun. (*De Facie*, 165-167).

Hence, the Moon might be allowed to be earthy and nevertheless a part of the Platonic scheme without having been furnished with indigenous life by the *demiourgos*. The Platonic Good alone does not provide the answer; nevertheless "nothing that has been said proves impossible the alleged inhabitation of the Moon." (*De Facie*, 167). One must consider more closely the physical difficulties, and refute them one by one. First, that about gravity, which we may skip since no new point is made; second, because

> …Egyptians and troglodytes for whom the sun stands in the zenith one moment of the day at the solstice and then departs are all burnt to a cinder by the dryness of the atmosphere, it is really likely that the men on the Moon endure twelve summers every year, the sun standing vertically above them each month? (*De Facie*, 161).

As we know, the difficulty of living under the Tropics was to remain much exaggerated up to the Portuguese discoveries. But Plutarch has a sensible answer: simply consider

> …the continuousness of the change… between [the extremes] they have a season nearly approaching spring. (*De Facie*, 169).

Hence, here also no radical difference between Moon and Earth is to be found. The third obstacle was (and has ever since remained), the most serious one:

> Winds and clouds and rains without which plants can neither arise, nor having arisen be preserved, because of the heat and tenuousness of the atmosphere cannot possibly be imagined as forming there, for not even here on Earth do the lofty mountains admit fierce and contrary storms, but the air being tenuous already… escapes this compaction and condensation… (*De Facie*, 161).

Let us not credit Plutarch with more prescience than he shows here. On the central point, he is correct: the Moon does not have an atmosphere, and he was at least not misinterpreting his visual observations as evidence for one in order to feed his Life-on-Moon fancy. Still, he is not pretending to have himself observed the Moon to be cloudless: he merely extrapolates the weakening of our own atmosphere as we go up, a phenomenon of which ancient geographers were somehow aware. In the process, he fails to see the consequences of his own lunar gravity concept: his Moon is dry and airless because it is high above Earth surface; our modern Moon, because it is small. However, the error is again unimportant and leads to the most interesting discussion of all, with surprisingly modern views on possible adaptability of life to exotic conditions:

> The fruits of tree and field here in our region are nourished by rains; but elsewhere… around Thebes and Syene, the land drinking water that springs from earth instead of rainwater… would refuse to adapt itself to the fruitfulness that attends the most abundant rainfall… Plants of the same kind which in our region, if sharply nipped by winter, bear good fruit in abundance, in Libya and in Egypt are very sensitive to cold and afraid of winter… [many examples are given here] and some plants…cannot even stand the dew, as is true of the majority of Arabian plants, but are blighted and destroyed by being moistened. What wonder then if on the Moon there grow roots and seeds and trees that have no need of rain nor yet of snow but are naturally adapted to a summery and rarefied air… They err then those … who demand that living beings there be equipped just as those here are for generation, nourishment and livelihood, [they] seem blind to the diversities of Nature among which we can discover more and greater differences and dissimilarities between living beings than between them and inanimate objects. It is plausible that the men on the Moon, if they do exist, are slight of body and capable of being nourished by whatever comes their way… We have no comprehension of these beings however, nor of the fact that a different place and nature and temperature are suitable to them. (*De Facie*, 171-179).

Admittedly, the endless diversity of the living world has been, then and now, a durable commonplace; this was for instance a favorite Aristotelian theme. But the Plutarch argumentation is worth quoting nearly in full, as it was to be repeated many times, and never more abundantly than today. We are still unable to describe, or even to name, alien forms of life. Down here, we cannot even guess what kind of creatures a few more million years of evolution will ultimately produce, provided that Intelligence does not mess up the planet, or the whole solar system. Our one certainty is: years by the million (or billion) will be available indeed. To gauge the modernity of Plutarch's view of lunar Life, one should remember the first *Apollo* landing on the Moon, and the elaborate quarantine of astronauts that followed; surely, the whole procedure was absurd to all scientists, still none dared to risk being caught "blind to the diversities of Nature." Remember also those extremely difficult decisions behind the selection of the *Viking* biological experiments, when the first Mars landing was being planned. How close to terrestrial life did one have to shoot for? Who could guarantee that the arbitrary choice made was neither too narrow nor too wide? What are we able to say today over and beyond Plutarch?

The dialogue ends with a last remark (the gist of which has since been repeated *ad nauseam*) which does delineate the scientific basis of the subject:

> Just as, assuming that we are unable to approach the sea or touch it, but only have a view of it from afar, and the information that it is bitter, undrinkable and salty water, if someone said that it supports in its depths many large animals of multifarious shapes, and is full of beasts that use water for all the ends we use air, his statements would seem to us like a tissue of myths and marvels; such appears to be our relation to the Moon, and our attitude towards her is apparently the same when we disbelieve that any men dwell there. Those men, I think, would be much more amazed at the Earth, when they look out at the sediment and dregs of

> the Universe as it were, obscurely visible in moisture, mists and clouds as a lightless, low, and motionless spot, to think that it engenders and nourishes animal beings which partake of motion, breath and warmth. If they should chance to hear somewhere these Homeric words: Dreadful and dank, which even Gods abhor, and Deep under Hell, as far as Earth from Heaven, these they would say are simply a description of this place, and Hell and Tartarus have been relegated hither, while the Moon alone is Earth… (*De Facie*, 179-181).

Around Year 2020 AD, we tend to dismiss Tartarus, Heaven and Hell from selenology and kindred subjects; but the spirit remains just the same, and the fashionable catch-phrase is "Absence of Evidence is not Evidence of Absence."

The later influence of Plutarch as cosmologist is small but definite. Copernicus, in his *Preface* to the *De Revolutionibus*, attempts to explain the origins of his own grand scheme: "I found in Cicero that Hicetas supposes the Earth to move. Later I also discovered in Plutarch that certain others were of the same opinion…"[5] Does this passage refer to the *De Facie* text? Copernicus several times quotes Aristarchus about technical matters (e.g., obliquity of ecliptic, length of the year) but not at this particular place, thus modern opinions are divided. The case of Newton is comparable; his own concern was not motion of the Earth, but possible antecedents to gravitation, and he probably read the above-quoted passage of *De Facie*, since he wrote that "…there must have been an esoteric knowledge of universal attraction among the ancients, as evidenced by Plutarch." (Newton quoted without a reference by Santillana 1970, 260). Neither Copernicus nor Newton had been concerned by the substance or structure of the Moon; however, Kepler was much interested, and he acknowledged a direct influence of Plutarch. The *De Facie* appeared to him so important that he wrote up a Latin translation as an appendix to his *Sommnium*, with plentiful marginal *Notes* of his own (Kepler 1608, see *Appendix D*, 209–211). For Huygens, Plutarch is no longer a source, but is nevertheless well remembered; when developing his own rambling speculations about extraterrestrial life, he writes: "Perhaps the moisture of the Earth [on the other planets] is just but sufficient to cause a Mist or Dew, which may be suitable to the growth of their Herbs. Which I remember is Plutarch's opinion, in his Dialogue upon this Subject." (Huygens 1698, 133). Today, Plutarch is usually given a tip of the hat as one ancient proponent of the inhabited-Moon fiction, but few authors actually bother to quote him, and the amazing modernity of his gravitation concept lies mostly forgotten.

[5] Copernicus (1543), p. 8. According to Santillana (1970), 263, this passage is the "sole source through which Copernicus learned of the existence of a "Copernican" system in antiquity." However A. Koyré, in the Introduction to his own translation of *De Revolutionibus* (1998, Diderot Editions, Paris), states that "Copernicus knew Aristarchus of Samos (as we do) through Archimedes."

Chapter 4
Patristic Cosmology Confirms the Single World

Shall [Neo-Platonists] not be compelled to dream with Epicurus about numberless Worlds? … They will have to grant these Worlds to have been created by God, who could not fail to fill the boundless immensity of these places surrounding this World of ours… I do not think they can go as far as proffering such utter nonsense.

Augustine, *De Civitate Dei*[1]

(Left) Augustine in his working cabinet, by Sandro Botticelli (ca 1480). Ognissanti, Florence. Wikimedia Commons
(Right) Augustine, De Civita Dei, manuscript in French (beginning of 15th century), Royal Library of Netherlands. Wikimedia Commons

[1] *De Civitate Dei*, XI, 6, 434, given here as quoted by Duhem's (1959) *Système du Monde* II, 465; however, we shall also use the *City of God* translation by H. Bettenson. As a guide to medieval astronomical thought (here and in the next chapter), we will often follow and quote the invaluable *Système du Monde*.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-41448-1_4

Following the development of any question about Nature during the Middle Ages, one is struck by the unity and immobility of thought during the entire period; Revelation has become the central fact, the only one deserving study. At no time did the Greeks ever have a universal reference textbook comparable to the Bible, out of which all truth worth knowing about man or the World alike could be extracted. And since Plurality is never explicitly mentioned in the Holy Book, it will only play a minor role.

This is however only a rough picture, to be corrected whenever finer shades are attempted. Within Middle Ages, the history of thought may be sorted into two different periods, patristic and scholastic. During the first (Figure 4.1), the Bible (as read by the Fathers of the Church) provides both questions and answers; all of astronomy becomes a minor subject, and while the Plurality problem is still occasionally referred to, it seldom generates any kind of discussion, the "true" state of things being so obvious. The second period begins in the twelfth century with the translation of major Greek works, in particular those of Aristotle and Ptolemy, which become accessible again. The Fathers are no longer the sole authority, and several disputes arise between Scholastics, all of them fully orthodox Christians, on the general theme of Reason and Faith: where exactly should the limits be drawn? Assuredly, there is not yet any conflict that might be called fundamental today; another half millennium will pass by before Reason is claimed by laymen, and at the time it was too much a direct gift of God to Man for any open contradiction with Faith. Still these controversies did engender notable progress, and our problem not only surfaced again, but even rose to prominence, under a new and unexpected

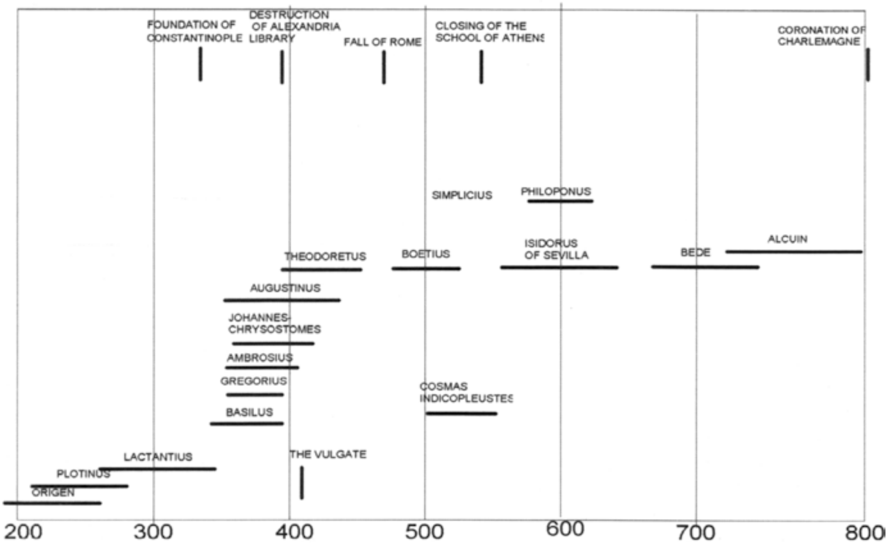

Figure 4.1 Chronology of the patristic era

shape. It might be dubbed *Virtual Plurality*, a novel fancy no Greek had ever dreamed about. Granted that Bible text and Peripatetic logic both picture Man as cozily tucked within the core of a unique World, still might not the Almighty make more of these if He fancied? Crudely summarized in this way the issue seems Byzantine in the extreme; our full story will attempt to show that it was not, and that the post-Renaissance enthusiastic endorsement of Plurality did in part grow out of such thirteenth century scholastic controversies.

Was this bizarre step a necessary one? We shall never know; this work is merely a History, i.e. a low form of intellectual activity, and not the objective account of some nicely controlled and repeatable scientific experiment. History, unlike historians, is supposed never to repeat itself. Or might that piece of popular wisdom be wrong after all, and shall we some day reach a more basic truth? Let us never forget the extraordinary (indeed, unique) character of our Plurality problem. An answer may become available, and it depends on the future outcome of our Search for Extraterrestrial Intelligence. Should that Search ultimately succeed, we shall know the answer; if we do communicate with other intelligent species, we shall learn all about their own histories, and how they went through that particular and crucial phase: discovery of the Plurality concept. That experiment may have been repeated already, perhaps many times, and History may yet turn into an experimental science; not quite in the sense that humans might perform those historical experiments themselves, but at least because they will be enabled to compare the results of independent trials, just through a visit to the Galactic Library.

The present Chapter covers only the early Middle Ages. In those times the main concern of any true Christian could not be the study of Nature *per se*: salvation was the only important goal and theology the one universally relevant science. All philosophical schools active at the time, Neo-Platonists, Stoics and Epicureans alike, had already put their concern with morals first; but Christians showed a loss of interest in the search for natural causes which went far beyond any other doctrine. Simultaneously, distrust for any kind of knowledge accumulated by the Greeks became marked, merely because it had grown out of pagan studies; and the later re-assimilation of Greek theories and discoveries was a slow and laborious process, not to be fully completed before the Renaissance.

These feelings are fairly often expressed by the Fathers of the Church; here we are mainly concerned with the attendant downgrading of astronomy. For Saint Basil, astronomers

> … who are given such a penetrating view for vanities have become willfully blind when the truth has to be apprehended. They measure the distance of stars… observe with great care retrogradations, declinations and motions of all celestial bodies with respect to the primary rotation; they determine the time taken by each of the moving bodies to accomplish its revolution; out of all the resources of invention, only one escapes them, that which will uncover God, creator of the Universe." (Basil, *Homilia I in Hexæmeron*, quoted by Duhem 1959, II, 396).

Henceforward, the study of the real world, the one gifted with a fairly obvious existence anyway, becomes a secondary matter. None of the fearful heresies, arianism, monophysm, nestorianism, that will wrack and nearly wreck Christendom was to involve any controversy about cosmology; and the same will be equally true of the later Orthodox and Protestant splits.

Augustine, who will later prove far more acute than Basil, is on this point in perfect agreement with him; and to all those who wonder about the complexities of celestial motions, he answers that "… these questions have to be treated with subtle and painstaking argumentation… I have no time to undertake such arguments … we merely want to know what is necessary for salvation and the good of the Church…"[2] Furthermore, pagan lies are multiple, a frequently recurring theme. Augustine again (now in his *City of God*): **"**How is it, then, that disciples have disagreed with teachers, and fellow-disciples with one another? Must it not be because they sought the answers to these questions as men relying on human senses and human powers of reasoning?" By contrast, Christian truth is unique: "Our authors do not disagree with one another in any way. Perish the thought!" Which shows that being a Father of the Church does not always imply the gift of prophecy. And Augustine goes on to mention Plurality as a specific pagan bone of contention:

> Some maintained that there is one World, others that there are countless Worlds, some that this one World came into being, others that it had no beginning, some that it is destined to perish, others that it will continue for ever, some that it is controlled by a divine mind, others that it is dependent on the fortuitous play of chances… (*De Civitate Dei*, XVIII, Chap. 51, p. 815-7; also discussed by Duhem 1959, II, 399-400)

Still, Augustine is fittingly impressed by pagan science when it leads to demonstrably exact conclusions, and singles out mathematics for praise, and also astronomical predictions (but not models):

> I do not know for how long will persist what I perceive through a physical sense, as for instance this Earth, this Heaven and such other bodies I perceive; however seven plus three makes ten not only now but forever; never at any time nor in any way seven plus three have produced any result other than ten… That is why I have said that this unalterable truth of numbers is common to myself and to anyone who reasons. (Augustine, quoted by Crombie 1959, I, 13).

As for astronomers, one must grant that

> … they inquire into these things through that natural light that You [my God] have given to them, and find many secrets; they predict several years in advance solar and lunar eclipses; they indicate the day, the hour the magnitude and the actual results follow their predictions… (Augustine, *Confessions,* quoted by Duhem 1959, II, 401).

Here, Augustine has picked the fields in which pagan science had impressive results to show. From such a starting point, it comes as no surprise to see him adopting a philosophy rather closely akin to Neo-platonism, and ignoring Aristotelian physics and cosmology. Aristotle's peripatetism was largely out of fashion at the time, even among pagans, and there are deep reasons for its exclusion by early Christians. For Aristotle, perception had been at the base of all knowledge of Nature,

[2] Augustine, *De Genesi ad litteram*, quoted by Duhem (1959), II, 397. Moreover, one should not forget his basic distrust of scientific enquiry whenever involving risks for faith: "There is another form of temptation, even more fraught with danger. This is the disease of curiosity … It is this which drives us to try to discover the secrets of nature, those secrets that are beyond our understanding."

and laborious observations of everything were required. Such a path was bound to appear far too slow to those for whom Revelation was the main source. Consider merely the rare Christians willing to grant that Faith and *Genesis* did not provide every single truth worth knowing: they still remained prone to find Platonic deductions from grand central principles more palatable than painstaking peripatetic scrutiny. Furthermore, a serious technical problem remained to be overcome before Aristotle might become respectable: his eternal, unchanging and uncreated Universe was thoroughly unchristian, and more will be heard about the point in the next chapter. While Aristotelian logic remained well known and much used, thanks to the *Organon*, his physics and cosmology were largely forgotten about up to the twelfth century. During the Patristic era, the affinity felt with Plato was such that (strange as it may seem today) a direct path was often fancied between the Bible and Plato's Academy. For instance, Augustine considered that Plato, travelling through Egypt, might have met Jeremy! He sensibly rejected that tale on chronological grounds, but nevertheless remained convinced that Plato might have learned something of Scripture through Jewish interpreters (*De Civitate Dei*, VIII, 11, 313–4).

Astronomy and astronomical models no longer mattered much, but astrology had become a quest of considerable import, as already seen with Ptolemy. For some Christians confirmation was found in *Genesis* from these fourth-day signs "… God said: Let there be lights in the firmament of heaven to divide the day from the night; and let them be for signs…" However, the Fathers had been unanimous in refuting any astrological interpretation of this passage as incompatible with human free will. Augustine again:

> These astrologers attempt to destroy this hallowed doctrine when they say: there exists in Heaven an inevitable cause that entails sin; Venus, Saturn or Mars lead you to some action or other, hence these people want that man, who is merely flesh and blood and rot compounded with pride, should be free of any fault; and they also want that all faults should rest on Him who has created Heaven and the celestial bodies and who rules over their motions."[3]

Still, it was felt impossible to deny that celestial motions do affect terrestrial happenings in some way, and the difficulty was to find where the line had to be drawn. For Augustine at least, the matter was clear enough:

> It could be maintained, without utter absurdity, that some influence from the stars have an effect… We observe that the variation of the seasons depends on the approach and withdrawal of the Sun, and the waxing and waning of the Moon produces growth and diminution in certain species such as sea-urchins and shell fish, and also the marvelous variations of the tides. [Nevertheless] it is not conceivable that the decisions of man's will are subjected to the dispositions of the stars. (*De Civitate Dei*, V, 7, 186; discussed by Duhem 1959, II, 455).

Which seems logical enough, at first glance; however he was led to grant a dangerous point and give a risky explanation:

> When astrologers give replies that are often surprisingly true, they are inspired in some mysterious way by spirits, but spirits of evil whose concern is to instill and confirm in men's minds false and baneful notions about "astral destiny." These true predictions do not come

[3] Augustine, *Confessions,* IV, chap. III. Actually, he had held these errors as articles of faith during his Manichean youth. See also Duhem (1959), II, 404.

> from any skill in the notation and inspection of horoscopes; that is a spurious art. (*De Civitate Dei*, V, 8, 188; discussed by Duhem 1959, II, 460).

At which point Augustinian logic seems faulty; surely, these evil spirits are not primary agents? They must have extracted these surprisingly true answers from somebody higher-up in the chain? During his wild Manichean youth, Augustine might have provided a more self-consistent answer; but he preferred to forget all about it in his mature age. Unfortunately such compromise solutions about astrology will be endorsed by the Church after Augustine, and prove enduringly popular. For our purpose, the point is that for centuries nobody will give a thought to any direct connection between the sublunary world and the Heavenly one, except on those terms.

Even with spiritual matters taking first, second and most other places, civilized man cannot live without some sort of cosmology. What kind did the Fathers offer?

Throughout the period, no progress either in observation or theory was made in the West, and contacts with the East were practically non-existent. The notion that other visible celestial bodies might be similar to Earth simply vanishes from surviving texts, while External Plurality is invariably treated in an offhand manner. There is no possibility of following any evolution of the theme, as there was during the classical Greek and Hellenistic times; one may only handle the incidental allusions when they appear. From the beginning, two opposing tendencies coexist; both are still very much alive today, though not in scientific circles; the two extreme forms may be called fundamentalism and allegorism. For a strict fundamentalist, then or now, all truth worth knowing is found in a literal reading of the Bible. The attitude gathers extreme stability from an unshakeable internal logic, which makes it impervious to attacks from any angle whatsoever; at the time, it entailed total rejection of Greek science. On the other hand, even before Christ started to teach, the Jewish philosopher Philo of Alexandria had shown the way of allegorism: "It would be a mark of great naivety to think that the World was created either in six days or in Time at all; for Time is nothing but a sequence of days and nights, and these things are necessarily connected with the notion of the Sun above or below the Earth." One applauds the program, but Philo's own interpretation is less appealing: "So when Moses says "God completed his works on the sixth day", one must understand that he is not speaking literally of a number of days, but that he takes six as a perfect number; for it is the first number which is equal to the sum of its numbers…" (Philo of Alexandria, *Allegories of the Sacred Laws*, quoted in Toolmin and Goodfield 1965, 59). Philo's God is not a strict Pythagorean, or he would have constructed a ten-day week, as the French revolutionaries later will.

The risky path of allegorism will prove most difficult to tread, sloping and then plunging ever more dangerously, with never a permanent resting-place. The trouble is that in the resulting construct, the divine contribution is forever dwindling compared to the human one. Very soon, *Genesis* gets buried in exegesis, the end product being too plainly man-made to inspire lasting confidence. Unfortunately, such was the road taken by the more enlightened Christians of the time. The great risks involved in unintelligent readings of the Bible are well brought out by Augustine: some pagans often have

> a knowledge of Earth, of heaven, of other elements, of this world, of motions, revolutions, magnitudes of celestial bodies, of animals, vegetables, minerals and other similar things which they draw with great certainty from reason and experience… When such people have caught a Christian red-handed in error within these matters, which they know so well, or proffering his hollow opinion as drawn from the Holy Scripture, how will they be able to believe in these same Holy Books about matters concerning resurrection of the dead or hope of eternal life and the heavenly kingdom? … How much sorrow and pain these presumptuous [Christians] bring to their more prudent brothers, one cannot stress it too much. (Augustine*, De Genesi ad litteram*, quoted by Duhem 1959, II, 492).

Here Augustine proves not merely a good observer of his own time but a sadly accurate prophet as well; his sound advice will require more than perfectly orthodox faith to be put in practice, and the distant future was to bring much sorrow and pain indeed.

The first all-out attempt to prove that *Genesis* is a reasonable story and not merely one that has to be taken on faith, seems due to Johannes Philoponus of Alexandria; he was a sixth-century Christian Neo-Platonist, who deserves a place of his own in the history of mechanics for a pertinent criticism of the Peripatetic concept of motion. Only his cosmological views are followed here; his starting point is broad-minded:

> Nobody should attempt to draw from Moses' work the technical considerations on Nature that have been actually imagined by his followers. One should not ask him questions such as: What are the material principles of things? Is it better to admit one or several? What is the substance of Heaven, and is that of sublunary beings different? … Such was not the intent of the admirable Moses. He was the first to attempt, under divine inspiration, to lead men towards the knowledge of God and to teach them to live in conformity with this knowledge. Hence everything he wrote was to fulfill this aim… (Philiponus, *De Opificio Mundi,* quoted by Duhem 1959, II, 495-6).

However, Philiponus himself soon finds out that such a program is difficult to follow. He is a rare case of a learned man well aware of the complexities of celestial motions unraveled by Greek and Alexandrian astronomers; hence, he tries to find compatible explanations for *Genesis.* God had created on the second day a starless firmament, and only on the fourth the Sun, the Moon and the stars. What does it all mean, and could that starless vault have an existence of its own? Simple enough, it is that ninth sphere that mathematicians had been compelled to reintroduce in order to explain precession:

> None of the mathematicians before Hipparcus and Ptolemy had known anything about the ninth starless sphere… Plato himself still thought, like all predecessors, that they were only eight…. For me, it is well demonstrated that Ptolemy and Hipparcus … borrowed from Moses the principle of their discovery. Moses indeed says that God placed the Sun, Moon and multitude of stars within the next sphere, the one he had called Firmament… (Philiponus, *De Opificio Mundi,* quoted by Duhem 1959, II, 497).

Such a careful fitting together of *Genesis* and scientific discoveries goes a long way beyond mere allegorism, and has deserved a specific name: *concordism*, a self-defeating process, but one still proceeding today. The absurdity soon becomes obvious, as Philiponus goes on to discuss most learnedly the other spheres, those carrying planets: he is never struck by the Bible failure to mention the said planets at all, while they make up a far more obvious sight than mere precession. Unfortunately, there is no way to twist the words of Moses (or of any other prophet) to account for the omission: the authors of Scripture had not been concerned with planets, and that's that.[4]

However, most of Philiponus fellow Christians were far less sophisticated in their views of the Cosmos and their interpretations of the double firmament remained frankly naive. In order to understand why the ardent Greek controversies about Plurality had so fully gone out of fashion, one must bear such simplicity in mind. The situation will be illustrated by two specific problems: the familiar topic of the Earth shape, and a new one, the Waters Above. This last and totally unexpected problem arose out of two embarrassing verses of *Genesis*:

> And God said: Let there be a firmament in the midst of the waters, and let it divide the waters from the waters. And God made the firmament and divided the waters which were under the firmament from the waters which were above the firmament. And it was so.

No one felt any particular qualms about the waters below, which sounded homely enough, but those Waters Above were to prove most troublesome. Lend your ears to Johannes Chrysostomos, the golden-mouthed Bishop of Patmos:

> We must receive with great modesty and a thanksgiving heart the Words that have been given to us and not exceed our own nature nor examine what is beyond us; let us merely know that the firmament has been created by command of God in order to separate the waters, to keep some underneath while others are carried upon its back. (Chrysostomos, *In Genesim Homilia*, quoted by Duhem 1959, II, 490).

The issue generally held worth discussing was not the existence nor cause of such a starless firmament, but God's aim itself. For Chrysostomos, the concept of the double heaven was clearly connected with the Plurality issue:

> How can some pretend that the Heavens have been created in multiple form? This is not from the Holy Writ that they have taken the idea; they drew it out of their own arguments. The blessed Moses never taught them anything beyond… Who shall tolerate these people who speak according to their own thought and pretend, against the Holy Scripture, that there are several Heavens? And they add: Here is the Blessed David praising the Lord in these terms: *Laudate eum caeli caelorum* (Psalm 148 a 4). Do not be troubled, dear friend, do not believe there is ever contradiction within the Holy Writ; rather learn the meaning of these words carefully and shut your own ears to the discourses of those who say the contrary. (Chrysostomus, *op. cit.*, quoted by Duhem 1959, II, 490).

The golden (but non-technical) tongue of the good Bishop is never more specific, nor does he say who were these Christians who had unwisely taken David for an apostle of Plurality.

As to Augustine, he shows great caution when treading those mysterious waters:

[4] In the Bible there are 51 references to "stars" (*Nelson's Complete Concordance of the revised version of the Bible,* 1957). They are sometimes qualified as "moving" or "falling", and indeed in *Revelation* they do a lot of falling. In only one case is "wandering" used, and that is in the *New Testament*: "Raging waves of the sea, foaming out of their own shame; wandering stars to whom is reserved the blackness of the darkness for ever" (*Jude, 13*). Which is definitely weak if used to prove that the Bible mentions planets.

> One must not assert anything lightly about this problem, because it is obscure and remote from the senses of men; in any case, before understanding, one must believe… Whatever these waters and the cause of their resting above the heaven should be, we must in no way doubt their existence because the authority of Scripture exceeds the capacity of any human mind. (Augustine*, De Genesi ad litteram*, quoted by Duhem 1959, II, 493-4).

Which is commendably orthodox, but rather unspecific. However he also reports two opinions, without frankly adopting either: The first is allegorical: the dividing of the higher from the lower waters might merely illustrate the separation of the good from the bad angels, as had been first proposed by Origen (Dreyer 1905, 209). This proposal offered a way of dealing with the physical difficulty:

> The reason of their opinion is the weight of the elements; they disbelieve that the aqueous nature, which is aqueous and grave, might reside in the upper quarters of the World;

but Augustine himself refuses that mere physics should be given too much weight in such problems. The second opinion is frankly concordist:

> For some people, the surface of the Heaven is covered by visible and cold waters; and they argue in favor of this opinion from the slowness of one of the seven planets [Saturn]… which took 30 years to describe the Zodiac; if it is so slow this is because (they say) that it is close to the cold waters that cover the Heaven. But, whichever way should these waters be held above Heaven, and whatever their nature, we must in no way doubt their existence; indeed the authority of Scripture exceeds the capacity of any human mind… In such matters we should never affirm anything lightly; they should be treated with caution and modesty. (Augustine, *De Genesi ad litteram*, quoted by Duhem 1959, II, 493).

Unfortunately, both before and after the Bishop of Hippone, caution and modesty have not been widely granted within exegetics, and the puzzle of these waters failing to cascade on our shoulders still cried out for explanations. Here, we follow this watery problem because it largely took the place of the Greek discussions on the substance of Heavens. Needless to say, as far as the future of Plurality goes, it will turn out an utter dead end; but, if written History involves mostly copies, History in the making proves a true rabbit warren of such dead ends.

At the same time as Augustine, Basil rejects the Peripatetic solution:

> Some philosophers have conceived a fifth corporeal essence, suitable to form the heaven and the stars… However another one has… refuted and demolished their argument, then brought in his own personal opinion. If we attempted to treat here these questions, we would fall in the same fancies as these people; let them ruin and refute each other…. (Basilius, *In Hexamæron homila*, quoted by Duhem 1959, II, 398).

Even so, Basil cannot resist proposing his own scheme, which implies a slight reworking of the outer surface of the stellar sphere; his brother Gregorius of Nysseus goes even farther, with an almost Earth-like place above our heads:

> The dorsal face of Heaven is cut and hollowed with valleys similar to those separating mountains on Earth; within these valleys the water is held. What about the arguments of our foes? They pretend that because of the rotation around the pole, when the part of the firmament that was above comes underneath, the water in these hollows will run out. Can't they imagine vessels within the thickness of the spheres? (Gregorius Nyssenus, *In Hexamæron liber,* quoted by Duhem 1959, II, 489).

Aristotle would have been much pleased with the mechanical operation of these ingenious devices, had his fine spheres not risked some tarnishing in the process.

Ambrosius, Bishop of Milan, provides an even simpler solution, by returning to first principles:

> What prevents them from admitting that the waters remain suspended above the Heaven? They say that the Earth is suspended in the center of the World and remains motionless there, while it is assuredly heavier than water; for the same reason they might say that the Water Above is not thrown down by the rotation of the heaven. (Ambrosius, Hexamæron, quoted by Duhem 1959, II, 489).

Here Aristotle the Stagyrite would have intensely disliked the scheme; still, he might have been delighted with Philiponus, who was better aware of standard physics, and determined to fit those Waters within Peripatetic doctrine:

> There are two Heavens, which occupy two different locations [and] they are not immediately contiguous… it is necessary that the intermediate space between both should not be empty because nothing that exists can in any way be empty. Hence there must be a body; and this body Moses has called water because it is fluid, freely running and diaphanous. (Philiponus, *De Opificio mundi,* quoted by Duhem 1959, II, 500).

So, for anyone willing to take allegorically that single word, Water, a most pleasing concordist interpretation became obvious: Moses had long anticipated Aristotle, and the Universe had truly been designed with built-in abhorrence of vacuum.

The last word on both the Waters and Plurality must be left to Theodoretus, Bishop of Cyprus:

> Whoever disbelieves in the existence of a second Heaven strays out from the true path; and whoever insists on a great number follows mere fables and disdains the writings of the Holy Spirit. Truly, in several places, the Holy Scripture speaks of the Heavens; but this is merely because the Hebraic tongue cannot use either Heaven or Water in the singular. (Theodoretus, *In loca difficilia Scripturae sacrae questiones selectae,* quoted by Duhem 1959, II, 490).

Hence, that *Laudate eum caeli caelorum* had just been a mistranslation? For many centuries, orthodox faith and accurate grammar were to be the most relevant weapons of philosophers in their attack upon Nature.

Another strange consequence followed: a flat Earth came back into fashion for the greater part of a millennium. Nothing in Scripture solidly supports this view; but the spherical Earth had been one of the most remarkable conquests of Greek reasoning against gross common sense. Hence mere hostility to Greek science was bound to produce a reaction, and ludicrous interpretations of the Bible moved in, as if to fill a conceptual vacuum.

Clement of Alexandria is first to propose that the Tabernacle gives a good likeness of Heaven and Earth, and such notions (reminiscent of Egyptian cosmology) will recur frequently under the pen of the Fathers. His main justification appears to be "And after these things I saw four Angels standing on the four corners of the Earth, holding the four winds of the Earth…" (*Revelations*, VII, 1). Next John, in his apocalyptic vision, gives another clue with "After this I looked and beheld, a door was opened in Heaven", which is more appropriate to some human place of abode than to any Platonic sphere. Also he writes several times about the Temple of the

Tabernacle *in* the Heaven; but he never says that this Temple *is* the Heaven, a step that later Patristic exegetes were to take lightly. Severianus, Bishop of Gabala, quotes Isaiah 40:22: “It is He that sitteth upon the circle of the Earth, and the inhabitants thereof are as grasshoppers; that stretcheth out the Heavens as a curtain and spreadeth them out as a tent to dwell in.” (Dreyer 1905, 211). The Bishop might have used this promising circle to erect some geometrical system, but his fancy was more taken by the tent itself: ergo, the Heaven must be some kind of building with a double roof, the lower one being frozen water etc.…

As usual Augustine is far more prudent, and refuses to venture within physics: for him, if the Earth was a sphere (which is unproved), the antipodes would not be peopled by men since these could not possibly be descendants of Adam (*De Civitate Dei,* XVI, 9, p. 664). Here is a new and unexpected twist to an old problem, and this point will prove of serious difficulty at the time of the Great Discoveries. The most thorough and best-remembered refutation of the spherical Earth is due to Lactantius, tutor of Constantine’s son and widely read Father. In his *False Wisdom of Philosophers* he uses not theological but physical arguments to reject the notion of antipodes. His opponents have been “so senseless as to believe… that the crops and trees grow downwards, that the rains and snow and hail fall upwards to the Earth…” These philosophers “make hanging fields and seas and cities and mountains.” Lactantius makes a painstaking search for the origin of such absurdities:

> They saw the course of the stars travelling towards the west; they saw that the Sun and the Moon always set towards the same quarter and rise from the same… they thought that the World is round like a ball… constructed brazen orbs and engraved upon them certain monstrous images… It followed from this rotundity of the heaven that the Earth was enclosed in the midst. But if this were so, the Earth also itself must be like a globe… there would be no part uninhabited by men and the other animals… But if you inquire from those would defend these marvelous fictions, why all things do not fall down into the lower part of the heaven, they reply that such is the nature of things, that heavy bodies are borne to the middle…

Let us grant here that we share his disbelief in the Aristotelian central singularity: it does not make sense. His conclusion: “I am at a loss what to say to those who, when they have once erred, consistently persevere in their folly, and defend one vain thing by another…” (Lactantius, c. 320, III, 50–1; see Dreyer 1905, 209).

Altogether, Lactantius stands close to Lucretius; why do extremes meet so easily on this unfortunate conclusion? The Christian and Epicurean views do share a common starting point: for both, morals come first, and no attempt at understanding Nature ever is an end in itself; human good of some kind has to result, else there is no justification for the quest. Within the godless Epicurean universe, αταραξια (ataraxia) is achieved if godlessness is understood with all implications taken in: absurd fears of natural phenomena vanish, and man feels both shielded and free. To attain this end, any explanation can do, the simpler the better, provided it remains materialistic; and it does not have to be true, only sensible. Mathematicians being distrusted, a flat Earth becomes perfectly suitable. On the other hand, for Christians, understanding and following the will of God is all that matters; no real harm may come from Nature itself, since God is ultimately responsible for all natural phenomena. So mathematicians are unnecessary, the simplest explanations prove adequate, and a flat Earth is again taken as first choice; hence that unexpected convergence.

However, on Plurality, there was utter divergence. For Epicureans the whole visible World, including the Earth (whatever its true shape might be) was one out of many, and Man felt secure precisely because of his inconspicuous location. But for early Christians, the operating principle of Nature was thorough anthropocentrism: Man felt safe (as long as he had Faith) because he was laying in the center of a cradle made for him; and there could be no point in a similar nest in any other place. For both parties, in the future irreconcilable enemies, the Earth was flat through mere laziness of mind, while the diametrically opposite Plurality-Unicity options were taken for safety of body and peace of soul.

Out of the entire Patristic argumentation, or lack of it, nothing proved of lasting value, and later Christians will easily endorse both Earth sphericity and a Plurality of Worlds; however, that development was to take a very long time, compared to the rapid evolution of thought during the great Greek centuries. In the meanwhile, many references are found to stupefying obsolete descriptions of Earth and Heaven. The *Christian Topography*, a 6th Century work by Cosmas, an Alexandrian monk, achieved some notoriety by attempting to systematize scattered extant notions about the World; Cosmas was a well-travelled man, who won the surname of *Indicopleustes*, the Navigator of the Indies. He had even reached Ethiopia, perhaps ten degrees from the Equator; but, unlike Pharaoh Necao's navigators, he never looked up during his trip. He was crudely aware of ancient cosmographical systems, and did mention epicycles but merely for derision; the Earth could not possibly be in the center of the Universe, since it was needed as footstool of the Lord, hence rested at the bottom of everything. Shaped like a rectangular table, it was surrounded by the Ocean, while Heaven had to be constructed on the plan of the Tabernacle, with four perpendicular walls and double roof. As it had been for Heraclitus, the Sun became very small; however, it was now propelled on its course by an angelic machinist, and so were all other celestial bodies (Dreyer 1905, 214).

Within such a framework, the Plurality theme unavoidably disappeared. All the old arguments and controversies had become irrelevant; there was no longer any point in speculating about the shape, substance or mode of illumination of the Moon, still less about its valleys or inhabitants. Routine condemnations of ancient doctrines are found because they opposed Scripture; but authors seldom take the trouble to be explicit about what they are in fact condemning. Still, Hippolytus in his *Philosophumena* states that belief in Plurality or infinity is a clear heresy; Eusebius, Bishop of Cæsarea describes these beliefs as vain conceits; and Theodoretus argues that the uniqueness of the World is what you must expect, since Man is the overall Cause. Chrysostomos best makes out the theological risk of such discussions: "How is it possible for some people to pretend that Heaven has been made multiple? It is not from Holy Scripture that they are able to say so: they do it from their own arguments. Moses never taught anything of the kind…" As the next chapter will show, multiple Worlds were bound to make a comeback, with Scripture getting buried under a thick layer of novel arguments.

That is all, and very little altogether. Even so, while rats and rot were eating their way through crumbling manuscripts we would today give our very eyes for, some of these devout Christians acting as doxographers preserved tiny crumbs of the abominable heresies they wanted to eradicate.

Then, very slowly, the Greek discoveries began to make their way back. The works of Pliny, a voluminous compilation from many sources, had never been completely forgotten. The *Commentary on the Dream of Scipio* by Macrobius, a fifth century Neo-Platonist and Christian convert, and the encyclopaedia of Martianus Capella (another fifth century Latin writer) remained popular. Through these works, at least the general lines of Neo-Platonic cosmology became available. Bede the Venerable made full use of Pliny in his own works, much perused during the following centuries. He described a spherical Earth with planets circling around, but had to fit the Waters somewhere in between the spheres. Next appeared anew the idea that not only the Earth is spherical but that the Antipodes are inhabitable, at least in the temperate zones; this step was necessary before other Worlds could be considered again (one even meets the idea that the Southern Hemisphere is too hot because the Sun is closer). Still, inhabitable did not mean actually inhabited, and humans could not survive under the Tropics; this strange rejection, already found in Ptolemy's *Geography*, was not put to test and rest until the Portuguese did cross both Tropics and Equator in the 15th century. The impossibility, or rather the impiety, of imagining these zones peopled by men not descending from Adam and unaware of Redemption, is expressed several times (Duhem 1959, III, 475, 416). However, in the eighth century, Vergilius of Salzburg, Abbot of Saint Peter in this city, taught about "another world and people under the Earth" (clearly antipodes), and got into trouble with Pope Zacharias on this account; but he does not seem to have been condemned for heresy, and even became a Bishop.

An important event was the election of a strikingly-different Pope: Gerbert d'Aurillac, an able mathematician with an interest in astronomy, became Sylvester II; even if he remained Pope only from 997 to 1003, Nature could never be perceived in the same way after him, and the four-cornered flat Earth (plus Tabernacle-shaped Heavens) went to the attic of discarded cosmologies. Unfortunately, it survives today with quite a number of laymen (Figure 4.2). A century and a half later, translations from the Arabic induced familiarity with Aristotle and Ptolemy plus all Eastern advances, and a very different period began. A geometrical cosmology again came to the forefront together with warm discussions of Plurality, which, if not arising out of new observations, at least implied skilled handling of acute logic.

Before proceeding to that promised land, one must still account for another important aspect of Christianized scientific thought: the concept of creation in time and of the World having a unique history with a precise chronology. Here again, some kinship was felt with Plato, since he had proposed the central feature, Creation itself; but no Greek thinker had ever been as definite about the process and date as Christians could be. The very-active Neo-Platonists felt that the Christian account involved a fundamental antinomy, since the World could not have been created at a particular instant. Time could not exist without motion, and there was no motion before matter had been brought into existence. Furthermore, why should God have picked this particular instant as more suitable for Creation? If He had done so, He

Figure 4.2 Square flat Earth according to Orlando Ferguson (1893). There are many recent images of the supposedly flat Earth. Their proponents pretend that NASA presents fake images of the Earth as seen from space. Library of Congress, Geography and Map Division

could clearly not have been immutable; hence one could not help feeling that His eternal perfection had been badly marred by such a belated Grand Start.

Indeed, had the Creator anticipated the number and weight of treatises to be written on the subject, he would certainly have given second thought to that deceptively easy-looking problem of Creation. There is no question of following here such controversies; still, the first refutation of the Neo-Platonist argument by Augustine is worth quoting at length, because it not only involves Plurality but sets the time and space framework of the problem better than any Plato or Aristotle surviving text had ever done:

> Those who admit, as we do, that God has created the World, but who question us as to the instant of Creation, should do well to ponder on this other problem: In which place was the World created? Just as we are asked why it has been made at such an instant and not before, we are free to ask why it has been made here where it lies, and not elsewhere. Since they imagine before the existence of the World an infinite stretch of time, and since they believe that God could not possibly have remained idle meanwhile, let them similarly attempt to conceive outside the World a place of infinite extent; and if somebody comes over to tell them that the unlimited Might of God could not have failed in these places, shall they not be compelled to dream with Epicurus about numberless Worlds? Between him and them, the only difference will be that Epicurus ascribed the generation and dissolution of these Worlds to chance motions of atoms; while they will have to grant these Worlds to have been created by God who could not fail (according to themselves) to fill the boundless immensity of these places surrounding this World of ours… The substance of God they do not locate at any given place; they think of this substance as lying whole everywhere with an incorpo-

> real presence, as is right and proper in the case of God; will they say that it is absent from the immensity of these places external to the World, that it occupies only the place where this World lies, this place so tiny compared to such an infinite space? I do not believe they will formulate such utter nonsense. (Augustine, *De Civitate Dei*, XI, 6, 434, from the slightly condensed translation of Duhem 1959, II, 465-6).

This remarkable text holds plenty of food for thought. To start with, Augustine simply ignores Aristotle, who had demonstrated the notion of Space outside the World to be not merely false but antinomic: his God might no more have filled that non-existent place with material bodies that he could have made seven plus three differ from ten. Augustine must have been unimpressed by the ancient proof; still, it is a pity we do not have a refutation from his own pen, because later orthodox but fully-Christian Peripatetics will reject the Augustinian view, while still trying to keep God bound by the chains of their own logic. The major interest of this passage is an anticipation of future trends, and specifically a clear introduction of the Plenitude of God theme to the Plurality problem. All future discussions of the divine ability and/or willingness to fill useless vacuum with useful Worlds start from here.

Such a solution Augustine himself unambiguously rejects, and the Universe he adopts is one of the closed and geometrical Pythagorean-Platonic family. Why? He does not say at this point, but compatibility with *Genesis* cannot help being for him the key issue, and he has brought Epicurus in merely to show the absurdity of his opponents. Still, he has unwillingly let the cat out of the bag; and his very distant Christian successors will go the whole hog, in two stages. First, in the thirteenth century, spurred by reintroduction of Peripatetic cosmology, they will explore the consequence of Plenitude as a theoretical possibility, largely because Aristotle so clearly denies it. Second, after the telescope had dissolved the bounds of the naively visual Platonic-Aristotelian universe, they will definitively adopt Plurality, which then slowly vanished as a theological issue. Nowadays, most Christians (apart from some true-blood fundamentalists) feel ready to accept, indeed often to welcome, such Worlds that "have been created by God who could not fail filling the boundless immensity of these places which surround this World of ours." The program, at least, had been delineated by Augustine.

The second point of interest is that aesthetically pleasing symmetry between time and space that Augustine introduces. His viewpoint will not be generally accepted by his followers; still, it deserves to be taken as a reference for much of our later discussions on space and time pluralities, particularly within the next chapter. More immediately, it may be used to introduce the Augustinian notion of time. When was the World created, and what does that deceptively simple question mean? Augustine himself has prudent (and often quoted) thoughts on the subject: "What is Time? If nobody asks me, I know; if somebody asks and I start explaining, I know it no more." (Augustine, *Confessions*, XI, 14). Even so, he is still convinced that he can wriggle away from that troublesome Neo-Platonist refutation of any Christian creation:

> Between Time and Eternity, one is justified to establish this distinction: Time does not exist without change, which implies motion; within Eternity there is no change… It is God, whose Eternity is free of all change, who creates and regulates Time; how could it be possible to pretend that the World has been created by Him after the lapse of a certain Time is something

> I cannot see… Hence there is no doubt that the World has not been created within Time, but with Time. (*De Civitate Dei* XI, 6, p. 435-6; translation from Duhem 1959, II, 467).

While such discussions are far from worthless, scientists of today do feel more at home with the Epicurean approach; remember Lucretius and his “Time by itself does not exist…” In any case, most of Augustine fellow-believers could not follow that degree of sophistication; for them, Time signified days and years, the meaning of which was obvious enough, and the Bible provided a precise count from that very First Day down to their own epoch. This simple fact was to dominate all branches of science up to the modern period. Every single science, from cosmology to biology and human history, had to fit within the Biblical framework, and the consequences were profound and long lasting; far more so than any learned controversy about the true nature of Time could ever have generated.

Still it would be wrong to believe all consequences equally retrograde, and one notable progress due to the Christian approach has to be granted. The Great Year fancy came under special attack, just as Astrology had done and for the same reason: it reintroduced a form of determinism. Palingenesis, or any form of Time Plurality, proves specifically incompatible with Redemption; the main point is already stressed by Origen:

> Those who believe in the apparition of successive Worlds, fully similar and equal between themselves, I do not know what proofs they could bring in. If one pretends that a second World will be similar in every point to ours, it will be necessary that Adam and Eve should do again exactly what they did in this one; the same Flood will happen again, the same Moses will bring out of Egypt six thousand men; Judas will betray the Lord again; another time Paul will watch over the clothes of those who will stone Stephan; and we shall admit that every single thing that happened during the life of this World will happen a second time. (Origen, Περι αρχων λιβρι, translation from Duhem 1949, II, 449).

The opponents to whom Origen is alluding must have been mostly Stoics, as we do not find a single Father of the Church adopting such beliefs. Still, some unnamed Christians did manage to find Scriptural authority for the Eternal Return fantasy; had not Solomon written?

> The thing that hath been, it is that which shall be; and that which is done is that which shall be done; and there is no new thing under the Sun. Is there any thing whereof it may be said, see, this is new? It hath been already of old time, which was before us. There is no remembrance of former things; neither shall there be any remembrance of things that are to come with those that shall come after.” (*Ecclesiastes,* I, 9,10,11).

One could hardly dream of a better fit with the Great Year; but Augustine refutes all such palingenetic interpretations of the Bible; he utterly disbelieves that.

> Solomon refers to those periodic revolutions of the Physicists… by which Plato taught his disciples at Athens in the fourth century, in the school called the Academy… [that] the same city, the same school, the same disciples have appeared time after time and are to reappear time after time in innumerable centuries in the future…. For Christ died once for all for our sins. (*De Civitate Dei* XII, 15, p. 488; discussed by Duhem 1959, II, 453).

Here again, the analogy between Plato and the Bible had been striking; some preferred to see it as a pilfering of the Bible by Plato. Augustine had been wise enough not to fall into the trap, but his authority did not prove sufficient in the matter, and the Great Year will make a comeback, and even pass through its acme during the Scholastic era.

What sort of construct was available to replace the Greek themes? The first explicit and accurate Christian chronology is due to Eusebius of Cæsarea, who played an important role during the Council of Nicea where, at the request of Constantine, the basic Christian doctrines were put in order. However, with commendable prudence, he only covered the period from Abraham to the present day. The next one is due to Jerome, best known for the Vulgate, who extended the Eusebius account back to the very day of Creation. His results were generally adopted, but some of his successors became convinced that further refinement was allowed; the process was not to end before the celebrated date of Saturday 22 October 4004 BC was derived by Bishop James Ussher in his 1654 *Annales Veteris et Novi Testamenti*; this impressive conclusion was to be widely trusted, particularly by Anglicans (about these chronologies and views of Time, see Toolmin and Goodfield 1965, Chap. 3).

Furthermore, not only the past but also the future could be extracted from Scripture; still, this second belief, while widely held, never quite reached an orthodox status. The starting point seems to have been *Psalm 90*: "For a thousand years in thy sight are but as yesterday when it is past, and as a watch in the night. Thou carriest them away as with a flood…" Hence arose the idea that the whole human history would take merely one "week" within which "days" lasted a thousand actual years. According to Julius Africanus (Toolmin and Goodfield 1965, 60), from creation to the birth of Christ five and a half such days had elapsed, and the second coming of Christ would take place at the end of the sixth day, i.e. in 500 AD. Roughly analogous schemes were still believed in at the time of Reformation, for instance by Luther himself, while ultimate Doom was felt uncomfortably close at hand.

However these views of the future were of little concern to scientists, while the concept of the past to be read out of the Bible was a far more binding matter; today, such beliefs have been rejected out of all branches of science for little more than a century. Consequences are still far from being universally adopted by laymen, and there are two main reasons. First, the technical proofs of antiquity for World, Earth and Man are highly difficult to follow for the non-scientific mind, far more so than any concerning size, shape and structure of macrocosm or microcosm alike: Time is still, with us as with Augustine, much more arduous to grasp than Space. Second, while these somewhat hazy Waters or the tent-shaped Heavens have finally been shelved, the core of *Genesis* and subsequent biblical narratives is fully definite, and requires far greater effort to be treated as allegorical. Hence the rise of allegorism will be by no means a smooth and continuous process; the Reformation period was to mark, for Catholics and Protestants alike, a wholesale return to fundamentalism.

Altogether, the definitive concept of Plurality, or what scientists presently believe to be such, will become accurately located in geometrical Space during the seventeenth century, but had to wait three hundred years more for a correct insertion within Time; this will be the subject of a part of our last Chapter. As these lines are being written, in 1981, a large country, noticeable among other things for excellent and widely available higher education, has just selected by the most democratic processes a President who went on record as favoring equal-time for the Bible story. Neither himself nor all the hyperactive "scientific creationists" realize how truly ancient are their own beliefs, far older indeed than Christianity itself. The Georgia judge who rules that "this monkey mythology of Darwin is the cause of permissiveness, promiscuity, pills, prophylactics, perversion, pregnancies, abortion, pornography, pollution, poisoning and proliferation of crimes of all types" (*Time Magazine,* March 16 1981) could be a citizen of Athens venting his anger against the novelties of the physiologers and blasting the Anaximander views of life and evolution. Aristophanes might have fitted him in one of his plays with the greatest ease; why not in the *Wasps* as an even madder colleague of his Philocleon? Which is a clear attempt at writing a piece of counterfeit history; but within his actual century, that judge does stand as a burgher of the planetary-wide Athens, the community of terrestrial intelligent beings, recoiling in horror from an unintelligent Universe. What about the Galactic Athens, even older and putatively wiser? Opinions unknown, so far.

Chapter 5
Scholastics Invent Virtual Plurality

[The proposition is hereby condemned as heretical] that the Primary cause would be unable to create a Plurality of Worlds.

Étienne Tempier, Bishop of Paris[1]

Therefore I conclude that God can, and could in His omnipotence make another World besides this one, or several like or unlike it. Nor will Aristotle or anyone else be able to prove completely the contrary. But of course there has never been nor will be more than one corporeal World as was stated above.

Nicolas Oresme, Bishop of Lisieux[2]

(Left) Oresme, from the French translation of De Caelo (manuscript, ca. 1410). Bibliothèque Nationale de France
(Right) Thomas Aquinas, by Carlo Crivelli (1476). National Gallery, London

[1] *Proposition 34* in the *Decrees* of Bishop Etienne Tempier (1277).

[2] Oresme (1377) *Livre du Ciel et du Monde*, I, 24, 179.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
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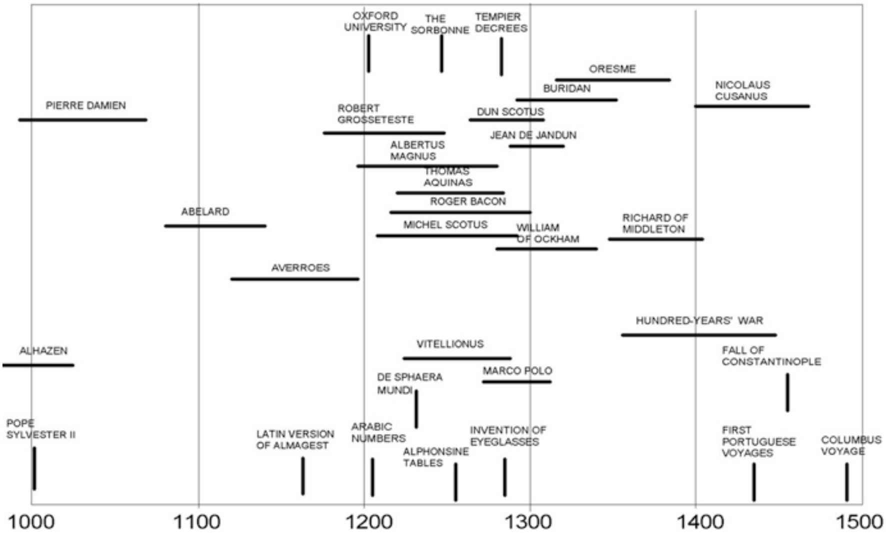

Figure 5.1 Chronology for the scholastic period (Chapter 5) and until Cusanus (Chapter 6)

The first great innovations that mark the twelfth and thirteenth centuries as beginning a different period, are the foundation of the Universities and of the mendicant orders; these orders, fortunately for the history of thought, soon forgot all about mendacity and devoted a large fraction of their wealth and activities to theology and teaching. Second came the discovery of Aristotle texts, together with those of his great Arab disciples and commentators. The Universities induced a density of scientific thought and a rapid turnover of concepts unknown since the antique world. Instead of a few compilers pouring in isolation over rare manuscripts, and communicating through the slow pen with colleagues long dead or yet unborn, one finds masters teaching much alive students. From one generation to the next marked changes are perceptible; and since University quadrangles tend to be less peaceful than monastic cells, controversies arose and bloomed almost from the first (Figure 5.1).

Seen from today's viewpoint, these fights do not seem, at first glance, to have affected the kernel of Christian beliefs, particularly those concerning the structure of the natural world, but contemporaries would have emphatically disagreed. As an almost immediate consequence, one finds the Plurality problem reappearing and evolving. Writing a history of the subject means having to tell a story. The crux of the matter is the invention of a new and specifically Christian argument: the Will and the Power of God. No human authority nor any logical construction may stand in His way, particularly if He fancies to fabricate many separate Worlds. In this act, the last before the great Renaissance and Reformation upheavals, God is the sole actor on stage; all other characters, even the Fathers of the Church, dwindle into insignificance.

The rediscovery of Aristotle's works produced a sizeable shock: here was an unbeliever who had been able to account for many particulars of the World in a far more detailed fashion than any Christian. Three different attitudes were possible about him, and all three are connected with the Plurality problem. A first group of Scholastics, overwhelmed by Aristotle and some of his Arab followers, adopted his teachings almost literally; the extreme form, called Averroism, came dangerously close to interpreting some points of Scripture in the light of Aristotle's Peripatetism, hence to serious heresy. A reaction of some sort was unavoidable, and a second group tried to uphold at all cost the Augustinian tradition, the Platonic content of which had so thoroughly blended with the Scriptural one that its pagan sources were partly forgotten. By contrast, Aristotelian novelties were at first felt anti-Christian, and repelled either in bulk or selectively. Such a rejection tended to prevail in the Church's hierarchy; condemnations for heresy were duly issued and played an important role in the story. Still, hardly anybody seems to have materially suffered: the religious and intellectual climate was far milder than during Reform and Counter-Reform.

However a compromise between the two extreme views finally evolved, and to this third position the name of Thomas Aquinas has remained attached. Aristotle, after purgation of his most blatant incompatibilities with Scripture, became not merely acceptable but the first and greatest human authority on almost any subject concerning Nature. At the time, it was felt that a clear and definitive frontier line between the domains of Reason and Faith had been drawn; Philosophy had grown out of being mere *ancilla theologiae*, and achieved a safe independent role. Indeed a period of relative intellectual stability set in, and left all devout Christians free to tear themselves to pieces about strictly personal matters: the great Western Schism (1378–1417) introduced the frightening novelty of two or more Popes in parallel, but had no appreciable philosophical connotation. A century later, Reformation itself was to be concerned mostly about salvation, and the Protestants introduced no great innovations about the material world. After that precursor thirteenth-century shock, the scholastic equilibrium about Nature was not to be disturbed again before the seventeenth century; but then, through novel tools, and with shattering results. The Aquinas compromise may be taken as the central reason why the scientific revolution ultimately took place in the West: Muslims never evolved a similar one.

Geography and Astronomy, Aristotle and Ptolemy

Relative to the patristic era or even to the Antique world, very little advance in astronomy is found in this period, but the same is not true of geography: the Earth becomes far better known, partly thanks to travellers like Marco Polo and Jean de Mandeville. In our previous chapter, Cosmas the *Indicopleustes* had visited the Near-East and part of Africa without even guessing that he was crawling over the surface of a sphere; but these new explorers understood at least the general lines of the problem, and added many new findings of their own. Their accounts, the *Devisement du Monde* and the *Voyage autour de la Terre*, written in medieval French around 1300 and 1350 respectively, became durable best sellers and were widely translated.

Figure 5.2 Map of the world, according to Ptolemy (Jacob d'Angelo, 1467). National Library of Poland. Wikimedia Commons

Ptolemy's *Geography*[3] had marked a great advance in the theory of the subject, and summarized ancient knowledge. While Hipparchus had already handled latitude and longitude, Ptolemy was first to make systematic use of these two coordinates, and his book contained tables of 8000 coordinate pairs for specific places. Very little is known of the accompanying maps (if any), and none has survived; today, the so-called Ptolemy maps (Figure 5.2) all derive from manuscripts no older than about 1300. Still, these were re-drawn from his coordinates, which is precisely what he had intended. However, the Ptolemy figures themselves had been mostly the results of dead-reckoning estimates: his standard tools were the *itinerarium* from some land traveller or the *periplus* of a navigator, which provided a list of distances between visited places, sometimes with a crude direction from one to the next and often with none. Altogether, for him, the *οικουμενη* (the inhabited world) extended in the North-South direction from the "lands of the unknown Skythians" to Taprobane (Sri-Lanka), and his grid is generally not too far wrong for latitudes, as many had been confirmed astronomically. No such checks existed for longitudes, and the distant East was known only through vague rumors. The easternmost place

[3] Berggren, J.L. & A. Jones, A. (2000) *Ptolemy's Geography Annotated Translation*, Princeton University Press. The *Introduction* and *Notes* makes the nature of the work (and the text) far more understandable than previous editions.

he mentions is an unidentified “Kattigara”, for which he computes a 180° distance, starting from the Canary Islands; somewhat by coincidence, the actual figure up to Behring’s Strait is 179°, thus Ptolemy’s notion about the size of the Eurasian land mass was not too far wrong.

Marco Polo did not travel with a copy of the just-rediscovered *Geography* in his luggage, and he never bothered about longitude at all; his sole unit of length was the distance covered during a one-day journey, and the corresponding ambiguities were to be in part responsible for the momentous planning error of Columbus. Clearly, he understood latitude, but his estimates remained hazy; he even wrote of a country (which he had not visited) “so far North that Pole Star is left behind towards the south” (sic! Polo c. 1300, *The Travels,* p. 103); which may be a mere slip of the pen from his ghost writer, Rustichello of Pisa. However, on his way back to Venice by sea, Polo passed through the Malacca Straight, about one degree north of the Equator, and thought that “it lies so far to the south that the Pole Star is not visible, either much or little”. Altogether, he contributed nothing to theoretical cosmography, but gave fascinating and partly fanciful accounts of far-off countries, like Java with its “pepper, nutmegs, spikenard, galingale, cubebs and cloves.” (*The Travels*, 251, 253). Physical conditions could be very different from our familiar ones; in India “The sun is so powerful that it is scarcely tolerable. For I assure you that if you put an egg into one of the rivers, you would not have long to wait before it boiled.” (*The Travels*, 287). Thus, we are not surprised to learn that local biology also evolved along different lines, and that many people “lived like beasts”, a frequent qualification. About a place, called Lambri (not visited either): “I give you my word that in this kingdom there are men who have tails fully a palm in length… as thick as a dog’s.” As to the island of Andaman, “all the men have heads like dogs, and teeth and eyes like dogs.” (*The Travels*, 256, 258). Herodotus had shown himself rather more skeptical with tall tales from far-distant places. For Marco Polo, and most of his thirteenth-century readers, these half-beastly men stood much like our Aliens do today; even so, those distant places, so far only hypothesized from geographical theory, slowly filled-up with life, even life of the intelligent variety.

As to the rather-mysterious Jean de Mandeville, who presents himself as *chevalier anglais* and born in Saint-Albans, his contribution clearly falls in the science-fiction category. Modern research has proved that much of his account is simply pilfered from Pliny and other encyclopedias; even so, he showed himself convinced that the journey around the globe was feasible, and even pretended that it had already been performed by some “valiant man who… went for so long by land and by sea during several seasons that he found an island where he heard his own language being spoken, and the oxen driven with the same words as in his own country.” (Mandeville 1371, *Voyage autour de la Terre* p.140). Which is precisely what will happen to Enrique, Magellan’s devoted Filipino slave and first human to close the Great Loop, when he finally reached home base: he heard his own language spoken. Mandeville stands like the Jules Verne of the future Earth-girdling journey, Enrique should be remembered as its Armstrong, and their descendants today naively hope to hear a babble of understandable idioms spoken all over the Galaxy.

However, the main discoveries of the Scholastic era were not geographical, but bibliographic. The starting point was the translation of Aristotle’s *Physica,* *Meteorologica* and *De Cælo* and of Ptolemy's *Almagest* from the Arabic, by Gerard of Cremona and his disciples around 1160. Other authors were also rediscovered during the next hundred years or so, for instance Euclid, Apollonius and Archimedes. Next, direct translations from the Greek began to appear and ultimately superseded the older ones. Simultaneously, Arab observations and instruments became available, and induced in the West a renewed interest in observing the sky. Neither techniques nor measuring accuracy had appreciably changed since Ptolemy's time; still the new data helped to produce in 1252 the famous *Alphonsine Tables* of planetary motions. These were the work of mostly Jewish and Muslim astronomers assembled at the court of King Alphonsus X the Wise of Castille; they were not to be superseded until the *Prutenic Tables* were generated 300 years later, from the Copernican planetary theory. Trustworthy tables were of great practical importance, as they proved essential for astrology. The *Almagest* itself remained a technical and difficult work perused by few readers; another indication of changed times is the publication of a widely-read textbook giving an elementary presentation of the Ptolemaic system: the *De Sphæra Mundi* of Johannes de Sacrobosco. This manual proved as popular as the Tables; numerous manuscript copies of both are still extent, and the texts were to figure later among the first printed books.

The work of Arab and other Near-East natural philosophers ranks a sizeable place within the history of science (see Grant 2007, Chapter 4). However, the fairly elaborate systems that they evolved largely derive from the Ptolemaic or Aristotelian models. Since both had adopted the closed, spherical and unique Platonic Universe, the concept of Plurality did not progress, and does not seem to have played any notable role in Arabic texts. Long before the disputations within the Christian West that will be discussed in the present Chapter, the Muslim thought experienced very similar troubles accepting Greek science: *ex-nihilo* Creation, Necessity superior to God, miracles within Nature, God having to operate through secondary causes, etc., all induced severe problems. One amazing but lonely free-thinker, al-Razi (or Rhazes) proceeded to remarkable and quasi-modern views of the respective roles and separation of science and religion. He was not followed, and Muslim philosophers never reached anything like the Aquinas compromise. Hence, Oriental cosmology does not deserve here a chapter of its own, and philosophical elements from the work of Averroes, the great Moslem commentator of Aristotle (himself translated by Michael Scotus around 1220), will prove of greater relevance.

Still, time had not erased the differences between the Aristotelian and Ptolemaic world machines, and in the thirteenth century they gave rise to controversies. Arabic-language astronomers had generally felt that physical reality was essential to any believable system of the World, hence they tended to criticize Ptolemy and abandon epicycles as merely geometrical fictions, which they were indeed. In particular al-Bitragi (Alpetragius, southern Spain Muslim astronomer) produced a planetary model derived from Aristotle; this incorporated spheres that were not merely homocentric but truly mechanical, filling space completely so as to leave no vacuum, and with planets attached. As far as fitting the calculated positions to observed ones, no great improvement seems to have been attempted. The *Treatise* of Alpetragius was translated by Michael Scotus in 1217, and subsequently achieved great popularity. Contemporaries knew even less about the original Eudoxus model than we do today; hence the two contenders were, on the one hand the Alpetragius system, then considered as deriving from Aristotle and fully conforming with his Peripatetic physics, and the Ptolemaic one on the other.

Most Scholastics of the thirteenth-fourteenth centuries were led to take sides; their positions have been extensively studied by Pierre Duhem, and his *Système du Monde*, which contains a complete account of medieval cosmology, will again be taken as our guide. Bonaventure, a Franciscan monk who taught in Paris, became a cardinal and achieved sainthood, has best presented the issue:

> About this matter there was a controversy between *naturales* [i.e. physicists] and mathematicians [i.e. geometrical astronomers]. The mathematicians consider mostly the celestial appearances… they imagine excentrics and epicycles, and they postulate planets to be moving uniformly on these epicycles; by this device the uniformity of motion is saved.

However, Bonaventure himself disapproves:

> If planets move by individual motions, it will happen that the two bodies will occupy the same place at the same time; then either the place of the planet must remain empty or else the celestial body must be susceptible of rarefaction or condensation, that is of corruption; but all these assumptions are obviously impossible… The hypothesis formulated by the physicists is in agreement with those of Aristotle and their Commentator [Averroes]. They suppose that planets have no motion other than the one of their orbs; similarly, a nail planted in a wheel moves with the motion of the wheel… [However] the hypotheses of mathematicians seem more exact … and do not lead to any errors concerning motions. (Bonaventure, *In Secundum Librum Sententiarum Disputata*, quoted by Duhem 1959, III, 409).

The senses refusing to accommodate themselves with the constructs from reason, observations disagreeing with predictions, theorists on one side and experimenters on the other: we feel on familiar ground. Wrong: for Bonaventure, reason is wholly on the physicist's side and the senses on the mathematician's; but he does consider essential to carry the planet on some believable supporting device. He cannot take seriously the mathematical tools (epicycles and eccentrics) even if they describe motions accurately. The serious physical difficulty arising from epicycles is best expressed by Duns Scotus, the "Subtle Doctor", adamant ennemy of Aristotle; one spoke of Thomist and Scotist schools at the time. He writes:

> If the stars were to move with an independent motion different from the one of their [solid] orbs, there would be in the Heaven empty spaces, or else the stars would divide celestial substance, or else again two bodies might coexist in the same place… Heaven cannot yield before the moving star as air or water do in front of a foreign body: an incorruptible body is unavoidably indivisible…" (Duns Scotus, *Secundus Scripti Oxoniensis*, quoted by Duhem 1959, III, 494).

Nevertheless, such suppositions were soon to appear, but they will not be faithful to the spirit of Aristotle.

The opposite Ptolemaic attitude is found for instance under the pen of Albertus Magnus, a Dominican monk who taught at the Sorbonne and wrote encyclopaedically; his best-known disciple was to be Aquinas. Albertus is far better aware of the actual complexity of things than Bonaventure:

> We observe changes in the apparent diameter of a given star [i.e. planet]; we also find that the Sun, sometimes greater and other times smaller, covers with an unequal motion equal quadrants of the Zodiac; hence we cannot admit that the planets describe in the Zodiacal plane concentric circles. Averroes has seriously erred… (Albertus Magnus, *De Cælo et Mundo*, quoted by Duhem 1959, III, 333).

Hence, Albertus is driven to choose the epicyclic system, and his solution is more elaborate and varied than the simplistic machine with rigid concentric spheres. While at first the Bonaventure viewpoint seems to have been widely shared, it was soon found impossible to ignore the needs of astronomers, and (of greater import) those of astrologers. Even with the modest accuracy requirements of the times, the homocentric system was just too crude; it had never been reduced to a working table, the tool any professional requires. None of them were any longer interested in the physical reality of the devices they worked with; hence, they endorsed Ptolemy, and in the fourteenth century, supporters of the Aristotle-Alpetragius system slowly vanished. The rather shaky compromise that finally prevailed was a Ptolemaic description of motions, but nevertheless Aristotelian physics even within the heavenly realm.

At this point, a summary account of the philosophical situation from the twelfth to the fourteenth centuries becomes necessary.

The Peripatetic Shock

The reintroduction of Aristotle had involved serious difficulties that would today be counted as metaphysical and of no concern to science, but such a sharp distinction was invisible at the time. The root of the trouble was the too-rationalistic attitude of Peripatetism about God, Nature and Man. That this was a God-endorsing rationalism is precisely what created the problem; at the time, nobody would have wasted ink nor parchment to refute Epicurus the Godless. The Peripatetic rationalism, coupled with its accurate logic, produced a rigid self-coherent system that could not fail to collide with Revelation on some essential issues. Determinism was the central one: total Determinism denies all freedom not only to Man, which is bad enough, but also to God, which is vastly worse. At first, for many Scholastics, the only possible answer was complete rejection. Hence arose the first two sets of ecclesiastic interdictions issued by the University of Paris: in 1210, it forbade to use the works of Aristotle and his commentators for teaching questions of natural philosophy, and similarly in 1215 for those concerning metaphysics.

However, in those moderate times, the mood remained far from book burning and the mere reading of Aristotle was by no means forbidden. The practical effects of the interdictions seem to have been limited, and not to have extended very far from Paris; even in Toulouse, Aristotle was still being taught. The technical superiority of Peripatetism over all substitutes was so patent that in 1231, Pope Gregorius IX had to institute a committee empowered to study all questions concerning natural sciences in need of revision. Unavoidably, Aristotle crept back; the best-known names associated with the process are those of Albertus Magnus and his disciple Thomas Aquinas in Paris, and in Oxford of Robert Grosseteste, who became Bishop of Lincoln. New translations of Aristotle directly from the Greek were produced by Guillaume de Moerbecke, at the request of Aquinas (see Duhem 1959, III, 356, 508). Just as unavoidably, a second anti-Aristotelian reaction set in and in 1277

Pope John XXI, feeling that University peace was threatened, instructed Etienne Tempier, Bishop of Paris, to take steps. A new condemnation resulted, but unlike the 1210 decree, which had prohibited Aristotle in bulk, it was selective, which makes it far more interesting. A lengthy but definite set of propositions taken from Aristotle and his followers were denounced as heresies, 219 articles being listed; within the same year, the decision was endorsed by John Peckham, Archbishop of Canterbury.

Pierre Duhem takes the 1277 Tempier's *Decrees* as playing a pivotal role in the history of science as a whole.[4] Within the present very narrow account, they certainly do because the Plurality issue proved central. No longer might any orthodox Christian believe that God had been constrained to build a single World; henceforward, divine fancy was to take the first place in front of human logic. Hence a clear paradox: Aristotle had demonstrated the World to be unique, and Moses (who never wrote a line about the matter) was understood to imply just the same. But the head-on collision between these two prophets produced the first medieval admission that Other Worlds were indeed possible. Revelation appeared to say, One only; Reason plus Logic agreed, but Divine Power swept such paltry arguments aside, and Christians were instructed to concede that both One or Many were all one to the Creator.

The intensity of the conflict is best illustrated by contrasting the two extremist positions. One would fail to grasp the strength of the Unlimited Divine Power concept without considering the case of Cardinal Pierre Damien who, two centuries before Tempier, had held that God was perfectly able to make that what had been, had not been; in plain words, to fabricate the past at will. However, Damien meant this ability quite literally. Such attitude is still with us, as shown by the success of negationism amongst certain layers of the population. Damien was far too serious a theologian ever to put his tongue in his cheek. In his *De Divina Omnipotentia*, he

> starts from a table conversation in which somebody quotes St Jerome: God can do anything, except make that what happened, did not happen. Damien next refutes Jerome, and proves that God's Will is the one cause of existence for what is. When somebody objects that God can destroy Rome, but not make that Rome should not have existed, he answers that if this is true of the past, it is also true of the present and future, because if it is impossible that what has happened should not have happened, it is also impossible that what happens should not happen… logical necessities of our conclusions are not valid for God. Indeed, God is living within an eternal present; he is free from all the conditions of the problem, since for Him, there is no past nor future.[5]

Through similar teachings (plus, one must add, an exemplary life), Damien earned for himself as safe a protection against the vagaries of the future as found anywhere in this sublunary world: a place in the calendar, February 25; not to speak of another impressive title, that of Doctor of the Church, granted after eight centuries of pondering. Even so, might God elect some day to reverse these historical facts?

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[4] Duhem (1959), VI, 20–66. A serious objection to the Duhem view is that the Tempier decrees were not remembered very long, as shown by the scanty quotations during the Scientific Renaissance.

[5] Gilson (1962), 237; quotation not found in the English version of his book. When locating God outside time, Damien is to some extent following Augustine.

This radical view of Damien exhibits the solidity arising from an unshakeable internal coherence. Whoever first refuted his conclusion took the perilous step of putting his own merely human logic first and God's Power second. An enormous weight of manuscript parchment plus printed paper shows how difficult it is to find a secure resting-place anywhere on that path. The 1277 *Decrees* resulted from an attempt to construct one, where reasonable Christians might shelter; and so they did, for a fairly long time.

At the other extreme, let us hear Aristotle himself. For the Master, his cosmic system is not merely true: it is wholly built and bound by *αναγκη* (Necessity), and God could not by any means have made it different from what it is. Without attempting one more discussion of *De Cælo*, and merely to give a feel of the Stagyrite's style, here are a few quotes from some pages where he tries to find the causes of celestial revolutions:

> The activity of a God is immortality, that is eternal life. Necessarily therefore the divine must be in eternal motion… It follows that there must be an Earth for it is what remains at rest in the middle… But if there must be Earth, there must also be fire; for if one of the contraries exists by nature, so also must the other… Again if earth and fire exist, so also must the intermediate bodies… From these considerations then the necessity of coming-to-be is clear… coming to be was inevitable if there was fire, and the other elements if there was earth… and the existence of the Earth was followed from the necessity of having something fixed for ever if there was to be something for ever in motion. (Aristotle, *De Cælo,* 149-153).

The Greek text is even more impressive; the English translator has laudably diversified his renderings, but under the Aristotle pen *αναγκη* rebounds twelve times like a leitmotiv, while his sadly impotent *θεοσ* has to make do with a single apparition. Altogether, the Peripatetic God leads those celestial motions as a figurehead leads a ship, and *De Cælo* often reads like a Thomas Hardy novel.

For some scholastic Peripatetics, Aristotle had come perilously close to holding the office of God's representative on Earth; they took their lead from Averroes: "Aristotle's doctrine is the sum of truth because his was the summit of all human intelligence… he was created and given us by Divine Providence, so that we should know what it is possible to know." (see Crombie 1959, I, 57–8). Even so, fitting Aristotle within Islam had been no trivial task, as Allah had inherited from Jehovah the double chore of not merely maintaining but also creating the World. The *Quran* teaches:

> Lo! In the creation of the Heavens and the Earth, and the difference of night and day,… and the water which Allah sends down from the sky, thereby reviving the earth after its death, and dispersing all kinds of beasts therein, and in the ordnance from the winds, and in the clouds obedient between Heaven and Earth: are signs [of Allah's sovereignty] for people who have sense. (Sura II, 164).

Still, the *Quran* nowhere provides a step-by-step account of Creation comparable to that in *Genesis*, and the adaptation of Peripatetism did not face Muslims with the difficulties later met by Christians. Averroes himself induced an almost equal state of veneration for Aristotle among his followers; Jean de Jandun (avowedly a Christian, but probably as close to a true unbeliever as it was possible to find at the time) writes that Averroes had been *"perfectissimus and gloriosissimus physicus,* *veritatis amator et defensor intrepidus."* (Jean de Jandun, quoted by Duhem 1959, IV, 100). The Averroist view was bound to imply that some points in Revelation were irrational, a dangerous enough thought; or even false, a case of clear heresy.

Intellectual jousts are seldom removed from political matters; the history of an isolated concept (as usually attempted in these pages) may induce false impressions if disconnected from general history. At the time, Jupiter the God had long been safely disposed of, but Allah remained very much in the news. Hence, any notion too directly lifted from Averroes himself was bound to be distasteful to the Church. After the 1277 *Decrees*, Averroism began to fade from the North, and retreated to Italy, particularly to Padova, where it remained active even during the sixteenth century thanks to the timely invention of the "double truth" doctrine: two explanations, one philosophical (i.e. rational) and another theological, coexisting with each other. Such beliefs were anathema to the opponents of Averroes, but they enabled his followers to survive within Christianity.

In between these two extremes, a continuous spectrum of attitudes may be found. One long debated question, leading to the best-remembered Scholastic controversy, was the famous problem of the Universals: do genders, species, substances, categories etc.… designate objective entities? or are they mere words with no reality outside human mind? All those with the slightest trace of Plato in them answered Yes to the first query, and were called Realists; some were extreme conservatives and rejected all novelties in bulk, while others, like Aquinas, proved far more adaptable. Their opponents, the Nominalists (later called Terminalists) are more interesting: of great relevance to science is the extreme position reached by William of Ockham, Oxford Franciscan monk. In the fourteenth century, Ockhamists were to prove the most devoted defenders of the freedom of God, to which they could not suffer limits from human arguments (without proceeding quite as far as Cardinal Damien). For them, God was able to manipulate Nature at His own will, and human reason could never become a sufficient guide. Even so, they were led to take a renewed interest in direct observation, and with the empirical component of Peripatetism they easily came to terms. For Ockham, the only true knowledge of Nature was through direct sense perception while all theories remained mere constructions of words. He was specifically hostile to teleology: "The special characteristic of a final cause is that it is able to cause when it does not exist, from which it follows that this movement towards an end is not real but metaphorical." (see Crombie 1959, II, 31–32). All Peripatetic categories, relations, substances, were to him empty concepts. In the natural world, all things were contingent; hence the need for observations. Still, as one could not escape looking for explanations altogether, the simplest ones, entailing the fewer hypotheses, were the best; hence the rule of maximum simplicity, the famous *Ockham's Razor* (actually a ninetieth century term), for which he is commonly remembered. Utter empiricism was the only way; but at the other end of the philosophical spectrum, and for different reasons, Averroists were also advocating some degree of empiricism. Long before Ockham, Roger Bacon, another Oxford Franciscan and pupil of Grosseteste, had even reached an almost modern view of the need and ultimate power of experimentation, about which Aristotle always remained very weak: some of his anticipations are often quoted.

Now Aristotle will be found waxing and Plato waning, up to Renaissance times. An acceptable compromise with Aristotle was largely the work of two Dominicans, Albertus Magnus and Thomas Aquinas; with them began the separation of philosophy from theology, and the study of Nature acquired an independent status. Here was no game of double truth as with Averroists, since no basic conflict was expected to survive once problems were truly understood. Albertus wrote that it was better to follow the Fathers of the Church than any of the philosophers on matters of faith or morals, and Aristotle, Galien or Hippocrates about physics or medicine; his own work as a naturalist acquired a well-deserved fame. Thus, Reason could henceforward be applied to understand Nature, but Reason by itself was unable to unravel some of the key points. For instance, as far as material philosophy went, the World might have been created eternal, as asserted by Aristotle; however, Aquinas wrote (and repeated in several places) "It is from our Faith alone that we hold this truth: the World did not exist of all eternity; it cannot be proved in a demonstrative manner." Even so, he showed suitable prudence, reminiscent of Augustine: one must not try to demonstrate the point using shoddy arguments, because "…these reasons would set pagans laughing, and they would think that similar reasons constitute our support on matters of faith." (Thomas Aquinas, quoted by Duhem 1959, V, 56).

On the other hand, Reason was not allowed to creep back within matters of faith, and specifically, not to put any constraints on God's Will. This rather sensible attitude ultimately prevailed, and provided firm ground for all Christian scientists to tread upon. Which it still does; and the long-term consequence of the Thomist compromise was that it enabled the Renaissance scientific revolution to take place within the Christian West, while so far the study of Nature had been rather more independent of theological constraints within the Muslim East. However, the path was to be far from smooth; and when the 1277 Tempier *Decrees* drew the official Church guideline, several of Aquinas own opinions were condemned as heresies, only three years after his death.

The Bishop Tempier's Decrees of 1277

The name of Etienne Tempier, Bishop of Paris will recur frequently in the present story, but he seems to have left no writings of his own; it is only because he put his signature to the *Decrees* that he has earned a place in the history of philosophy, theology and science. He had already condemned a first batch of fifteen mostly-Peripatetic theses in 1270, with relatively little effect, and our discussion will be restricted to the more interesting 217 articles of 1277. After receipt of the papal injunction, Tempier rather hurriedly put together a committee of sixteen theologians from the University (Figure 5.3), of course picked mostly from the conservative party ranks and hardly otherwise remembered. However, the Tempier *Decrees* were not of merely local import, as they were soon confirmed by John Peckham, Archbishop of Canterbury.

Figure 5.3 A meeting of doctors at the University of Paris, miniature of 1537, Étienne Colaud. The Tempier meeting was probably not very different, except that it gathered 16 theologians instead of 10 here. Bibliothèque Nationale de France. Wikimedia Commons

The list of articles is without logical order, contains repetitions or even seeming contradictions, and some items are rather obscure. By far the greatest number concerned metaphysical or theological matters, not to be followed here; the epoch was still very much within the Middle Ages, and the material world remained less interesting than the spiritual one. However, finding the frontier between the two is not easy, because it was far from clear at the time; the difficulty is best illustrated by an example. Aquinas had held that

> An angel can be in a place; however when we say that a body is in a place and that an angel is in a place, that is mere homonymy. Indeed, a body is in a place by virtue of its volume being in contact with this place. Angels have no volume; hence it is merely through application of the angelic force (whatever its true nature) that we are able to say that the angel is located within a corporeal place. (Aquinas, quoted by Duhem 1959, VI, 22; also Russell 1946, 450.

This too-daring proposition was soon to be condemned by Tempier, and the faithful were no longer allowed to dissociate angelic substance and action. Today, any scientist would rank the matter as purely theological, and keep aloof; still, the opinions held or reproved here about place, substance and action are closely connected to the cosmological issues we are to discuss further, and in the mind of both the Bishop and his Committee, they formed a coherent whole.

Such is the background out of which arose the ultimate shattering of the closed Universe, hence modern Plurality. Some would far prefer to learn that it all came out of some bright fellow digging out a manuscript of Democritus or Epicurus, and being all of a sudden struck by the blinding light of materialistic Reason; history of science would then definitely be made more coherent and appealing, but things just did not proceed in that way. The Averroists were closest to the modern attitude in their view of knowledge and religion, but at the same time remained prisoners within the hermetically-sealed Plato-Aristotle bubble. Quoting Etienne Gilson (1962), p. 559:

> Some of the condemned [Averroist] theses show how far one could then proceed, perhaps in writings and certainly in discussions: that Christian religion is an impediment to instruction; that there are fables and errors within Christian religion just as in others; that one knows nothing more when one knows theology; that what theologians say is grounded in fables. One might be listening not even to Fontenelle, ever so prudent, but to Voltaire when he is sure of impunity.

Altogether, when scholars (mostly churchmen) began to exercise their minds about the proper place of angels, and invented a virtual form of Plurality, then at that precise instant we discern the first glimpses of Other Worlds in a boundless Space.

Out of the 217 propositions condemned by Tempier, nineteen seem most relevant to cosmology and Plurality and are given here numbered as in the original text (from Duhem 1959, VI, 20–66), but placed in an attempted logical order:

> 53 "God makes out of necessity everything that comes from Him."
>
> 54 "God has infinite power not because He has made something out of nothing, but because He gave continuity to infinite motion."
>
> 84 "The World is eternal because whatever has by nature the possibility of existing eternally in the future, also must have existed by nature throughout the past and will do so in the future."
>
> 19 "There has not been a first man and there will not be any last man; man has always engendered man in the past, and will do so in the future."
>
> 20 "Nothing results from chance; everything happens out of necessity; all future events that will be, will be events arising out of necessity; what will not take place is the impossible; nothing happens in a contingent manner, provided one takes all causes into account."
>
> 133 "[Human] will and intelligence do not actually move by themselves, what moves them is an eternal cause, namely celestial bodies."
>
> 161 "Stars have on free will occult influences."
>
> 167 "Through certain signs [i.e. celestial positions] one knows what the intentions of a man will be, whether these intentions will change or be executed. Through such signs one knows what will happen to travellers, whether men will be taken into captivity or captives freed; one knows whether an individual will become a learned man or a thief."

> 6 "When celestial bodies all come back to the same place, which will happen in 36 000 years, the same effects as at present will take place."
>
> 10 "Generation of man is cyclical because the form of a man will return several times to the same portion of matter."
>
> 63 "God could not produce the effect of a secondary cause without the help of this secondary cause."
>
> 92 "Celestial bodies are moved by an intrinsic principle which is a soul; they are moved by this soul by virtue of an appetite, like an animal would. Just as an animal moves when he feels a desire to move, so does the Heaven."
>
> 102 "The soul of each Heaven [i.e. sphere] is an Intelligence and the celestial orbs are not merely the instruments of these Intelligences but the organs, just as ears and eyes are the organs of sensitive virtue."
>
> 186 "Heaven never stops because the generation of inferior beings, which is the aim of heavenly motions, must not stop. Furthermore, Heavens draws its existence and virtue out of its Motor; it is because such motion and virtue maintain Heaven that if Heaven interrupted its motion it would cease to exist."
>
> 79 "If Heaven stopped, fire would be without action on oakum, because [Time] would not exist."
>
> 192 "When theologians say that Heaven did sometimes stop, they are stating a wrong assumption. To say that Heaven exists, and does not move is to admit contradictory statements."
>
> 49 "God could not submit Heaven to a translation, because Heaven moved in this way would leave a vacuum behind."
>
> 201 "He who admits a complete generation of the World admits a vacuum; indeed and necessarily, a place antedates whatever is created within this place; and as a consequence, before the creation of the World, there would have been a place without any located body, that is to say a vacuum."
>
> 34 "That the Primary Cause would be unable to create a Plurality of Worlds" *(Quod prima causa non posset plures mundos facere.)*

The first (*Proposition 53*), covers the key point, i.e. that Aristotelian Necessity is heretical, and the next propositions are mere consequences. Some specifically forbidden beliefs: God did not create matter, but merely endowed some primordial stuff with order and motion (*54*); the World has an infinite past (*84*); there has been no first Man, because Man has always engendered Man (*19*); Necessity rules everything (*20*); human will and intelligence are subject to celestial bodies, which can be used for predictions (*133, 167*). Thus, astrology is condemned only insofar as it pretends to predict human thoughts and actions, but the governing influence of stars on the non-human sublunary world is not questioned. More heresies: all forms of Eternal Return (*10*), and specifically the 36,000-year Great Year (*6*). A more subtle error: the belief that "God could not produce the effect of a secondary cause without the help of this secondary cause" (*63*). Hence, God is freed to intervene within Nature in the manner that suits Him best, not bothering with human-deduced laws, a freedom which abides poorly for the future of Science; however, that decree will be repeatedly flouted by generations of concordist exegetes. Do not believe either that "The soul of each Heaven [i.e., sphere] is an Intelligence" (*102*); the arduous problem of Intelligences as intermediary causes of celestial motions was being voluminously argued at the time, and the long-term consequences of these Tempier exclusions will be seen when discussing Buridan.

Peripatetics had been keen on all heavenly motions being eternal, and their own God could not conceivably stop any; hence Tempier condemns the proposition that "When theologians say that Heaven did sometimes stop, they are stating a wrong assumption" (*192*). Thus, the first head-on collision between Josuah stopping the Sun (clearly alluded to) and Science did not involve Galileo but Aristotle as the champion of human rationality. Those vociferous seventeenth-century opponents of heliocentrism who were to brandish "this Sun which stood still in the midst of Heaven and hasted not to go down about a whole day", forgot that such a miraculous breakdown of the natural order had proved just as incompatible with Aristotle and Ptolemy as it was with Copernicus.

Next, Tempier makes a heresy of the Peripatetic negation of vacuum. One may wonder why; Moses had not been concerned about vacuum at all, hence good Christians might appear free to reject or play with the concept at will. Grave error! God must be free to create a vacuum if He wants to, irrespective of human logic; moreover, the mere possibility of a vacuum touched the sensitive issue of Creation *ex nihilo*, since Peripatetics had been arguing that before creation of the World, "there would have been a place without any located body, that is to say a vacuum." (*201*). Moreover, they had also outlawed all translations (as opposed to rotations) in the Cosmos, because "Heaven moved in this way would leave a vacuum behind" (*49*). The present story is far from finished with the rejection of vacuum; it will play a central role in the cosmology of Descartes.

Finally, the anathema with the most lasting consequences struck a fatal blow at those heretics who had clung to *Proposition 34*. Hence, while Plurality in Time has just been strictly excluded, the possibility of Plurality in Space is not merely authorized: it is made almost compulsory. The aesthetically pleasing Augustinian space-time symmetry is broken, and the fear that Augustine had expressed has finally come true: the boundless spaces beyond Heaven begin to fill. The artisans are neither his Neo-Platonist or Epicurians opponents, but orthodox Christians; first of all, a fellow Bishop, his long-term successor in the Church. Plato had simply ignored the Unlimited Power of God, putting to the fore his own concept of a paramount Good, which had entailed symmetry, smoothness and unicity. Augustine had glimpsed at the horror of Plurality, and retreated in fright; but eight centuries later, the newly invented Unlimited Divine Power sweeps all such miserable arguments aside, and Man is forbidden to forbid God anything He might have in mind.

Shortly before the Peripatetic Renaissance, around 1140, the Bolognese monk Franciscus Gratianus had included in his *Concordia Discordantium Canonum* (a much-perused compilation of Church canons) the heresy of those who "are of the opinion that numberless worlds exist" (see Grant 2007, 394–5). In his time, the official line had still been Augustinian. Now, thanks to the Pope and the Bishop of Paris, and with full approval of all ecclesiastical authorities, *Virtual Plurality* has been launched. It will never die out, only metamorphose to Actual Plurality under the pens of Cusanus and Bruno, and later, the tools of Galileo. By then, the ponderous machinery of the Church will have shifted again to the opposite direction, with disastrous and well-remembered results.

Matter, Vacuum and Gravity Comply With Theology

Theology is a major actor, and the year 1277 occupies the central place in the drama. Still, scientific discussions (as we would call them) had not vanished. There were three principal relevant issues, and all three were hotly debated. The first was about matter: could the available matter be adequate for fabricating several independent Worlds? The second was vacuum, for which the Tempier endorsement has just been told; since vacuum remained an impossibility within Nature, apart from an act of God, some way had to be invented to fill the intervening space between separate and spherical Worlds. Third, gravity: how could these independent Worlds be maintained in stable positions and not just fall down on our heads? One suspects that some learned Doctors must have turned their gowns inside out and used much the same arguments both ways before and after the *Decrees*, or else what is sharply honed logic good for? Maximum resistance came from the Averroists, who refused to accommodate their physics or cosmology to suit the whims of the Church. Jean de Jandun took refuge in Italy; the best known Averroist in the Sorbonne, Siger de Brabant, also had to leave and was even jailed in Rome.

The problem of matter is connected with Creation, thus was a theological issue. Vacuum appears today as quite free of metaphysical or logical implications, but was not so in the thirteenth century; Aristotle had demonstrated that vacuum was not merely impossible, but antinomic. Hence the question: might God himself create a vacuum? Everybody agreed that God, and God alone, was in a position to do so; still, what was His *modus operandi* that could dodge all human logic? Here was a thorny problem indeed, and the connection with Plurality was to be used both ways: some Scholastics started from their views of vacuum to deduce features of these alien Worlds, while others did the reverse. Lastly, gravity had not been mentioned by Tempier, and was permitted ground for natural philosophy; nor had Revelation said anything about it, and the Power of God did not seem to be pulling bodies one way or the other. Consequently, in the fourteenth century, William of Ockham, Jean Buridan and Nicolas Oresme were to introduce some frankly anti-Peripatetic novelties. This unique natural place which all heavies sought for might not be so unique after all; even, more radically, it might prove a mere Peripatetic fiction, and the fall of graves became explainable through a Platonic-type attraction. These half-theological notions, while vague and qualitative, later proved adequate to leave room for the system of Copernicus, the Pluralities of Cusanus and Bruno, the infinite universe of Thomas Digges and even the earthly Moon of Galileo.

First, let us consider Matter, and start before 1277. Roger Bacon introduces the argument, which to non-scholastic ears sounds maddeningly formal:

> Aristotle says…that the World unites its own matter within a single individual of a single species… hence there cannot be several separated worlds pertaining to this same species, and there cannot be either several Suns nor several Moons even if many people have formulated such suppositions.

Happily, he next becomes more technical

> …one cannot either pretend that a second World surrounds the first since both centers would coincide, and there would be a single Earth for both; the same would apply to the other parts of the World, hence there would be a single World.

Which seems a bit too obvious, and it will recur again and again, never to proceed any further.

The case of Aquinas is particularly interesting. In his refutation of Plurality, he is first concerned with those scholars who are incautiously wielding God's Infinite Power:

> To their argument, one must answer in this way: if God were to make other Worlds, He would make them similar or different; if He made them similar to this one, His work would be in vain, which does not suit His wisdom. If He made them different, then none of them would include the entirety of the sensible body; none would be perfect, and it is only their whole which would constitute a single and perfect World.

What is wrong with this result? Aquinas does not conclude his own dangerous argument: he is patently lecturing God on what He should have done, by putting first his own concept of perfection, clearly inherited from Plato and not from Moses. And he makes his case even worse

> a greater power is needed to produce one single perfect individual than many imperfect ones…it does suit the goodness of the World that it should be one; uniqueness is the reason of its goodness itself… (Aquinas, quoted by Duhem 1959, IX, 373).

Such constraints on the Creator, well meant as they were, could not be tolerated even from Aquinas, and Tempier was to refute specifically these lines. Aquinas did not become *Saint-Thomas d'Aquin* until much dust (beyond his own) had settled on the case.

Next, we present some of the post-1277 arguments. The subject of matter is confronted head-on by Godefroy de Fontaines, professor at the Sorbonne (the Paris University):

> God, who has already created one sort of matter, is able to create a new one and out of it He may produce something else. Hence the fact that this World [of ours] contains the entirety of its own matter does not make the existence of another World impossible. (quoted by Duhem 1959, IX, 375).

The argument does make sense to modern ears; the strictly formal Peripatetic demonstration of Bacon is shown to be a total blank. No deduction from logic alone about this World of ours will ever prove that nothing exists outside; still, we have to put on record that the device responsible for that capital widening of the human horizon was not the Lucretian arrow, but God's Free Will, an agent we would today no longer dream of invoking in the case. History is not a course on logic.

However, the times were by no means through with Scholasticism, and we feel less impressed when Gilles of Rome, a disciple of Aquinas, attempts to overthrow the next Baconian point, a unique Sun; all because such is now the will of God and (more cogently) that of the Church:

> If two Suns were in existence, one might say of each that each contains the whole of its matter; within each indeed there would be no change either in form or in essence; all the matter that can be under the form of this Sun is there in full actuality, and similarly for all the matter under the form of that other Sun…[etc., etc…] (Gilles of Rome, quoted by Duhem 1959, IX, 379).

The argument, which goes on and on, is formal Peripatetic twaddle twisted to produce a conclusion that would have been anathema to Aristotle. Such distortions were the baptism price to be paid before Aristotle could become fully Christian. Conclusion:

> Through divine Power it might happen that an element should be totally changed with another element, or generated from the others; but this cannot happen according to the ways of Nature." (Gilles of Rome, quoted by Duhem 1959, IX, 380).

Here, Gilles de Rome has shown the essence of the compromise that will last as long as Scholasticism. Within the past, God is granted utter freedom to have made one, several or an infinity of Worlds according to His own fancy and to no human rule, and today He would be just as free to operate in any manner He would like; but apart from such outside interventions, Nature still has to obey Aristotle slavishly.

This thirteenth century debate should not be dismissed as mere tempest in a teacup. It will leave a lasting residual: after the Galilean discoveries are finally assimilated, Catholics and Protestants alike will admit (some with great enthusiasm) that Divine Power had been able to fabricate these many Worlds, no longer hidden behind the last sphere but now identified with familiar objects within the starry vault.

The rejection of vacuum that extended from Aristotle to Descartes is particularly hard to understand today. To reach the perfect vacuum concept, we now merely remove by thought the last molecules remaining within that glass jar, and do not feel bothered by the actual performance of the pump at hand, nor by the practical difficulties of outgassing etc.; and neither did the Greek atomists. The thirteenth-century novelty was that God might decide to create a vacuum even if Nature could not; from then on, the notion had to be considered in earnest.

Before Tempier, Peripatetics merely followed Aristotle and his Commentator Averroes. The latter had transmitted the mechanical argument against vacuum: "if [moving bodies] were not located within a resisting medium, they would accomplish their motion in zero time." (quoted by Duhem 1959, VIII, 15). Which is intelligible enough, but more formal claims no longer make sense; they must be followed however, because of their direct connection with the existence of Other Worlds. The central point was made by Michael Scotus:

> Between the convex surfaces of the spheres that limit these several Worlds, there would of necessity exist some space. Then, either there would be a body filling this space or not. But …such a body would be foreign to all Worlds since it would be outside the spheres…If there is no body filling this space, it must be empty; but there cannot be a vacuum in Nature, as demonstrated by Aristotle…hence several Worlds cannot be. (quoted by Duhem 1959, VIII, 29).

This maddening argument was tirelessly repeated, and sometimes rejected but never from any of the reasons that seem obvious today. No one got rid of these sharp boundaries or of their so-inconvenient spherical shape; it is a pity that the Tabernacle-shaped Heaven was so thoroughly out of fashion, since parallelepipeds pack nicely! Hence the issue rested on whether vacuum was permissible or not.

Let us now pass to the post-1277 developments. Tempier had ordered that God should be allowed to translate Heaven even if that action were to produce a vacuum (*Proposition 49*), but he had not explicitly stated that He would have required the said vacuum. From such constraints, in order to explain multiple Worlds, two lines of thought emerged. Along the first, even with tangent spheres a vacuum may not be required; but most of the arguments are meaningless today. In the second line of thought, which proves easier to follow, Vacuum is possible to God, or (in modern terms), God may be used as a tool within a perfectly sensible thought experiment. The first to propose the operation is Richard of Middleton, an English Franciscan brother like Bacon, but writing mostly in the post-Tempier era. His discussion (while far from limpid) leads to the clear conclusion that vacuum had never been antinomic at all. Attempted translation to modern jargon: (1) God operates a vacuum pump; (2) he shores up the container to prevent its collapse; (3) lo! a successful vacuum has been created inside.

Altogether, a miraculous emptiness has been created, and as nobody questions miracles, the issue has to be faced. Reason becomes compelled to consider vacuum, together with its built-in dimensions, instead of rejecting the mere notion a priori; which stands as a first-magnitude positive consequence of the Tempier decrees. Middleton will be followed by many others who elaborate the same thought experiment. Here is Duns Scotus, the *Doctor Subtilis* and opponent of Aquinas:

> In an absolute manner God might annihilate all elements without changing the existence of Heaven in any way…the walls of Heaven would not come to meet instantaneously, because Nature cannot in any way produce such a change instantaneously; the concave surface of Heaven would hence subsist, and nevertheless this surface would no longer enclose any body at all. (quoted by Duhem 1959, VIII, 45).

So far, this vacuum is strictly virtual: God might make it, but there is no hint that He ever took the trouble. The last step is taken by Robert Holcot, disciple of Ockham and (like other Ockhamists) emphatic supporter of God's free will:

> If God has the power to create a second World, he would have to create it in some place, just as this World of ours, in such a way that between the parts of this World there would be distances.

These distances are just a way of stating that such an alien World would have been gifted with a sensible volume.

> Hence, I do ask, what lies there presently where this World would be created? Nothing or something? If there is something, then in actuality there is something outside the World. If nothing, we can reason thus: outside the World, there is nothing, and outside the World, there might [however] exist something; hence outside the World lies a vacuum; because where a body could exist and does not exist, there is a vacuum. Hence, presently, vacuum exists. (Robert Holcot, quoted by Duhem 1959, VIII, 50).

The Holcot conclusion will not be adopted overnight, but the path is open. The destruction of a potent Peripatetic absurdity has been achieved without any input from materialism or experimentation. Divine Power is the sole tool, and the ground has been pulled out from under the anti-Plurality tangent-spheres argument. And, in the longer term, from under all Aristotelian mechanics.

The third issue is Gravity, for which the Aristotle view has been presented in Chapter 2. His follower Averroes comments:

> [Older] philosophers had argued that motion or rest of the Earth were caused by mutual attraction between the Earth and its natural place; but it is obvious that a mass of earth does not move towards the whole Earth independently of the terrestrial globe position; if it were the case, this motion would be comparable to the motion of iron towards a magnet; hence it would happen that a mass of earth might move naturally upwards… (quoted by Duhem 1959, I, 236-8).

This refusal of attraction, and specifically of the magnet analogy, will remain a stumbling block up to the fourteenth century. A piece of iron between two magnet poles moves obviously enough towards the closest one, but Aristotle's gravity had nothing in common with magnetism. Plutarch had wriggled out of the difficulty with the greatest ease, but he was forgotten in the Scholastic era.

So much for orthodox Peripatetics. Gravity had not been openly tackled by Tempier, but some Doctors still felt bothered by the stability of these Worlds, now virtually suspended above their heads; and standard Aristotelian mechanics did not work. Might other Worlds possess a gravity similar to ours, "natural one, due to some connection with our Earth." (Godefroy de Fontaines, quoted by Duhem 1959, IX, 376). The clumsy argument nevertheless contains a precious novelty, in which the idea is present, but at first in a highly confused form. Godefroy de Fontaines: "Since, with respect to our Heaven this other Earth would have no relation, and would feel no influence from it, if it were to move towards the surface that encloses our World, that would happen through a violent motion". Within this other World, the natural motion of graves might take place in the direction of its own World center, and not of ours. Godefroy does not call in Divine Power in this respect, and indeed Tempier had requested nothing of the kind. Still, the argument is unmistakably post-1277; no novel logical device nor observation (still less experiment) was forcing any revision of Aristotelian mechanics; but these Worlds had to be accommodated somehow, and God's free Will was having its way. In this crooked manner, and through the agency of merely virtual other Worlds, the revision leading to modern mechanics had been launched.

Polycentric gravity becomes clearer with Richard of Middleton. First comes the Power of God: "I say that God has been able, and that He is still able, to create another Universe. If we attribute this power to God, we do not run into any contradiction." Next he shows that indeed no contradictions appear in specific cases:

> Just as the Earth of our own Universe rests naturally in the center of it, in the same way, the Earth of this second Universe would naturally rest in the center of its own World… In favor of such an opinion, one can invoke the sentence of Mylord Etienne [Tempier] … he has excommunicated those who teach that God has not been able to create several Worlds. (Richard of Middleton, quoted by Duhem 1959, IX, 377).

Richard anticipates modern thought: matter behaves in the same way throughout these Worlds, and the same laws of mechanics apply everywhere.

Still, Peripatetism spirit thrived even if one particular dogma had been condemned. Guillaume de Varon:

> …In two different men, the vital spirits are of the same species; nevertheless they occupy different places, so to say different homes within these two men. Similarly, we must say that all the earth located under our own [celestial] sphere has the same natural place; but the earth of the other World… does not descend to the center of our World; it finds its resting place in its own center. (quoted by Duhem 1959, IX, 383).

Hence, these compulsory new Worlds did not by themselves imply abandoning the animal or human analogies of ancient hylozoism. With Bruno, such interpretations will soon be seen coexisting with a completely modern description of the said Worlds, as far as geometry and even kinematics went.

Of course, the strict Averroists did not comply and there were rearguard fights. But altogether, the Plurality concept promoted by Tempier certainly helped physics.

Nicolas Oresme and Jean Buridan

The theory of gravity developed by Nicolas Oresme marks a clear break from Peripatetism and a return to Plato's *Timaeus.* Nicolas Oresme was Bishop of Lisieux, and educator of the future king Charles V; a fairly good reference since his charge grew up to win (like Alphonsus of Castille) the nickname of *Le Sage* (The Wise), a sadly unique case among French Kings. Oresme is of such importance to the history of science that he deserves to have his views on space, vacuum, gravity, the rotation of the Earth, and Plurality, treated as a whole. I also note, with some relish, that he was the first among the scholars so far mentioned to drop Latin for his native language: King Charles was insistent on the use of French, like some of his successors under quite-different regimes. The main work of Oresme, the *Livre du Ciel et du Monde,*[6] is a heavily-critical comment of Aristotle written in 1377, a century after Tempier.

Oresme is best remembered today for his well-argued proposal of a diurnal Earth rotation. However, that part of his thought is the least important for our purpose, because he does not consider orbital motion. Merely attributing to the Earth some rotation around an internal axis does not establish a similarity with other celestial bodies, since none appear to exhibit a similar effect in any obvious manner. Hence, his rich and detailed argumentation will not be followed; he shows very well that rotating the Earth saves some celestial phenomena, but Ptolemy had already

[6]The *Livre du Ciel et du Monde* (Oresme 1377) contains a full translation of Aristotle's *De Cælo* to French from the Latin version; like most contemporaries, Oresme knew no Greek. In the process, he had to invent several hundred words that have become indispensable in both scientific and everyday French. Here, we are solely concerned with the running commentary, often longer than the text, where Oresme presents his own views. All quotations here are from the A. D. Menut English translation.

admitted that much. However he openly contradicts Ptolemy's next point, that an arrow shot up vertically would be seen falling to the West; he does it by presenting the first recorded version of the powerful moving-ship thought experiment:

> If a man were in a ship moving rapidly eastwards without his being aware of the movement, and if he drew his hand in a straight line down the ship's mast, it would seem to him that his hand were moving in a rectilinear motion; so, according to this theory, it seems to us that the same thing happens with the arrow which is shot straight down or straight up. (*Livre du Ciel et du Monde,* II, 25, 525).

However, Oresme cannot prove that earthly rotation explains the phenomena any more cogently than the heavenly one, except by arguing that it is more adequate for the Earth to be heated in that way, since "the meat being roasted before the fire receives around it the heat of the fire by being turned and not by turning of the fire around the meat." (II, 25, 533). His opponents, for instance Albert of Saxony, will immediately point out that planetary motions are not explained at all in this way. Furthermore, while his geometrical and mechanical discussions show Oresme himself preferring Earth rotation as far as natural philosophy goes, he does not dare to attack the theological difficulties and has to admit *in fine* that, truly, the Earth does not move. He begins by alluding to (Joshua 10,13) in a sensible manner:

> We could reply that in the time of Joshua the Sun stopped, and in the time of Hezekiah it returned, but only apparently so, for in fact it was the Earth that stopped moving… whichever occurrence we prefer to believe the effect would be the same. The latter opinion seems more reasonable than the former. (II, 25, 531).

That is the second appearance of Joshua on stage, and more will follow. But while Oresme believes that he may dispose of these particular Biblical verses, still the weight of Scripture shored by tradition is too strong for him. Before the evidence given in Psalms 93, 1, he surrenders:

> However every one maintains, and I think myself, that the Heavens do move and not the Earth: for God has established the World which shall not be moved in spite of contrary reasons… What I have said by way of diversion or intellectual exercise can in this manner serve as a valuable means of refuting and checking those who would like to impugn our faith by argument. (II, 25, 537).

Oresme's conclusion is orthodox: Faith has to come first. Copernicus will not only propose a far more complete and fully worked-out machine, but will insist that it is the only true one.

Oresme's concepts of space, vacuum and gravity mark clear progress relative to those of the Tempier era; after him, only a small step will be needed to reach Cusanus. His starting point is precisely that Plurality of Worlds had been made an article of faith by Tempier one century before. In *Article 34*, Tempier had written about *"plures mundos"*, not an infinite number; still, he would not have dreamed of ordering God to stop at any specific complement. The full implications took some time to sink in; for instance Ockham (whose influence on Oresme is manifest) first worked out the consequences: in the problem of infinity also, Reason (meaning Aristotle) had to bow before Divine Power. Nevertheless, Ockham's infinite had remained merely virtual, and the transition to an actual infinite was to consume an immense amount of parchment. Ockham's arguments are repeated *ad infinitum*, little pebbles being generally preferred to water drops, no doubt because of easier handling. The most polished form is due to Gregorius of Rimini:

> God might have, each day, created a stone of one cubic foot, and joined it to the previously created one; unquestionably, such an infinite multitude of stones would constitute an infinite magnitude (cited by Duhem 1959, VII, 137).

For Scholastics, the momentous conclusion is that the operation might be presently terminated, hence such an infinite body might exist in actuality. However, even God met a serious difficulty: he should have made his start before Creation! Some disputants even inverted the weapon, and turned it into a concordist proof of the finite age of the World, starting from its finite (Peripatetic) size. Hence the second Gregorius argument:

> … it is also certain that God might create a stone and proceed as above within each of the proportional parts of an hour; since the multitude of these proportional parts is infinite, at the end of an hour, there would be an infinite stone [made by joining all individual ones].

No great enthusiasm will be felt today, since we distrust infinite velocities as much as infinite sizes; but the argument appears to have been rather successful, and did enable the notion of spatial infinity to take root without endangering Creation. In much the same vein, it also turned handy for proving that God was able to create Infinite Charity; such were the ways of the time.

Oresme himself starts from the theological constraints: "All matter now existing or that has ever existed is comprised in our World, nevertheless, in truth, God could create ex-nihilo new matter and make another World." (*Livre du Ciel et du Monde,* I, 24, 175*).* However, from then on, his arguments will be those of a lay cosmologist; only in his conclusion does he fall back on Scripture for help. He first summarizes the classical Peripatetic refutation of vacuum, together with the standard tangent-spheres argument. Next, he gives his own answer, and at once reaches our modern view: the concept of a vacant, boundless space beyond the finite material World does not have to induce any kind of headache: "The human mind consents naturally… to the idea that beyond the heavens and outside the World which is not infinite, there exists some space… It seems to me that this is a reasonable opinion." One of the main concepts of the Atomists and Epicureans has been recovered, starting from a diametrically opposite philosophical basis. God's will is seen at work, clearing away the Peripatetic rubble, and the Lucretian arrow is now ready to fly within a fully Christian Heaven.

Oresme presents his own version of the miraculous vacuum experiment: If the World

> were to be destroyed while the heavens remained as they are, it would necessarily follow that in this concavity there would be a great expanse and empty space. Such a situation can surely be imagined and is definitely possible, although it could not arise from purely natural causes…

This passage marks a transition to the modern approach: God is not explicitly brought in, as a mere Bishop performs the experiment, but the conclusion is unambiguous:

> Thus, outside the Heavens there is an empty incorporeal space quite different from any plenum or corporeal space…. infinite and indivisible, and is the immensity of God, and God himself, just as the duration of God called eternity is infinite, indivisible and God himself. (I, 24, 177).

That particular brand of Space was to enjoy lasting success: it is precisely Newton's space, which he was to call "God's *sensorium",* and it proved fully adequate to support physics and cosmology, at least until an even more subtle Bishop, George Berkeley appeared on the scene in the 18th century, with his distant followers Ernst Mach and Albert Einstein. Meanwhile, Oresme concludes

> that God can, and could in His omnipotence make another World besides this one, or several like or unlike it. Nor will Aristotle or anyone else be able to prove completely the contrary. But of course there has never been nor will be more than one corporeal World as was stated above. (I, 24, 179).

Altogether, Oresme merely shared the general attitude after the Tempier decrees, and showed the quite definite limits of Virtual Plurality. Nevertheless, and despite this acknowledged Virtuality, the notion had played a pivotal role in the transition of Space from medieval to modern, and it was Oresme who most clearly illuminated the process.

The remaining question is Gravity. Oresme starts from the Ockham thought experiment: a light body (light in the Peripatetic sense) located at the center of our World would divide and climb to north and south simultaneously, but he proceeds much further. By using Plurality as logical lever, he is able to derive a similar result also for the graves:

> If a portion of earth were equidistant between two Worlds, and if it could be separated, one part would go to the center of one World, and the other portion to the center of the other. If the portion could not be divided, it would not move at all, because of the lack of inclination, being like a piece of iron halfway between two magnets of equal strength. If it were nearer one World than the other, it would move in the direction of the nearer World. (I, 17, 135).

Oresme even considers the case of strictly equal distances; then, an equilibrium would result

> But it could not exist in this manner by nature because of variations or changes or other motions which commonly occur, as in the case of a heavy sword which would not stand for any length of time upright on its point. (I, 2, 137).

The language is now so modern that the reader feels out of Scholasticism: Oresme has adopted the appropriate magnet analogy, and shown the cosmic equilibrium as unstable, through a well-chosen and down-to-earth experiment. His celestial mechanics are adequate to support primitive versions of interplanetary travel: Kepler, in his precisely described Moon voyage, will make use of a similar gravity that is almost gravitation.

Such an outcome is still far in the future, but some consequences are soon deducted: these other Worlds, virtual as they are, might persist in a natural way. God's contribution remains essential, but as a designer who has built the stage on which Man is now at liberty to play. No doubt He would have had to create these other Worlds, but neither more nor less than He did create our own; once brought into existence, all would similarly stand

> if God in His infinite power, created a portion of earth and set it in the Heavens where the stars are, or beyond the Heavens, this earth would have no tendency whatever to be moved toward the center of our World … and if God created another World like our own, the earth and the other elements of this other World would be present there just as they are in our own World… All heavy bodies in this World tend to be united in one mass… and if one part of the earth in this other World were in this World, it would tend toward the center of this World, and become united with the mass and conversely.

The whole scheme is fully Christian; Aristotle had written that several Worlds would require several Gods, but

> I reply that God is infinite in His immensity, and if several Worlds existed, no one of them would be outside Him nor outside His power. (I, 24, 173-5).

Altogether, we have progressed to a (still virtual) polycentric Universe, within which each of these centers is not a mere geometric point but a physical center of mass: wherever matter exists, a center results. Such centers are free to move, the terrestrial one included: a momentous consequence, later spelled out by Cusanus. As to Oresme, he is able to form a novel picture of the sublunary equilibrium, in which the implicit reference is no longer Aristotle but Archimedes:

> I imagine the case of a tile or copper pipe so long that it reaches from the center of the Earth to the upper limit of the region of the elements, that is up to the very Heavens. I say that if this tile were filled with fire except for a small amount of air at the very top, this air would drop down to the center of the Earth for the reason that the less-light body always descends beneath the lighter body. And if this tile was full of water, save for a small quantity of air near the center, this air would mount up to the Heavens because by nature air always moves upward in water… These two motions are both simple and contrary and thus a simple body is by its nature capable of moving with two contrary motions. (I, 4, 71).

At this point, very little is left of Peripatetic mechanics. Furthermore, no explicit or implicit call to God's help has been made: Oresme himself is the one who erected that pipe. Within a few pages we have witnessed the transition to the modern thought experiment in which, as far as imagination goes, Man is becoming God's equal.

In this manner, Oresme recovers most of Plutarch's *De Facie* results, and even progresses farther. For Plutarch, lunar matter had attracted only lunar matter, and the same applied to earthly matter; hence he had remained unable to consider the half-way case. Moreover, he had been exclusively concerned about the Moon, and gave no inkling that planets nor stars might behave in the same fashion by holding up their own stuff. By contrast, Oresme is treating a general abstract case, and his notions will later prove applicable to all celestial bodies; however (and unlike Plutarch) he never stoops to consider any specific case, and the *Livre du Ciel et du Monde* offers no hint that our familiar Moon might harbor an equilibrium similar to the one so well described on Earth. Oresme is also willing to grant God the right to place these lumps of earth within Heavens, where the stars are located; but he never states that the stars themselves might be these Worlds from which proceeds his whole argument. For him, all stars are real while other Worlds remain virtual.

The second important progress of mechanics in the fourteenth century is the development of the *impetus* theory by Jean Buridan, Nominalist Rector of the Sorbonne. About one generation older than Oresme, he still used Latin in his

Questiones octavi libri physicorum, a critical and constructive analysis of the eighth book in *Physica* where Aristotle had treated projectiles.[7] He was not a theologian nor even a churchman; surely here we move into a purely lay domain where God's power, unlimited as it is, will be of no material help? Wait and see.

Impetus is a crude but clear forerunner of momentum and even of kinetic energy, and was to play an important role in the overthrow of Peripatetic physics. Buridan himself never mentions other Worlds, but consequences of his theory were soon to make possible the rebirth of Internal Plurality. Oresme had never been interested in the individual motions of all celestial bodies; Buridan is, and simultaneously in those of projectiles. The result is the first system of mechanics that tries to unite both; which does not prove that planets are Earths, and indeed Buridan reaches no such conclusion, but one essential difference between sublunary happenings and heavenly ones is *ipso facto* removed. An adequate treatment of projectiles, starting from Aristotle and covering the evolution of the theme during the Scholastic era, would take us too far; here is a mere summary. For Aristotle, the revolution of celestial bodies is a natural motion, circular and eternal, while that of projectiles is of a radically different nature, violent, forced and transient. Furthermore, vacuum being unthinkable, motion always takes place within air, and air acts as a continuously running motor.

Tempier was not concerned with projectiles, which go unmentioned in the *Decrees*; in his innocent age, the paramount issue was to optimize the performance of the divine Will, not that of human ordnance. However, within the general reaction against Peripatetism, Ockham was bound to present the opposite view. The Aristotle theory had proceeded from a conceptual difficulty that was to outlast Aristotle by many centuries: the refusal to admit action at a distance. Which attitude is a clear case of anthropomorphism: the human body cannot move any external object except by direct handling. Ockham proceeds from the very opposite position: "I say that it is not universally true that motor and mobile have to be joined in mathematical contact", and he introduces the magnet analogy:

> This iron from which it is locally distant, the magnet pulls it in an immediate manner, and not through some virtue existing either in medium or in the iron. The [magnetic] stone acts immediately at a distance, without acting on the medium." (Ockham, quoted by Duhem 1959, VIII, 190-1).

Ockham anticipates Newton, Coulomb and Ampère, but opposes Faraday and Maxwell. Next, he tackles the motion of projectiles:

> The motor principle cannot be the air because when an arrow and a stone cross, the air would have to move by contrary motions… After the mobile has been separated from the instrument that produced the initial motion, the motor is the mobile body considered in itself … motor and mobile are one and the same indivisible thing. (Ockham, quoted by Duhem 1959, VIII, 194).

[7] Poor Buridan is universally remembered from his highly mediatic ass, ever racking his brains in unstable equilibrium between two symmetrical bags of oats. Since he never wrote anything of the kind (see Gilson 1962, 680), this ass must have been either a classroom device to get laughs from the students, or a later invention.

Which is not yet *impetus*, and Ockham's concept is far from clear, but still a step in that direction.

Buridan starts from the same viewpoint as Ockham, but his objection against air as a motor are frankly modern: "It appears that the projectile cannot be moved by air after it has left the hand that threw it; air indeed must be divided by the projectile, and rather seems to oppose the motion." (Buridan, quoted by Duhem 1959, VIII, 201). Next, he proceeds to demolish the Peripatetic theory by well-chosen examples, within which no miraculous device is required; in the process, he makes liberal use of a word with a notable future of its own: *experimentum* (Pliny already wrote about *experimenta agere*; even so, the word had been very little used until Buridan).

> The first experiment is of the spinning top, or of the blacksmith's grinding wheel: this body rotates for a long time without exiting from the place it occupies, hence air does not have to fill any relinquished place… Second experiment: if one throws a spear in which the rear end is as sharply pointed as the front one… the air that follows it could not push strongly this point without getting divided. Third experiment: a ship rapidly towed against as stream does not stop instantly; it goes on for a long time after towing has stopped. Still, the boatman standing on desk does not feel air pushing him from behind, but indeed air resisting in front…

Here follows a detailed and quite correct discussion of the role of air in all three cases.

Here is Buridan's own theory:

> While the motor acts on the mobile, it provides it with a certain impetus, a kind of power capable of moving this mobile in the same direction, either up or down or to the side, or circularly. The greater the speed with which the motor sends the mobile, the greater will be the given impetus… but the resistance of air and also gravity tend to move the stone in the contrary direction, and impetus continually weakens; hence the motion slows down and the impetus is finally vanquished and destroyed in such a way that gravity prevails and moves the stone to its natural place. (Buridan, quoted by Duhem 1959, VIII, 207).

The ensuing discussion shows the language to be still largely Peripatetic; this *impetus*, does it have reality of its own? is it violent or natural? Still, we have been provided with a new physical quantity, intrinsic to the mobile body, and more-or-less proportional to volume, density and velocity: *impetus* is an ancestor of the Descartes *momentum*. However, the accelerated fall of graves is still far from being understood. For Buridan, *impetus* by itself explains acceleration:

> At the beginning of the fall gravity alone produces the motion, hence the fall is relatively slow; soon gravity impresses a certain impetus to the heavy body, and this impetus moves the body at the same time as gravity; motion then becomes faster, but the faster it becomes, the more intense grows the impetus; hence we see the motion accelerate continuously. (Buridan, quoted by Duhem 1959, VIII, 281).

Impetus was generally well received in Paris (but not in Oxford nor Padova) and found itself adopted by Oresme. In his discussion, the Bishop presented a remarkable new experiment, without knowing it had already been outlined by Plutarch:

> … I posit that the Earth is pierced clear through, and that we can see through a great hole farther and farther right up to the other end where the Antipodes would be if the whole of the Earth were inhabited; I say, first of all, that if we dropped a stone through this hole, it would fall and pass beyond the center of the Earth going straight on toward the other side

> for a certain limited distance, and that then it would turn back beyond the center, but not so far as before; it would come and go in this way several times with a reduction of its reflex motions until finally it would rest in the center of the Earth…We can understand this easily by taking note of something perceptible to the senses; if a heavy object is hung on a long string and pushed forward it begins to move backwards and then forwards making several swings until it finally rests absolutely perpendicular and as near the center as possible.[8]

The Plutarch experiment has been improved and the oscillations well described; while the damping is not specifically ascribed to air, there is little doubt that Oresme, who followed Buridan, understood the mechanism.

Very little seems needed before launching the Newton artificial satellite, but in fact three more centuries will still be required; and it was not Oresme but Buridan who applied *impetus* to the superlunary world. What were the prevalent ideas about the causes of celestial motions at the time? Tempier's *Articles* 92 and 102 had prohibited the use of "souls" or "intelligences" as causes of motions for celestial bodies. Such agents came straight out of Aristotle's *Physics* and *Metaphysics*: to each celestial sphere had been allocated a pure "intelligence", in fact a secondary god. No attempt will be made here to follow the endless variations on the theme by Greek, then Arab Neo-platonists, nor even later developments by Scholastics. By the thirteenth century, the system had been thoroughly Christianized by the unsubtle device of substituting angels. The whole living world contained a *plenum* of creatures, with Man representing an intermediate grade, and angels were admirably suited to the purpose of moving stars and planets around. The process is well illustrated by Aquinas, who gives his opinion within a discussion of astrology, in which he does not greatly depart from Augustine. For him, material events on Earth (but not human thoughts nor actions) are wholly programmed by celestial motions, which are in turn regulated by angels; still, in the last analysis, those agents are themselves submitted to God who may also intervene personally whenever He fancies. Aquinas presents a set of questions and answers:

> Does God move directly any body? The common order, instituted by God has this feature that God moves corporeal creatures by means of spiritual ones… However, the power of God is not chained to this order, and He might, whenever it would please Him, produce an effect without going through the order of secondary causes… (Aquinas cited by Duhem 1959, VIII, 357-8).

Even so, Tempier will be nonplussed: the glaring fact is that *Genesis* mentions no angels at all. Constraining God to use secondary agents, even picked from the crowd of His most faithful servants, was a restriction on His freedom. Hence the prohibition: "intelligences", even angelic ones, became unorthodox, and Aquinas earned one more rebuff.

However, Tempier had never provided an alternative solution of his own, and celestial bodies still went their rounds unmindful of the turmoil in the Sorbonne.

[8] *Livre du Ciel et du Monde*, II, 31, 573; Oresme provides a drawing of an oscillating pendulum in his Fig. 42. In 1368, Albert of Saxony, in his Quaestiones super de Caelo et Mundo, gives a description of a similar free-fall experiment. Thus, he seems to have preceded Oresme; unlike him, he makes use of the Buridan impetus. See Duhem (1959), IV, 94, and Duhem (1906), 95.

Explanations of some sort were badly needed; why not try purely mechanical ones? This is exactly what Buridan did, always with understandable caution: theologians had never shown any interest in projectiles, but stars or planets were far more dangerous to handle:

> One might say that God, when He created the World, gave whatever motion He pleased to each celestial orb; to each of them he gave an impetus that ever since has moved it; accordingly, God no longer has to move these orbs, except through His general influence, similar to the one He exerts on all happenings; in this very manner He has been able to rest on the seventh day from the work He had accomplished. These impeti that God has impressed on celestial bodies have been neither weakened nor destroyed in time, because there was, in these bodies, no inclination towards other motions, nor any resistance that might corrupt or repress these impeti. All of which I do not present as certain; I only ask the theologians to show me how all these things can take place. (Buridan, cited by Duhem 1959, VIII, 329)

Is it possible to show more clearly that *impetus* could be catholic even beyond the Moon? Two distinct anticipations are found here, in between references to Tempier's *Articles* 63, 92, 102, and a prudent tip of the lay hat to those who ultimately knew best in heavenly matters. The first is Galileo's circular inertia, and the second is the grand Newton mechanism, God-created, and God-impulsed, but presently smoothly running all of its own, according to strict mechanical laws (at least, as later perfected by Laplace and others). And such laws are for Buridan not merely amenable to Reason: they can be observed at work. Assuredly, he is still far from the coherent mechanism to be worked out by Galileo, Kepler and Newton: the fall of his graves is not mathematically described, nor its cause understood in terms of a continuously acting force. More immediately, circular inertia could not show great appeal as long as planets did not follow circles, but were merely moved by circular epicycles. Still, the way was open to a unified treatment of the visible World as a whole, hence to Internal Plurality.

Oresme was to endorse Buridan fully, and write:

> The situation is much like that of a man making a clock and letting it run and be moved by itself. In this manner did God allow the Heavens to be moved continually according to the proportions of the motive powers to the resistances, and according to the established order. (*Livre du Ciel et du Monde*, II, 2, 289).

Here was the theologian's approval that Buridan had been hoping for; and, ironically enough, expressed almost in the same terms Voltaire will make famous: *"L'univers m'embarrasse, et je ne puis songer / Que cette horloge existe, et n'ait point d'horloger."* (The Universe dumbfounds me, and I cannot believe / That this Clock exists, all without a clockmaker.)

As to poor Tempier, he had never dreamed of the disastrous reduction in God's role that was to result from his own *Articles*. By granting Him untrammelled play of unlimited will during Creation, he was ultimately to banish Him from current world affairs. Truly, he had opened Pandora's box, and that incautious exclusion of the Aquinas angels from the management of all things celestial was to be the key. The angels having flown away, nothing in the long run could keep the tools of Democritus from filling their vacant place.

The Substance of Heavens

With Buridan and Oresme, medieval thought has proceeded to the point where Plurality is ready to become fully accepted; but there has been no similar progress about celestial matter, still understood in Peripatetic terms with minor variations. Notions about the Moon remain confused in the extreme, and the simple Plutarchian pictures are still forgotten. At first, Peripatetism mostly prevailed, and the tirelessly repeated arguments make little sense today. Next, Ockham is the first to present a novel view; as usual, he destroys the Peripatetic logical constructions, first in the name of God's freedom, and second in that of greater simplicity:

> Does there exist in Heaven a matter of the same species as the matter down here?… Matter of Heaven can potentially take multiple forms, none of which could be produced by a natural agent, but merely by God… Let us suppose that God should introduce in Heaven the form of fire, which is possible because no contradiction is implied: if one were then to bring water in, and that water should be stronger than fire, then it would corrupt the form of fire and introduce the form of water within this matter that was primitively under the form of Heaven. (Ockham, quoted by Duhem 1959, VI, 612).

Thus, Divine Power has again been instrumental in the destruction of one of the most stultifying Peripatetic beliefs, which had established a difference in kind between the Earth and the rest of the Universe. Moreover, Ockham has a second line of attack, along which God provides no help. He is wielding his Razor:

> It appears to me that in Heaven and in the bodies on Earth there is a matter of the same species, because one must never (as often told before) admit plurality [of causes, explanations, hypotheses…] when it is not required. (Ockham, quoted by Duhem 1959, VI, 613).

Professional astronomers still tended to keep aloof from such discussions; for them, saving the phenomena still meant adopting Ptolemy's system, and not bothering about substance. New observations performed since Ptolemy's time (either in the East or the West) provided no help at all and even in the case of the Moon no progress was made. We know that Aristotle had treated the Moon as a borderline case, and Averroes went even further, arguing from a lost fragment of the Master:

> Aristotle says in his treatise on animals that the nature of the Moon has something in common with earthly nature, because it lacks light… the parts of the Moon which are diaphanous have a nature with something in common with the natures of air and water. (Averroes, quoted by Duhem 1959, IX, 410).

For Averroes, the Moon cannot be a mirror because, just like Plutarch, he understands specular reflection; Arabic optics had made such important advances with Alhazen that they could not be ignored:

> The Sun makes her luminous; then light issues from her just like it does from other stars, that is from each point of the Moon issues an infinite number of rays. If the Moon's illuminating power derived from reflection, it would illuminate on Earth only some well defined places that would depend on its actual position; reflection indeed takes place only under a well-defined angle. (Averroes, quoted by Duhem 1959, IX, 411).

Scholastics present endless variations on the theme, but make little progress. Albertus Magnus, like Averroes, believes stars to be illuminated by the Sun:

> This reception of light does not take place by reflection; rather, light becomes incorporated to stars… they are like spherical receptacles of light; as soon as they are touched by a sun ray, they are immediately filled with light throughout their body, except for the Moon, which is less noble.

Still, moon-spots have to be explained: "They come from the nature of the Moon, which is earthy." (Albertus Magnus, quoted by Duhem 1959, IX, 415). Which sounds startling from an orthodox Peripatetic; still, nowhere is found any discussion of a truly-earthy Moon in the Plutarchian sense of having mountains, valleys etc.…

The plain idea that the Moon could just be rough, hence scatter light, is always missed, even by Buridan and Oresme. Here is Buridan; some opponent had written that

> the Moon is like a wall; when sunrays fall on a wall, it is seen entirely illuminated and not merely along lines where incident and reflected rays make equal angles; such is the Moon's case." Answer: "We suppose the Moon to be perfectly smooth without any asperity; Aristotle indeed has believed all celestial bodies to be made in this way." (Buridan, quoted by Duhem 1959, IX, 420).

One could not present the facts better and miss the conclusion more completely; and the call to the authority of the Master is all the more surprising, coming from one who has done so much for his overthrow in the subject of motion. Oresme gets stuck at exactly the same point; he starts by demonstrating a precise knowledge of convex mirrors:

> Nor do we see sunlight on the Moon as in a mirror, for one should then not see the Moon as we do; rather, the sun would appear in only a small portion of that part of the Moon which seems lighted to us, and at times it would appear in no part at all. (*Livre du Ciel et du Monde*, II, 16, 457).

He next discusses correctly opaque and transparent bodies, scatterers and reflectors; but his only conclusion is that the Moon is not wholly transparent:

> The Moon is a perfectly polished spherical body… such as crystal or glass at least in those parts near its surface… sunlight penetrates the Moon to some degree, but it does not pierce nor pass completely through because of its the great size and depth …as we can see in very clear water, if the water is very deep, sunlight does nor reach the bottom. (*Livre du Ciel et du Monde*, II, 16, 459).

Starting like Plutarch from valid laboratory data, he has (unlike him) gone astray in his astrophysical analysis.

As for the spots,

> The parts of the Moon by their very nature cannot be all uniformly transparent and clear… just as in the case of an alabaster stone… the clearer some parts are, so that the sun's penetration is deeper, the darker those parts appear and the others proportionally lighter. (*Livre du Ciel et du Monde*, II, 16, 459).

This analogy, with a polished semitransparent body of terrestrial origin, is the best anybody seems to have reached at the time. Most puzzling is the Oresme refusal to drop the smoothness assumption, while he never mentions the one sole plausible argument in favour of lunar transparency: shadow light.

Oresme's gravity had been well suited for treating the Moon as another Earth and his optics more than adequate; but he never took the last step, for us so obvious. Here the matter rested for more than a century, as the University of Paris, largely ruined by the Hundred Years War, lost and never regained the place it had held before. Then, under another geographical climate and different intellectual context, Leonardo Vinci and a few of his contemporaries will revive the ideas of Plutarch.

Astrology and Plurality in Time

Never was the Great Year more hotly debated than during the Scholastic era; Augustine had not succeeded in killing that notion, which Tempier anathematizes anew together with its attendant fatalism, and at least part of the astrological implications. The space taken by these questions within the *Decrees* shows that they were frequent topics. Tempier mentioned the 36,000-year period as a matter of course, since it was the most popular one at the time. The exact figure may seem a secondary matter, compared to the question of whether a Great Year is a fact or not.

The central issue in the debates was Determinism, the extreme form of which had been described by Avicenna (Abu Ali Ibn Sina) who had studied Aristotle from Persia, more than a century before Averroes:

> Any will which is in ourselves has a cause; the causes of our wills cannot form an infinitely extending series; they originate in external ones, that is in terrestrial or celestial causes; but terrestrial causes originate in celestial ones; hence all these things come necessarily out of the Necessity that characterizes Divine Will. Chance comes merely from the concourse of all these causes; if you analyze all things, all things will most assuredly be referred to principles, the Necessity of which comes from God.

A profound difference with Aristotle becomes apparent: Necessity is no longer the universal tyrant hiding behind God's shoulder and manipulating him like a puppet, but it proceeds from God himself. Still, God cannot operate freely; He is bound by His own choices, made long ago, and Man is not free either. Avicenna spells out the consequences most clearly:

> If it was possible for a man to know all the events which [presently] take place in Heaven and on Earth and their nature, he would certainly know all future events with all their particulars. (Avicenna, quoted by Duhem 1959, VIII, 377).

Seven centuries later, Pierre-Simon de Laplace will make exactly the same point:

> Hence we must consider the present state of the Universe as the consequence of the previous one, and the cause of what will follow. An intelligence which at a given time would be aware of all the forces acting in Nature, and of the situation of all beings within… would encompass in the same formula all the motions of all the great bodies in the Universe down to the smallest atom; for this intelligence, nothing would be uncertain, and the future, like the past, would be present before its eyes. (Laplace 1825, 3-4).

However, for Avicenna and all its medieval readers, the link between celestial and terrestrial events is solely astrological; out of their concept of determinism, nothing but empty talk has ever resulted. As to Laplace, he prudently forgot about atoms and stuck to the superlunary region where he carried the art of prediction almost as far as could humanly be done; only chaos (present in the Solar system) and quantum mechanics were to show the limits of Laplacian determinism.

Avicenna is the author most frequently quoted by Aquinas, who of course does not follow his brand of absolute determinism; his compromise has to be described before the thirteenth century attitude toward Eternal return can be understood. We have already seen the Aquinas conception of celestial activity with angels as motors, and its categorical rejection by Tempier, despite the secondary role of angels and their total submission to God's will. The new point is that Aquinas held all terrestrial motions to be fully under control of the celestial ones, an opinion he expresses many times. In which he was a true Peripatetic, but nevertheless managed to feel in agreement with the Fathers at the same time:

> The providence of angels is universal, and extends to all corporeal creatures… this administration is performed through the agency of motions; angels move the superior [i.e. celestial] bodies, and their motions cause the motions of inferior bodies… According to the order of Nature, then, could a blacksmith move his hand without the ministration of angels who move celestial bodies? … if the motion of Heaven were to stop, there would exist neither blacksmiths nor hammers… (Aquinas, quoted by Duhem 1959, VIII, 357, 359).

While Aquinas himself does not seem to have explicitly discussed the embarrassing Eternal Return consequence, this quotation shows that it cannot have been far from his mind. However, "the Divine Power is not so completely bound to this [preestablished] order that it cannot, when He pleases, produce some action independent of the secondary causes." (Aquinas, quoted by Duhem 1959, VIII, 357). Moreover, only the body of Man is bound, not his mind nor intellect, which calls for some delicate casuistry:

> Celestial bodies are not the direct causes of our choices: they cannot directly act on our will; nevertheless they are able to influence indirectly our choices because of their actions on our bodies… For instance if celestial bodies induce in air an intense cold, we decide to warm ourselves close to the fire. (Aquinas, quoted by Duhem 1959, VIII, 363).

Why is it so, and how do human will and intelligence manage to escape that great Chain of Causes ultimately anchored to the stars? Aquinas has a purely teleological explanation:

> Man has the faculty of examining and deciding which action he may accomplish … such a faculty would be meaningless if our choice was caused by celestial bodies, which are outside the range of our power; hence it is impossible that such bodies should be the causes of our choice. (Aquinas, quoted by Duhem 1959, VIII, 362).

His main concern in this compromise with astrological determinism is transparent: no Christian appearing before his Judge must be able to plead compliance with orders from a higher authority; which would put the said Judge in a highly embarrassing position, since He cumulates judiciary with legislative and executive powers; not to speak of creative ones. And the embarrassment felt at this point among all human interpreters of the Divine Plan is merely one outcome of the thorniest problem of them all, far too vast to be discussed here: How may human logic accommodate human free will with the abilities of a God who knows everything worth knowing about the future, and through His prophets, is even markedly indiscreet about His knowledge?

The Aquinas view of astrology may now be understood. How much of the future is it possible, or allowed, to predict from celestial observations, and (by way of consequence) how is history able to escape strict periodic repetitions? For material events his endorsement of astrology is unequivocal: "There is no sin involved in using astrological opinions for predicting corporeal effects such as tempests or clear weather, good health or sickness of body, abundance or failure of crops." (Aquinas, quoted by Duhem 1959, VIII, 368). When the actions of men have to be accounted for, his attitude is more subtle: "The crowd follows its passions; wise men however, reject them… Consequently, it is more likely that the action will take place in the direction favored by the celestial body when a crowd is concerned; a given individual may through the use of his reason resist the inclination." And quoting Ptolemy, whom he fully approves: "The astrologer must not attempt to predict individual effects, but merely universal ones." (Aquinas, quoted by Duhem 1959, VIII, 365). Roger Bacon takes the same position. Needless to say, professional astrologers will pay little heed, personal predictions being just what the customer is paying for.

Any cyclic repetition of History could no longer take the strict form Origen and Augustine had warned against, but only the looser one of statistically-similar successive Worlds. Actually, the theme had never died out; ever since Julius Africanus, some form of more-or-less periodic chronology had remained popular (but never official) not only among Christians, but also with Jews. For instance, in the *Zohar* (main commentary of the Pentateuch) is found:

> The World will subsist for the 6000 years alluded to by the six first words of Genesis. At the beginning of the sixth millennium, the entire World will be annihilated in twelve hours. At the thirteenth hour, God will redeem us through His mercy, and make the World anew, setting it back to what it had been during the first six millennia. (The *Zohar,* quoted by Duhem 1959, V, 133).

Levi ben Gerson, Rabbi, astronomer, inventor of Jacob's staff, and disciple of Maimonides, who was to be abundantly read during the later Middle Ages, had taught that

> if some man who follows the Law wanted to believe that matter has existed eternally and that multiple worlds preceded our own, his faith will remain untarnished provided he does hold that this World is new, that it did originate at a definite time, and that this time marked the beginning of the human species with Adam and Eve. (Levi ben Gerson, quoted by Duhem 1959, V, 224).

Similar views were common enough among Christians to require the specific Tempier articles against the Great Year. However, later authors still loved playing with that dangerous but fascinating notion. A method for christianizing the Great Year was invented by a subtle use of Resurrection: might it be periodic, and submitted to natural laws? Richard of Middleton asks the question:

> At the time of Resurrection, will Nature be the efficient cause that will reconstruct human bodies? … When all parts of Heaven will return to the original places they occupied at the time of Creation, then all bodies submitted to generation and corruption will come back and be numerically identical to what they had been … And this disposition of Heaven will take place 36 000 years after the time of Creation. (Richard of Middleton, quoted by Duhem 1959, VII, 433).

The conclusion of Richard is easily predictable because it is post-Tempier: as far as human bodies are concerned, such beliefs are absurd, God will indeed reconstruct them, but at the instant when He pleases. He cannot in any way be tied down to celestial motions, "but for other beings this objection does not hold", and Richard produces a lengthy explanation, correctly Peripatetic, proving that all objects might be reconstructed in a natural way. Ockham goes distinctly farther, and admits that exact repetition in Time is possible, and that "… in such a way, resurrection would be a natural phenomenon." (Ockham, quoted by Duhem 1959, VII, 450). Hence, he seems to favor strict Eternal return; the steady champion of Divine Freedom must have convinced himself that denying God that possibility was an even worse sin than tying him down to some rigid schedule. As tool for unraveling Nature, the Will of the Christian Creator was proving even more difficult to wield than the Good of the Platonic Grand Artificer.

Such were the attitudes, or at least a sample of them, about the philosophical and theological problem. But some scholars began at long last to perceive that there had been a technical hitch all along: even granting the Aristotelian principle of inescapable correlation between heavenly and earthly events, was it true that the sky-vault configuration was subject to strict repetition? Were all celestial motions commensurable indeed? If the answer was No, the whole Eternal Return myth might most simply exploded, since the Great Year itself could not even be defined.

The modern view is that commensurability between two motions may be proved only by observations both lengthy and accurate, followed by the discovery of some connecting physical mechanism. A clear example was to be provided much later by the first three Galilean satellites of Jupiter, the orbital periods of which were found to be as 1, 2 and 4; these exact ratios have now held good during four centuries, and the explanation from mutual Newtonian attractions is complete. In the late Middle Ages, such precise observations were not available, hence authors merely followed their philosophical bent.

Nicolas Oresme was to prove an adamant foe of astrology; against it he wrote no less than three highly sensible treatises, particularly for the edification of Charles V, but the King (wise as he was nicknamed) must have been unimpressed since his Court swarmed with astrologers. Neither were his successors and the vogue of astrology with Kings and Emperors alike reached an all-time high in the sixteenth century. In his search for weapons, Oresme was led to write a fourth treatise on *Proportionality of Celestial Motions*; he could not demonstrate incommensurability, but he merely asserted that it was the simplest hypothesis, the preferred one in the Ockham sense, and deduced the consequences, which proved deadly for astrology:

> Given a large number of quantities the ratios of which are unknown; it is possible that one of these should be incommensurable with some other, and that is likely." Moreover, "true Astrology is hidden from all except Him who enumerates the multitude of the stars, and governs the World through His divine reason. (Oresme, quoted by Duhem 1959, VIII, 450).

Conclusion: Divine Reason has simply never entailed exact ratios, and God has not given Man any handle to the future. Neither Augustine nor Tempier had ever dared to outlaw astrology: both rejected the Great Year, but merely because it contradicted Revelation, not Reason. Here Oresme concludes that a rational World, while still the end product of intelligent design, may escape the tyranny of Pythagorean exact numbers.

Of all thinkers so far sampled, Oresme has best approximated the modern concepts of vacuum, infinite space and Spatial Plurality; and he is also the one who provided the first rational rejection of Time Plurality. This is no coincidence. Time Plurality has made here its last appearance on stage. The fascinating Eternal Return theme had been a totally *a priori* construct of the human mind, and not a single observational fact giving it some solidity was to be uncovered later. When these Other Worlds so much ink had been wasted about began to be located in Space, around the familiar stars studding our sky vault, then the fascination about inaccessible ones far away in past or future was bound to vane. Should we conclude that nothing is left of this vast concept today? Of the Pythagorean rigidly cyclical repetition, nothing indeed. But a time barrier between separate Worlds is still with us, and it may well prove impossible to surmount. The discovery of the finite speed of light has locked time and space together. Unlike Oresme, we believe today that many actual Worlds can be simultaneously present; still, if randomly scattered civilizations exist throughout the Galaxy, randomly igniting and then dying out after a finite lifetime, then perhaps none or only a few are simultaneous with our own as far as communicating is concerned. Our radio signals stand a greater chance of reaching undeveloped or worn-out planets and humanity may have vanished altogether long before an alien signal reaches its solar system. In this sense, and in this sense only, modern Plurality may still be thought of as involving Time.

Conclusion: The Great Theological Thought Experiment

How much had scholastic thought truly achieved? Was the controversy centered in Paris and Oxford a Byzantine debate? Or should one endorse Duhem's conclusion: modern science, born in the Renaissance, had been conceived in 1277?

At the close of the Middle Ages, four subjects have entered permitted ground, largely as a consequence of the Tempier *Decrees*: vacuum, infinite space, unified terrestrial-celestial mechanics, and Plurality. None was fully new; for the Ionians, Atomists and Epicureans, all four had been primary concepts, in little need of further demonstrations. Their logical interconnections were compelling: Vacuum enabled the motion of atoms or Worlds alike to take place; both Vacuum and atoms were everywhere identical to themselves, and they allowed for no singularity at any place. Infinite space and time were required to accommodate their random motions; lastly, both had to be filled by randomly scattered Worlds, mostly for reasons we would today classify as aesthetic, which does not mean we are free of them. Hence, Ionian Plurality, if not demonstrated, had been a fully coherent logical choice. By contrast, Pythagoreans and their followers had singled out circularity and circular motion for praise, or even adoration. From this initial choice, a closed Space, a cyclical Time and a unique World had been logical consequences.

The theological climate of the late Middle Ages was so different that none of the ancient inputs could be reused. Nevertheless, all four concepts were recovered as outputs of elaborate disputations in which a single novelty was injected: the unrestrained Will and infinite Power of God. All the artisans who wielded that tool would have emphatically rejected any connection with Greek materialism, and most of them were not even aware of any similarity between their conclusions and those of Epicurus & C°. As medieval thinkers, they had been primarily concerned with the laws governing human actions and morals, not with Nature *per se*; but the imperative need to free Man from the Peripatetic determinism soon entailed an even greater one to free the Creator from similar shackles. And in the process, the weaknesses of the key Aristotelian demonstrations were bound to become exposed.

The demolition of the Peripatetic edifice did not progress equally far in all four cases. Vacuum and infinite space proceeded from virtual to actual with Holcot ("Hence, presently, vacuum exists") and Oresme ("Outside Heavens is an empty incorporeal space"). Universal unified mechanics, fully materialistic in operation, are a borderline case, proposed as merely hypothetical by Buridan, the cautious layman, but endorsed as actual by Bishop Oresme ("God has left Heavens run continuously according to the given proportion"). However, Plurality itself remained virtual (Oresme: "Nevertheless, in actual fact, there has never been and never will be more than one corporeal World"). All Scholastics finally agreed, except hard-boiled Averroists, who at the bottom of their hearts did not concede even to God himself the ability to build outside the Plato-Aristotle sphere, and merely bowed to ecclesiastical authorities. Altogether, the brand of Plurality adopted by the waning Middle Ages remained comfortable and safe: virtual, since God was no more compelled than forbidden to implement the scheme; external, thus unobservable even in the future. These other Worlds were not permitted to collide with our own; eternity of our sky vault was still fully insured. The decoupling between sub- and super-lunary events remained absolute, apart from astrological influences. New stars, dark spots on the Sun, mountains on the Moon were undreamed of or voluntarily ignored; still, other Worlds henceforward became devices one could think about without either impiety or absurdity. From heretical and antinomic, Plurality had become both orthodox and logical, deduced but not observed, compelled by the Church but not compelling by itself; in short, virtual, not actual.

The concept of a *Gedankenexperiment* (or thought experiment) is familiar enough today, and its use is frequent in all branches of physics. This procedure ignores technical limitations in order to concentrate on fundamental issues: we postulate a perfect vacuum, an ideally-polished mirror or frictionless motion, and from then on we develop conclusions which will be taken as valid if no internal contradiction develops. Here, we may consider the Power of God intervention as a cosmic thought experiment within which Theology took the place Physics holds today, while Physics (or rather Natural Philosophy, to avoid blatant anachronisms) held that of Technology. At the beginning of the controversy, no Scholastic believed that Nature could accommodate Vacuum, Infinity nor Plurality. The technical difficulties involved in pumping out air, or getting away from the spheres of Air and Fire, or in observing fainter stars, did not matter in the least; for thirteenth-century minds, basic impossibilities were involved in all three cases. These we perceive today as naively anthropocentric; still they appeared at the time just as solid as our hallowed thermodynamic principles do today, or our equally revered fetish, the speed of light as a universal velocity limit. Probably even more so, as Schoolmen had not witnessed the chastening spectacle of sundry physical theories hastily erected upon the ruins of older sisters, and soon crumbling to pieces in their turn… After the reintroduction of Peripatetism, scientific thought had been truly moving, yet the rate of wear for new concepts did not approach the tempo we have since got used to.

Fortunately, Schoolmen felt compelled to introduce one new dogma: Plenitude, and to explore all consequences, disregarding everything they believed firmly demonstrated about Nature, even human reason itself in the extreme case of the Ockhamists. Their only limitation was to operate within correct theology; in the same way, today we are willing to disregard any practical constraints, provided the assumptions remain physically allowed. Within that great debate, the mechanism of a thought experiment is present; but all of Natural Philosophy, not mere technology, was disregarded. However, in the absence of actual experimentation, this new device pointed the way to modern science. Vacuum was conceived, not engineered; before that future step, Torricelli's tube would be needed. Neither could Space be opened and filled with actual Worlds before another tool, the *optick tube,* came into play. However, the minds of men had been opened, and the next two chapters will show Plurality progressing from virtual to actual, still without any experimental input.

While Tempier's *Decrees* did open up Space in order to accommodate those *plures mundos*, they did nothing of the kind for Time, which remained strictly biblical, hence bounded. This contrast between the two diametrically opposite attitudes taken by Tempier's Committee is worth pondering about. At first glance, Revelation seems equally unambiguous in both cases: Genesis gives no hint that other Worlds might have been created by God either (1) beyond these "lights in the firmament", or (2) before the "evening and the morning [that] were the first day." In Tempier's time, none of the feeble hints that early Christians had managed to find in Scripture were any longer taken seriously; e.g. the *"Laudate eum caeli caelorum"*, or *the* "thing that has been, it is what it shall be…" Hence, the only strictly Christian attitude could be that of Johannes Chrysostomos: "How can some pretend that the Heavens have been created in multiple form? This is not from the Holy Writ that they have taken the idea; they drew it out of their own arguments." But on the other hand, a strictly logical attitude would have started from the Augustinian time-space symmetry: "Just as we are asked why [the World] has been made at such an instant and not before, we are free to ask why it has been made where it is and not elsewhere." From this beginning, two self-consistent options remained open: one might either fill both Time and Space with many Worlds or reject both altogether. Strangely, Tempier came out with the bastard compromise of endorsing Space Plurality while prohibiting its Time twin. Why? Neither himself nor anybody else at the time expatiated on this arbitrary choice; let us attempt to reconstruct the hidden motivations.

First, there is indeed an asymmetry in the treatment of Space and Time in Genesis. The very first line comes as a hammer blow: "In the Beginning, God created the Heaven and the Earth". That opening is final: the wording leaves no possibility of escape to God. Had He committed the unforgivable treachery of creating other Worlds before that Beginning without telling poor mortals, none of his subsequent accounts might have been relied upon. Hence, the Tempier's anathema against the Great Year truly comes straight out of Revelation. On the other hand, the limits set to Space had been, to say the least, rather fuzzy. The starless firmament, the Waters Above (and below), and then the lights in the firmament appear on their appointed days; next, as the fifth one dawns, attention turns to earthly matters with fowls and whales in urgent need of creation. One gathers the impression of a somewhat unfinished account as far as the Heavens went; such places remained open, at least to interpretation. No definite or definitive boundaries had been set; we might conceivably forgive God if He had not detailed every single feature in or beyond that firmament. Such indeed will be the argumentation of that most devout Catholic, Galileo Galilei, which his own Church will finally endorse after two centuries of pondering; and such must have been Tempier's understanding of Revelation.

Still, why not play it safe by following Johannes Chrysostomos? When he endorsed those *plures mundos*, Tempier was indeed "drawing them out of his own arguments, and not out of the Holy Writ." Worse, he was unaware that such arguments were pagan in origin. That infinite Power of God is nowhere explicit in the Bible: it is a Greek invention. Sure enough, Scripture describes God as a person who acts essentially as He pleases, unfettered by technical difficulties; still, the notions of infinite will and power, or infinite anything, have no meaning without some arithmetical or geometrical background Moses had not been provided with. Tempier shatters the eighth (or ninth) Aristotelian sphere as a limit God himself could not have passed; but the very concept of limits (or lack of) for Earth and Heavens is not a Christian contribution at all, but a Greek one. The key argument, Plenitude, had not been merely lifted out of Scripture: it had incorporated many Platonic components, which were no longer remembered as such at the time.

Such are some of the reasons why Tempier favored Space Plurality over a literal reading of Genesis. And that is also why this Scholastic controversy is, hopefully, still of interest to the modern scientist: it is neither Byzantine nor merely theological. The arguments are no longer those we call in when dealing with such matters: we have progressed to the stage where scattered stars and planetary systems randomly forming and dissolving are tentatively explained without recourse to intelligent design. Still, we have to grant that Divine Power was the tool that turned the minds of our ancestors in the direction we are still following.

As understood today, are these other Worlds real? Worlds in the sense of celestial bodies analogous to our own planet, with full complement of living and intelligent creatures aboard? We do not know, and perhaps we will never know. That intelligent message may never come; the author's view is frankly pessimistic. Worse for the logical mind, in the absence of new facts, a conclusive argument proving actual Plurality may never be fabricated. Does it follow that discussing the whole problem is a waste of paper, and that it should remain a scientific no man's land? No; irrespective of anything the future may bring, the mere concept of Plurality has already done much for science. Whenever we manipulate our everyday tools, vacuum, unbounded space, universal laws of motion, we must acknowledge that they were partly forged out of the materials gathered by the advocates of Plurality during that unjustly forgotten case: Divine Power and Will against human reason.

Chapter 6
Nicolaus CUSANUS: The Homogeneous Cosmos

Anywhere a man is, he will believe himself in the center.
Nicolaus Cusanus, *De Docta Ignorantia* (1440)[1]


(left) Nicolaus Cusanus, painting by the Master of the Life of the Virgin, ca 1480. St.-Nikolaus-Hospital, Bernkastel-Kues, Germany. Wikimedia Commons
(right) Cusanus' arms on his grave in San Pietro in Vincoli, Rome. His true name was Nicklaus Krebs (crayfish in German). Wikimedia Commons

[1] Nicolaus Cusanus (1440) *De Docta Ignorantia*. The Fr. Germain Heron English translation will be normally used (and referred to as *De Docta Ignorantia)*; however, the Cusanus thought is particularly difficult to pin down, and interpretations differ markedly; thus, in the case of the above quotation and some others, I have preferred (mostly for clarity and/or compactness) to modify the wording in the G. Heron translation with help from the French translation of L. Moulinier, or from the large fragments given in the chapter *Nicolas de Cues* of Pierre Duhem's (1959) *Système du Monde*, X, 247–347; or from those given by Alexandre Koyré (1957) *From the Closed World to the Infinite Universe.* Both Duhem and Koyré have been taken as main guides to the Cusanus philosophy and cosmology; the *Introduction* to the Heron translation by J.B. Hawkins has also been helpful.

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In the preceding chapter, unlimited Divine Power has generated and enforced Virtual Plurality. Without some human help, it could go no further; no Schoolman ever dreamed of ordering God to fabricate these other Worlds in actuality, because of the glaring lack of Scriptural hints. A new input was required: one had to prove that several Worlds were somehow better suited to the Divine Nature, and to remain an orthodox believer at the same time. Such was to be the contribution of Nicklaus Krebs, a priest of humble origins, born together with the fifteenth century in the German village of Küs near Trier; according to the prevalent custom, he latinized his name to Nicolaus Cusanus. He rose rapidly in the Church hierarchy, becoming a Bishop and a Cardinal at a time when German Cardinals were said to be as rare as white crows. He was also a Papal legate entrusted with such important missions that under Pius II he was sometimes dubbed the Vice-Pope.

With Cusanus the first breeze of humanism is felt blowing, and the debate moves away from Oxford and Paris to Germany and Italy. Under his Cardinal robe several quite different persons may be discerned. He was first a high official, devoted to fighting corruption and promoting the badly needed reform within the Church; second, a humanist who knew Greek and Hebrew, and discovered many ancient manuscripts, including some of importance, e.g. the *Commentary on Scipio's Dream* by Macrobius, and several Plautus comedies. He was also a scientist with wide ranging interests, for instance producing in 1451 the oldest map of Germany still extant, and organizing colloquia on cosmography within his Roman home. His *De Staticis Experimentis* proposes the systematic use of scales for chemistry and shows a clear understanding of mass conservation. Cusanus founded a library, and helped to propagate in Italy what he called the "divine art of printing." Lastly, he also did some work as astronomer and mathematician.

However, it is as a theologian and metaphysician that Cusanus was most esteemed in his own time, and he is still considered as one of the foremost fifteenth-century philosophers. Today, his scientific contribution would be forgotten if within his main work, the *De Docta Ignorantia*, he had not hidden a few pages describing his cosmology. Despite the revolutionary nature of the proposed system, these went unnoticed at the time. While his philosophical opinions were abundantly discussed without ever making him suspect of heterodoxy, the Cusanus cosmology produced no impression at all. The easy but empty explanation is that it came at the wrong time: the book appeared in 1440, i.e. a century and a half after the Tempier decrees, when the excitement generated by the Plurality issue had long died down, and a century before the Copernicus *De Revolutionibus*. Apparently, Giordano Bruno was to be the first writer who referred to Cusanus on cosmological matters.

The fact that Cusanus presented his system of the World within a text devoted to non-scientific matters is not accidental. Cusanus the cosmologist had nothing to do with the man who discussed the use of scales for chemical operations, and rather little with Cusanus the astronomer. His only recorded contribution to practical astronomy is a proposal for calendar reform: *De Reparatio Calendarii*, presented at the Council of Basle in 1436, where he played an important role in the controversies about the supremacy of the Pope versus Council. His own proposal, the suppression of one leap year for every 304 years, is somewhat less accurate than the one already formulated by Parisian astronomers: suppression of 3 leap years out of 400 years. The latter calendar was to be ultimately adopted by Pope Gregorius XIII, after the Church had pondered on the matter for a century-and-a-half after Basle; the Church Fathers had more pressing matters on their minds.

Indeed, Cusanus was little interested in finding the most exact solution (an unfortunate attitude for a calendar reformer), because he had been convinced *a priori* that no exact solution existed. This viewpoint was to play an important role in his thought; exact numbers, strict equalities, rigorously definable motions had no place anywhere within his Universe:

> The length of the year is in doubt; hence, some astronomers have been led to declare that any celestial motion is incommensurable with human reason, that it depends on an irrational ratio, a deaf root that cannot be named; given any human measurement that approximates some motion, one may invariably give another more exact one. They say that celestial motions may be understood by the human mind in the same way as the squaring of the circle… (Cusanus, *De Reparatio Calendarii,* quoted by Duhem 1959, X, 311).

For Cusanus, celestial motions are incommensurable not merely between themselves, but also with human understanding: they are not to be apprehended exactly because of fundamental causes, not mere technical matters. More accurate observations are not required, because they are not even possible. Hence, the Cusanian starting point was utterly different from the Copernican one: Copernicus will pursue throughout his life an attempt to improve on Ptolemy, while Cusanus could not have cared less. From his limited knowledge of technical astronomy he merely drew a deep distrust of too-accurate models. The consequence was important: since no motion was susceptible of exact description, strict immobility (of any celestial body or even of any reference point) was out of question, and the Earth was treated as a mere special case.

The same situation arises for Cusanus the mathematician. His contributions seem unremarkable, or even, better forgotten about: he published a *De quadratura circuli*, believing to have solved the old problem. However, he did not make any use of his mathematical knowledge when building up a model of the universe. We may as well face the dreadful truth: the Cusanian universe, distinctly closer to our own than any model constructed after the time of the Atomists, is wholly grounded in metaphysics; thus, the poor scientist who tries to follow his thought feels in deep waters. Here, more than ever, our bull has to be most careful of his tread on all that china. The unlimited Will and Power of a Divine Creator and Ruler had been plain concepts, easily grasped by non-metaphysicians, but a distinct exertion will be required to follow the reasons why Cusanus was led to propose his innovations: an infinite space, an universe without center and a Plurality of inhabited Worlds. The language, and the thought behind it, is rather trying, but the effort is worthwhile. Within that indigestible brew, a pure gem will be uncovered, one that has never shown a flaw so far, surviving unscathed all three great scientific revolutions of Gravitation, Evolution and Relativity: our so-called Cosmological principle. Cusanus was the first to write openly that the human vantage point is unremarkable, because the Universe looks the same wherever you stand.

Here are some guidelines to Cusanian metaphysics, taken solely from *De Docta Ignorantia*, as there is no shred of cosmology in any of his other works. The contents are summarized in the concluding page:

> Every endeavor of our human intelligence should be bent to the achieving of that simplicity where contradictories are reconciled; and this is the scope of the First Book. The Second Book … makes a few deductions on the Universe which many will find unusual. And now, at last, I have finished the Third Book on the ever-blessed Jesus." (*De Docta Ignorantia,* 173).

The account of Book I sounds rather inauspicious, but it contains most of the Cusanus principles and methods. Book II (or rather the small part devoted to the physical world) actually gives the cosmology, and is somewhat more readable; Book III may be skipped, except for some brief quotations.

First, what does the strange title mean? Merely: I know nothing, but at least I know that I know nothing. He who practices *Docta Ignorantia* admits that he can in no way reach the Absolute, and is satisfied with establishing relations: "every enquiry is, therefore, comparative, and uses the method of analogy… for this reason the infinite as infinite is unknown since it is away and above all comparison." Both pagan and Christian authorities are brought in for help: "Socrates thought that he knew nothing save his own ignorance, whilst Solomon the Wise affirmed that in all things there are difficulties which beggar explanations in words." (*De Docta Ignorantia,* 7–8). More surprisingly, in the concluding chapter, the author even concedes that "believers in Christ are led in learned ignorance to the mountain that is Christ… when we endeavour to gaze upon Him with the eye of the mind, we fall into darkness." (*De Docta Ignorantia,* 161). As to God himself, we are able to say of Him "neither that He is nor that He is not, nor that He is and is not…" (*neque sit, neque non sit, neque sit et non sit…*, Cusanus, *Excitationum*, quoted by Duhem 1959, X, 266). The Cusanus approach to understanding the Universe will be much the same, through diffuse and obscure language; still, by this path, he was led to ask truly new questions and anticipate our modern answers. His *Learned Ignorance* already contains a hint of the Cartesian Doubt; Descartes will peruse Cusanus, and sometimes refer to him.

The base of the Cusanian argumentation is metaphysical, but never narrowly theological, even if much of the book is devoted to questions of purely Christian doctrine: the third Book is centered on the figure of Christ, with the Trinity mystery re-surfacing every few pages. However, there are rather few Scriptural quotations, and not a single one within the short cosmological section. Cusanus seems unaware that his God had long ago provided an explicit blueprint for the Universe. He never hints that difficulties might arise when comparing his own picture with that of *Genesis*, nor shows any kind of caution. There is not *in fine* any retractation like the one Oresme added after exposing his hypothesis of the rotation of the Earth, or like the tongue-in-cheek Galileo addendum at the close of his *Dialogues*. To the modern reader, Cusanus appears unconscious of treading on perilous ground, and the reason is simple enough: in those blessed times, he was not. In between the Tempier decrees and the Reform-Counter Reform movements of return to Scripture, there was nothing very dangerous in asserting an acentric Universe or a Plurality of Worlds. Moreover, all his contemporaries missed the revolutionary character of his well-concealed cosmology; had he devoted a full book or *Dialogue* (like Bruno or

Galileo) to publicizing his astronomical views, at least an open discussion would have taken place; but he never did. Even so, his disregard of *Genesis* is striking; when delineating these other Worlds more precisely than any predecessor, he did "draw them out of his own arguments."

If the Cusanus Universe does not rest on Scripture, it is not based on blind materialism either. On this point, he is quite explicit, as such childish fancies have been refuted long ago:

> Was it not solely by the mathematical demonstrations of the Pythagoreans and the Peripatetics that the Epicurean's teaching about the atoms in the void was refuted, a teaching that at once involved the denial of God's existence and the collapse of all truth? (*De Docta Ignorantia,* 26).

Within a rather abstruse discussion entitled *On Possibility or Matter of the Universe* one reads.

> … if the possibility of things were not limited, there could be no rational explanation of anything, but all would be due to chance, as Epicurus wrongly maintained… that was the reason why this World was brought into actual existence… the same can be said of the Earth, the Sun and the rest." (*De Docta Ignorantia,* 95–6).

Chronologically, it is possible that Cusanus should have read Lucretius: the *De Natura Rerum* had been re-discovered about twenty years earlier, and we know his acute interest in ancient manuscripts. However there is no indication that he ever did so, which matters little, as he could hardly have treated Lucretius any better than Epicurus. A greater puzzle is that, while Cusanus abominates the Epicureans' creed of godless Chance, he remains unaware of the similarity between their World system and his own. Both are non-mathematical and non-geometrical, neither has any use for orbits, distances, and periods; and both endorse infinite space and a Plurality of Worlds.

The Cusanian cosmic machine does not anticipate our modern model in one central respect: it is intelligently designed and, like the Platonic one, it is essentially Good. Cusanus introduces a system of explanations with a considerable (and scientifically disastrous) future of its own; within the very first sentence of Book I, he presents his own concept of universal teleology within Divine Plenitude: "God has implanted in all things a natural desire to exist in the fullest measure of existence compatible with their particular nature." (*De Docta Ignorantia,* 36). Often he will resort to the Best as sole explanation; in the chapter devoted to "The Spirit of the Universe" is found a lengthy and abstruse discussion, from which a few quotations will give a fair sample of the standard Cusanian prose (readers have to take the plunge sooner or later):

> This is the finite spirit that is diffused throughout the entire Universe and to which is given the name Nature. Nature therefore embraces all things which owe their origin to movement…. This movement or spirit descends from the Spirit of God who put all things in movement by movement itself… This created spirit is the spirit without which there is no unity, without which nothing can subsist. It fills the whole Earth … this is the movement of a love that links all in one with the result that that all things form one Universe. All things are moved individually to be precisely what they are; and they would not be another thing equally as well, for they are what they are in the best possible way. (*De Docta Ignorantia,* 105–6).

Even with help from some true metaphysician, no scientist will find the Cusanian thought easy to pin down. Peripatetics prove far more readable, but their impeccable logic had got them permanently stuck within the ninth sphere; now is the time to break out, and Cusanus is the one who shows the way. Within a few more lines, this muddled and mystical treatment of motion will lead to a crystal-clear result: attributing absolute rest to the Earth is plain nonsense. However, it is too early to follow the Cardinal that far; more of his method has to be explained first, and the rest of the quotation will be given with his System of the World. The point made at the present stage is that outspoken reference to the Best, from the very pen that will soon propose Actual Plurality. Both notions were fated to thrive together and achieve immense popularity, peaking in the eighteenth century: for those distant followers of Cusanus, the Best of all possible designs had to be filled with alien Worlds as an obligatory consequence.

Some of the most specific Cusanian devices will now be described. Reason is nearly useless, Intellect somewhat better, but it is Intuition that gives the key to Nature; one discerns in his thought Neo-Platonist, Ockhamist and mystic strains. By contrast, Logic (Peripatetic or not) fares badly, and a constantly recurring theme of *Docta Ignorantia* is the meeting of contraries. This contrasting is not original by itself, but derives from an old Greek tool, first proposed by Heraclitus and much used by Neo-Platonists. It had been anathema to Pythagoreans and Peripatetics for whom the classical oppositions one-multiple, limited-unlimited, odd-even, hot-cold etc.… had precise meanings.[2] Cusanus carries the meeting of contraries to the dignity of a system. His starting point is the infinite Power of God; what is or appears contradictory to human reason is just not so to Him; here, Cusanus lies fully in the line of thought starting at the Tempier *Decrees* and developed by Ockhamists:

> God encompasses all things, even contradictories… Whether we have done this or its opposite or nothing at all, all was implicitly contained in God's Providence… Human nature encompasses that variable content just as infinite unity contains every number. So is it with God's infinite Providence: it embraces what shall happen and what, though possible, shall not happen… God's knowledge of things is not subject to the sequence of time, for He does not know the future as future nor the past as past, but He knows all things are subject to change in His unchangeable eternity. (*De Docta Ignorantia,* 49–50).

The Cusanian thought sometimes drifts alarmingly close to that of another Cardinal for whom past and future had coincided. Cusanus shared at least Pierre Damien's starting point, when he wrote of his own God that "In Him, the past is nothing but the future, and the future nothing but the present." (*De Docta Ignorantia,* 47). Nevertheless, Cusanus has managed to convey that (1) what we take as unique may be multiple to God, and vice-versa; (2) such Plurality applies to His actual Creation. Moreover, he will not stay half-hidden behind those lofty metaphysical clouds, but he will soon come down and consider the physical world. We may not

[2] Cusanus himself writes that "the Aristotle sect holds as heresy the meeting of contraries; but admitting their concurrence is the beginning of our ascension towards Mystic theology." (*Apologia Doctae Ignorantiae*, quoted by Duhem 1959, X, 261)

be pleased with, or convinced by, the Cusanian argumentation; but we have to grant that it exploded the old Platonic dogma, which insured that:

> The God wishing to make this World most nearly like that intelligible thing which is best and in every way complete, fashioned it as a single living creature… For that reason, its Maker did not make two Worlds nor yet an indefinite number; but this Heaven has come to be, is, and thereafter shall be one and unique.

All of which had been stated with refreshing Platonic clarity, but was hopelessly naive just the same: the Universe nicely coincided with that particular Heavens seen by our naked eyes, and all Platonists and Peripatetics had just followed suit. By distrusting both human senses and human reason, Cusanus had broken a two-millennium deadlock. No Platonic reasoning could stand in his way: God could be One, and still have created a Plurality of Worlds; these were One as seen from His viewpoint, and Many from our own. We are free to suppose that his attitude about Scriptural counter-arguments may have been in keeping; if some unrecorded opponent, Bible in hand, ever objected to his Plurality, Cusanus the anti-logician must have answered that such a contradiction was a mere artefact of human logic. God might well have said that He had created the Heaven<u>s</u> and the Earth<u>s</u>, while the singular written up in *Genesis* was just what poor humans were reading.

After the meeting of contraries, a second set of Cusanus tools derives from a concept we may call Universal Inaccuracy, or perhaps Universal Indetermination; Duhem proposes "Astronomical Scepticism", which is not self-explanatory. This theme has already been met with the calendar, and will be much used and abused in Cusanus' cosmology; it will frequently recur under his pen, and is most clearly expressed in the *Preliminary Corollaries for establishing Infinite Universal Unity*:

> It is impossible to find two things that are perfectly equal in weight, or length, or thickness; and it is likewise impossible for the various notes of flutes, bells and of the human voices to be perfectly in concord…. The most perfect, faultless harmony exists not in things sensible but only as an ideal perceived by the mind. (*De Docta Ignorantia,* 68).

Cusanus is outspokenly anti-Pythagorean; how much of an anticipation do we find in these lines? Today, we agree that simple mathematical formulas never describe actual events. Planets do not follow strictly Keplerian orbits: their true motions are highly complex, since many perturbations have to be taken into account. Even so, the simple Kepler laws have proved an invaluable intermediate step in the unraveling of the true phenomena. The Cusanus view is quite different: for him, any attempt at finding harmonious proportions in the material world is a waste of time. Since they have no reality in Nature (here he is a full Ockhamist), why look for them?

Nevertheless, he makes frequent references to Pythagoras, to the essential role of numbers, and one of his chapters is headed *Mathematics are a very great help in the understanding of different divine truths*. Sometimes, his inspiration is clearly Platonic:

> All our greatest philosophers and theologians unanimously assert that the visible Universe is a faithful reflection of the invisible… Was not the key to all truth to be found in numbers, according to Pythagoras, first to be called a philosopher? The Platonists and the chief of our own philosophers, like Augustine and later Boethius, have not hesitated to assert that number was the essential exemplar in the mind of the Creator of all things to be created. (*De Docta Ignorantia,* 26).

However, for him, numbers were needed merely in the ideal Platonic world, while the actual one was ruled by Universal Indetermination; and this is why his mathematical knowledge never produced any tangible result. His professed love of numbers led merely to a Pythagorean-type enthusiasm about Number Ten and to mystical ramblings:

> Absolute unity [i.e., that of God] is the first unity, and unity of the Universe (a unity in plurality) is the second…The second unity is tenfold, for it comprises the ten predicaments… Since there is no number above it, ten is a number that embraces all things … The unity of the Universe is the root of all, as ten is the square root of a hundred and the cube root of a thousand… (*De Docta Ignorantia,* 125).

He also attributes to Pythagoras a great love of Number Three, from which he will often expatiate on Trinity. He even presents a geometrical demonstration that quaternity is not possible in divine things:

> Anything beyond a trinity in the Maximum, e.g. four, five or more, would be in contradiction with its simplicity or perfection. The simplest figure to which any polygon can be reduced is a triangle…. What unity is in numbers, the triangle is in polygons [and so on for two pages]… Thus we call the Maximum a trinity, though it is infinitely above every trinity… (*De Docta Ignorantia,* 44–46).

Cusanus is able to start from Pythagorean and Neo-Platonic premises, and still to build an un-mathematical model of the Universe. He is willing to use numbers, but solely for the numeration of discrete elements; neither epicycles nor periods nor distances hold any meaning for him. In this respect he anticipates another and far more accomplished mathematician: René Descartes. Fully convinced as he was that the secrets of Nature were written in mathematical terms, Descartes never took notice of the Galilean formulation of free fall, nor of the Keplerian planetary laws, and produced a strictly qualitative system of the World. In the same vein, for Cartesians just as for Cusanus, the Universe was to be filled to the brim (except that it had no brim) with Worlds for strictly *a priori* reasons, today held as either metaphysical or esthetical, and not one shred of mathematical argumentation was needed.

The analogy may be pursued. In both systems, God alone is granted the use of Infinite as an epithet; the Universe is downgraded to more modest qualifications like indefinite or unlimited, the precaution being required to preserve a suitable hierarchy between Creator and created. Descartes will be outspoken on the subject:

> …and we shall call these things indefinite rather than infinite, in order to reserve to God alone the name of infinite; as much because we see no limits in his perfection as because we are fully certain there cannot be any.[3]

Cusanus had adopted much the same distinction, for instance when identifying God with the Absolute Maximum, and the Universe with a restricted one. For him,

> the Universe, though it embraces all else, does not include God; if we consider it as termless and privatively infinite in consequence, we would have to say that it is neither finite nor infinite…. From the point of view of God's infinite or limitless power, the Universe could be greater; but from the point of view of possibility or matter, it cannot be… it is a creature and necessarily owes its existence to the Absolute Being. (*De Docta Ignorantia,* 70–1).

[3] Descartes, *Principes de philosophie* (1647) § 27. For the Cusanus-Descartes connection, see Koyré (1957), 19.

Despite its lack of Cartesian clarity, the distinction anticipates that of Descartes.

The Cusanus Universe was without limits, like that of Oresme; but he proceeded much farther than the Bishop of Lisieux had ever done, making it without center and filled with Worlds similar to our own. And he also explored unknown territory: all these Worlds could not fail being ornamented with living creatures.

The Cusanian System of the World

Two short chapters, the *Corollaries on Motion*, and the *Conditions of the Earth* present the Cusanian cosmology. They are followed by the equally-brief *Admirable Act of God in creating the World and its elements*, where some account of cosmogony might be hoped for; unfortunately, Cusanus never tries to explain how the World was created, and merely speculates on the Why, which is of far less interest to scientists. Even so, Learned Ignorance led him to a most sensible conclusion: "Never to hope to penetrate to the reasons of all the works of God, but only to admire." (*De Docta Ignorantia,* 120). Apart from such views, the Cusanian text may be followed linearly, beginning with his *Corollaries*.

The central issue is the meaning of those two words: motion and rest. Cusanus starts from his metaphysical beliefs: the Absolute Maximum coincides with God, and the created World is universally inaccurate. From which he derives a clear physical consequence: attributing absolute rest to the Earth (or any other body), is meaningless. A first hint is found immediately after an abstruse discussion of motion: "…the movement of a love that links all in one with the result that that all things form one Universe…" Who would have dreamed of it leading to a solid and intelligible conclusion? Nevertheless, here it is: "No movement is therefore absolute, for absolute movement is rest." (*De Docta Ignorantia,* 106). Next, and right away, the Cardinal drifts back to heavy metaphysics, ornamented with some Christian theology, which will no longer be followed; enough quotations have been given to show how independent of reason, observations or even of the senses is the great Cusanus discovery.

What are the arguments for motion of the Earth? Earth mobility is largely a consequence of Universal Indetermination:

> it is impossible to find in the Universe two beings perfectly equal in all things… consequently impossible for the motor of the World to have the material Earth, air, fire or anything else for a fixed, immovable center… therefore the center and the circumference are identical. (*De Docta Ignorantia,* 107).

The theme of the infinite being like a circle or sphere whose center is everywhere and the circumference nowhere, had been an old scholastic toy, attributed to the mythical Hermes Trismegistus, whom Cusanus often quotes in other works. In a previous chapter of *Docta Ignorantia*, he had gone rambling over "…the infinite circle, having neither beginning nor end, eternal, infinitely one and infinite in capacity… center, diameter and circumference are one and the same,"[4] all of which had

[4] *De Docta Ignorantia,* 47. About Hermes Trismegistus, see *Note 1* by Koyré (1957) p. 30.

been pure mathematical fancy, ever so close to the metaphysical one. However, here in his *Corollaries* Cusanus is now describing the actual World, the one we see with our eyes, endowed with air and fire and celestial bodies. And he is fully out of metaphysics: when he just wrote that "the center and the circumference are identical" we have to understand it as his own way of painting a homogeneous and acentric Universe, without a singularity anywhere, either physical or kinematical.

Let him proceed: "The World cannot be enclosed within a material circumference and center, it is unintelligible without God as its center and circumference. It is not infinite, yet it cannot be conceived as finite, since there are no limits…" (*De Docta Ignorantia,* 107). Despite the insistence, strange but fully in character, that such an acentric and rimless World is unintelligible, we do find here a sober result: all that heavy Peripatetic logic about the ninth sphere as an absolute limit with neither Space nor Time beyond, is just plain twaddle. Still, so far, Cusanus has not proceeded beyond Oresme; but consequences never seen by Oresme will now unfold:

> The Earth, which cannot be the center, must in some way be in motion… Just as it is not the center of the World, so the circumference of the World is not the sphere of the fixed stars… The Earth is not the center of the eighth or any other sphere… The center itself of the World is no more within than outside the Earth [which] has no center nor has any other sphere… Only in God are we able to find a center perfectly equidistant from all points.

There are some rare attempts at giving more technical information:

> In the Heavens there are no fixed immovable poles…. Certain stars seem to describe the maximum circle, whilst others describe the minimum, but there is no star which does not describe a circle. (*De Docta Ignorantia*, 109).

These quotations illustrate the limitations of Cusanian thought; his final model remains hazy, and will be interpreted in different manners. Cusanus does not anticipate Copernicus in any way; nevertheless he will be seen a little later proceeding far beyond him when stars, and not planetary motions, are concerned. Let us summarize:

1) The Earth cannot be in the center of the spheres, because all spheres in the actual World are imperfect. Cusanus does not eliminate those spheres, and why they are still needed at all remains unclear. They do not support celestial bodies; the sphere of the fixed stars is not a limit, but it is still present. In a previous passage, he had gone rambling, like any good Pythagorean, about "the sphere, the ultimate perfection of all figures, such as no greater can be", but these had been ideal spheres while the worldly ones did not deserve such praise. The Earth is just an irregular approximation of a sphere, and so are all the others. Whenever he writes *sphæra*, a more correct translation should be spheroid.
2) The Earth cannot be at rest either, absolute rest being an attribute of God alone, and of no material body. God is "the Universal Measure"; he is also the sole reference point, geometry is of no help.
3) The position and motion attributed to the Earth are never made clear. The feeble attempts at discussing observations are hopelessly muddled. Cusanus stresses rightly that no star coincides with the celestial poles; but as he never hits on the idea that diurnal rotation may be apparent, all his subsequent argumentation is either useless or wrong.

The mere concept of relativity of motion, already found in Aristotle, had been discussed by Oresme far more perceptively. Cusanus does not understand that he cannot prove that the Earth moves just by observing apparent celestial motions. His Universal Indetermination prevents him from taking any interest either in the Ptolemy or Aristotle systems, and from proposing any solution of his own. Still, Cusanus could not help wondering about the nature of these astronomical motions. In 1843 a short manuscript text in his hand was discovered, written on the last page of an astronomical treatise from his own library; it is given in full and discussed by Duhem (1959, X, 313). Here, Cusanus proposes a diurnal rotation of the Earth, like Oresme (about whom he knew apparently nothing).

So far, this quaint concept has helped him in the right direction, but from now on it will turn into a hindrance. In particular, the vaguely described discrepancies between ancient and recent observations could not have been explained by any displacement of the Earth; and solid observations of stellar proper motions were still very far in the future. Cusanian ideas about celestial motions remain vague in the extreme:

> We have learned from the movement of a comet that the elements of air and fire are in movement, and that the Moon is moved less from east to west than Mercury or Venus or the Sun… it follows that the Earth is moved least of all…though as a star it may be nearer the central pole, it does not describe in its movement the minimum circle. (*De Docta Ignorantia,* 109-110).

His few allusions to planets are hazy, and he is plainly not interested; later, he will describe the Earth as a star, but never as a planet, nor treat it as such. The embarrassed statements that the Earth "moves least of all", or "is nearer to a central pole" (the existence of which he has just disproved), seem to imply that the Earth still has a preferred role, and there is not yet any anticipation of the brilliant and universal principle soon to be proposed.

We have indeed (most laboriously) reached the crux in the story: "Suppose one person were on the Earth under the arctic pole, and another on the arctic pole; to him on Earth the pole would seem at the zenith, whereas to the person on the pole the center would appear at the zenith… Anywhere a man will be, he will believe himself in the center." Our Cosmological Principle indeed, clearly and simply stated. What a pity that its author immediately proceeds to draw a disheartening (and false) consequence: "… the impossibility of comprehending the World, its movement and form, for it will appear as a wheel within a wheel, a sphere within a sphere…" (*De Docta Ignorantia,* 110). In brief, Cusanus deduces the Principle from his *a priori* notion that the Universe cannot be exactly described by numbers or geometry; he makes only the most rudimentary attempt at showing to be compatible with actual observations; lastly, he reverts to his usual way of thinking, i.e. more exact data or better modeling of the World are useless. Further progress in cosmology required a Copernicus plus a Galileo and a Kepler, not a Cusanus.

Still, we are not through with Cusanian cosmology, having merely reached his second chapter on *The Conditions of the Earth*, in which he draws from his own Principle the ultimate and most daring conclusions, indeed startling ones coming from such an eminent Christian. He starts with his own version of the ship thought-experiment:

> How would a person know that a ship was in movement if the banks were invisible to him, and he was ignorant of the fact that water flows? Every man, whether he be on Earth, on the Sun or on another planet, always has the impression that all other things are in movement… there will be a machina mundi whose center is everywhere, whose circumference is nowhere, for God is its center [etc, etc …] (*De Docta Ignorantia,* 155).

The ship analogy has already been found under Oresme's pen, where it had assumed a more modern form: no reference to God, explicit or implicit, had been required, and the description of relative motion was far more precise. The novelty is that, starting from his ship, Cusanus speculates on a translation of the Earth, while Oresme had been content with mere rotation. In the long run, this advance will prove essential: it is because the Earth makes use of a translation that Copernicus, Galileo and their followers will be able to treat it as one more planet; but Cusanus himself did nothing of the kind.

This is the last discussion of kinematics found in *Docta Ignorantia*, as the next chapter is devoted to exploring universal physics and biology. Cusanus will manage to weld the Principle of the Best and his own Principle of uniformity with Peripatetic physics to reach a momentous conclusion that will long outlast Peripatetism: the Best of all possible Worlds is one that must be fully inhabited. From Aristotle he keeps the four terrestrial elements, but definitely not the fifth (quintessence), his universal uniformity prohibiting any physical difference between Earth and celestial bodies. He rejects two ancient beliefs: that the Earth is the center of everything, and that it is the lowest and vilest of all bodies; these notions appear contradictory from today's viewpoint, but both long managed to coexist. His Earth is granted an intermediate and unremarkable place within a continuous chain of created abodes. Which is all for the Best: Man is not in the center nor is he the final cause of everything, but nevertheless the World operates through final causes, with God the ultimate one. Centuries later, Cusanian cosmology will meet with wide and long-lasting success within the Christian world.

In his own words:

> The movement of any part is for the perfection of the whole; e.g. heavy bodies move toward the Earth, light things upwards, earth towards Earth, water to water, air to air, fire to fire… every figure inclines to the spherical… It is untrue to say that the Earth is the basest and lowest planet, the darkness of color is not a proof of the Earth's baseness: the brightness of the Sun, which is visible to us, would not be perceived by anyone in the Sun… If one were outside the region of fire [i.e. the Aristotelian sphere of fire], our Earth would appear as a bright star…

As to the Moon appearing less bright, this is merely because

> we are on the near side of its circumference, in its watery region… Our Earth seems to lie between the regions of the Sun and the Moon. (*De Docta Ignorantia,* 157).

Thus, except for the demise of quintessence, multiple copies of Peripatetic physics rule throughout the Universe. The four Earth-centered spheres of earth, water air and fire are taken for granted, and each celestial body is fitted with a similar complement. There is no basic difference between Earth, Moon, Sun and stars; the Moon merely looks different because it is so close. Observers located anywhere (so far, only as a thought-experiment) would watch the same scenery and scenarios. However, Cusanus carries universal uniformity too far; not being a careful observer himself, he misses the actual differences between celestial bodies and Earth. When looking at the Sun, he believes to have seen "near the center, a sort of Earth, at the circumference a sort of fiery brightness, and midway between them a kind of watery cloud and clearer air". These were pure artefacts of irradiation within the eye and did not anticipate sunspots, protuberances nor corona.

Some more cosmological consequences: "the Earth is smaller than the Sun… [nevertheless] it is not the smallest star, for eclipses have shown us that it is larger than the Moon, and some say larger even than Mercury… no proof can be alleged of its baseness." (*De Docta Ignorantia,* 114); true, but no one had then any idea of the real size of Mercury. There is even a hint of a general "mutual relation of the influences between stars." (*De Docta Ignorantia,* 114). Such influences remain most vague, but they are clearly not astrological. This quasi-metaphysical principle of action and reaction is a direct consequence of the Cusanian Cosmological Principle: if we receive something from them, they must receive something from us, irrespective of what the involved influences truly are.

Behind the scenery, the hidden cause:

> All stars move and sparkle for one sole purpose: the realization of the best possible existence for them… light gives light not that I may see, but it is of its very nature to give light… Whilst each thing strives to conserve its own being as a gift of God, it does so in participation with other things; e.g., the foot has only one purpose, viz. walking, but it is of service to the eyes, hands, body and to the whole man… Plato said the World was an animal; if you conceive God as its soul, much of what I have said will be clear to you. (*De Docta Ignorantia,* 113).

One begins to understand how the Cusanus Universe is able to fit within the divine plan: its guiding principle is a non-anthropocentric teleology. All celestial bodies or features, for instance light, play their roles, but they are not intended for Man. Platonic hylozoism is preserved, although Plato himself would have been horrified to see the World multiple and non-spherical. The overall picture is roughly the one that will be adopted by most Christians four centuries later.

And now for the grandest consequence of all, Universal Life:

> Rather than think that so many stars and parts of the Heavens are uninhabited and that this Earth of ours alone is peopled, and that with beings of an inferior type, we will suppose that in every region there are inhabitants differing in nature by rank, and all owing their origin to God, center and circumference of all stellar regions… It seems inconceivable that anything more noble and perfect could be found than the intellectual nature that exists here on this Earth. (*De Docta Ignorantia,* 114-5).

Within a few lines, in a completely matter-of-fact tone, as a direct and inescapable consequence of his Principle, Cusanus has filled the Universe with living creatures, all different but all striving towards an Intelligence which is essentially One. The central argument is Plenitude: these places cannot be empty, and throughout the rest of this History, we shall meet it again and again*, ad infinitum*. For Plato, Round and Smooth had been best; from now on, Full is better. Emptiness, of life and intelligence in particular, becomes a serious design flaw. The Universe would not be the animal-like harmonious whole that Cusanus has just endorsed if these outside places remained void of intelligible purpose.

All of which is no mere thought-experiment. Such distant places are not constructions of the mind; they are not the external Worlds of the Atomists or Lucretius, which nobody had ever observed nor could hope to discover in the future; neither are they the Tempier-endorsed virtual *plures mundos.* They are the Sun and the Moon, plus the common stars, the ones we see with our own eyes at night. Every species of celestial dweller exhibits predictable idiosyncrasies:

> In the area of the Sun, there exist solar beings, bright and enlightened intellectual denizens, by nature more spiritual than such as may inhabit the Moon (who are possibly lunatics), whilst those on Earth are more gross and material… We make these conjectures from the fiery nature of the Sun, the water and air elements of the Moon, and the weighty bulk of the Earth; and we may make parallel surmise of other stellar areas that none of them lack inhabitants… (*De Docta Ignorantia,* 116).

The way in which Cusanus grants diverse qualities to extraterrestrial species is of course naive, and remains what we might expect from his century; nevertheless, what an improvement compared to the radical Earth-Heavens Peripatetic duality, unambiguously rejected: "The physical decay which we see upon the Earth is no convincing proof that our Earth is vile. Given a single cosmos, with the reaction of star upon star, we can never pronounce any one thing to be pure, irredeemable corruption." (*De Docta Ignorantia,* 116). Here follow two pages of abstruse argumentation on death and place of body and soul; still, one clear conclusion is that neither Paradise nor Hell are located within the material World.

In his third chapter, the *Admirable act of God in his creation of the World and its elements*, Cusanus does not revert to the theme of Plurality, nor improves his own System of the World; he merely stresses how fully compatible it is with the glory and greatness of God. A typical encomium: "Who could help admiring this craftsman who in spheres and stars and in the vast stellar spaces employs such skill…weighing and adjusting the vast bulk and movement of the stars… giving each its own splendor, its own power of influence, its own shape, color and heat…. He is the absolute maximum and the author and comprehender of all His works…" (*De Docta Ignorantia,* 120–1). Maybe the Cardinal had a bit neglected Scripture, but nobody could reproach him for belittling its divine Author.

A summary of the Cusanian Universe may now be attempted. It is intelligently designed, but not according to any plan apprehensible to human reason; wholly-teleological, but not anthropocentric; center-less and rimless, but not infinite; neither round nor smooth, but not fitting any shape from geometry textbooks either; operating through unspecified motions, nevertheless harmonious and not chaotic; and essentially homogeneous, thus filled by countless Worlds. Planets are almost ignored, and their motions appear meaningless; like Moon and Sun and Earth, they are merely additional stars. All obey local Peripatetic physics, offer the same scenery to on-the-spot observers, and interact through unspecified influences. Each is the abode of some specific species of living creature, which differs from neighbors in degree but not in kind; all share the "intellectual nature" of Man. Any view of evolution, or of Time indeed, is lacking; since nothing is said about the Creation of this multifarious Universe, Christians are free to assume the work was done within the *Genesis* time scale. However an embarrassing point is the absence of any hint of Redemption for all these alien beings, who are clearly nothing but imperfect and mortal creatures. How could the Cardinal fail to provide some means for their salvation, and if Christ had visited them, why did not Scripture narrate His journey? This severe difficulty will be raised in the future after Plurality had become fashionable, and never be fully solved.

Let us now try to assess the Cusanus achievement. We remember that, according to Plutarch, Plato had made all Philosophy respectable because he had "…submitted the necessary natural causes to the Divine Power as to a more excellent principle." In exactly the same way, Cusanus was to make Plurality respectable, since he found the device through which the concept will know explosive success: intelligent design. A success that was far from immediate, as the Cusanian cosmology went unread for almost two centuries, and the disastrous Bruno episode still has to be narrated. A second adequate comparison may be with Aquinas: just as the Angelic Doctor had christianized Peripatetism, and made the development of science possible within the West, Cusanus christianized these other Worlds. He showed that Jehovah had never been bound to follow slavishly Pythagoras or Plato in that particular fancy of them: the smooth and round enclosed bubble. Unicity had never been better than Plurality; Heaven could be designed all for the Best, and still not remain "one and unique" as Socrates had advised Timaeus. In the future, Epicurean Plurality would never have been widely accepted before the nineteenth century. Cusanian Plurality could, and ultimately was, with all the critical discoveries about the Universe taking place just during that period. Augustine and Chrysostomos must have been turning in their graves, or rather watching in horrified impotence from their ring-side seats around the Throne: the exact consequence they had feared was taking place, and Christian Plurality could no longer be stopped.

And presently, Cusanus himself must also be watching our World, from a somewhat lower rank within the celestial hierarchy since he never achieved sainthood. He had made the severe mistake of earnestly promoting Reform at the wrong time; even worse, that of holding remarkably broad-minded views of religion. For him, men all over the world were just giving different names to a common concept of God, and there was *religio una in rituum varietate*. In his grand vision, the physical World was not the sole polycentric one, and plurality within basic unity applied first of all to matters of the Faith. In his *De Pace Fidei* he presents a sort of Symposium, in which the "Word that was made Flesh" acts as Chair; the speakers are (in order of appearance) a Greek, an Italian, an Arab, an Indian, a Chaldean, a Jew, a Scythian, a Frenchman, a Persian, a Syrian, a Spaniard, a Turk, a German, a Tartar, an Armenian, a Bohemian; and last of all, an Englishman, who shows himself mostly concerned about "fasting, ecclesiastical offices, abstinence from foods and drinks and forms of prayers." Despite such ritual difficulties, all manage to share a common language; truly, the reader feels like attending a fifteenth-century meeting of benevolent Aliens.[5]

If Cusanus is indeed still contemplating our Universe, he must feel even greater horror: modern disciples have captured his cosmic vision full-fledged (except for trifling changes, such as putting fellow creatures aboard planets rather than stars), but emptied of all meaning: the Best-of-all-possible-Worlds lies upon the junkyard of discarded concepts. These Epicureans Cusanus had dismissed as long-refuted are back in fashion: Plurality is no longer requested "in order to prevent so many celestial and stellar places from being empty." The scientists among us tend to believe that if Life thrives around the cosmos, it does so from efficient causes, and solely through chance.

Solely through chance? Are we so sure? If some intelligent beings somehow manage to pass through our present stage of civilization and survive, then the spreading of life from World to neighboring World may take place as the result of some grand master plan. The formation of intelligent nuclei becomes induced, like laser radiation, and is no longer spontaneous; coherence prevails, design is paramount. Applied to the origin and past history of Man, this fanciful scenario is sheer flying-saucer stuff; but we cannot quite rule out something along that line presently taking place within some dark and distant corner of the Universe, maybe even within our own Galaxy. Plurality is an open question; history reaches to the present day, but does not stop at such a thoroughly unremarkable time.

Let us hope that Cusanus sticks to his second-row seat: the present human comedy is quite exciting, and the next acts might prove well worth the entry price. Why should he show haste anyway, having reached (despite the lack of Church laurels) at least that blessed state in which "the past is nothing but the future and the future nothing but the present."

[5] Cusanus (1453), *De Pace Fidei*, translation and analysis by Jasper Hopkins. See also his *Cribratio Alkorani* (literally: passing the Quoran through a sieve) of 1460/1. Judging from the volume of modern bibliography, the religious views of Cusanus are presently attracting far more interest than the cosmological ones.

Chapter 7
Nicolaus Copernicus: Earth No Centre

By long and intense study I finally found that if the motions of the other planets are correlated with the orbiting of the Earth, not only do their phenomena follow therefrom but also the order and size of all planets and spheres, and Heaven itself is so linked together that in no portion of it can anything be shifted without disturbing the remaining parts and the Universe as a whole.

Nicolaus Copernicus, *De Revolutionibus*[1]

(left) Presumed portrait of Copernicus, by Holbein's workshop or follower, end of 16th century. Bibliothèque de l'Observatoire de Paris.
(right) The system of Copernicus, from *De Revolutionibus*. Bibliothèque de l'Observatoire de Paris

[1] Nicolaus Copernicus (1543) *De Revolutionibus Orbium Coelestium, Libri VI*, translation by Edward Rosen (referred to as *De Rev.*, Rosen). Also used are the translations by Ch. Glenn Wallis, and by J.F. Dobson & S. Brodetsky (*Chap. I* only), given by Milton K. Munitz (referred to as *MKM*). Of at least equal importance here are the *Three Copernican Treatises*: *Commentariolus* (c. 1514), Rheticus' *Narratio Prima* (1540), *Letter against Werner* (1524), translated with *Introduction* and *Notes* by E. Rosen, who gives a biography, plus a bibliography which contains 1092 entries solely from 1939 to 1958.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-41448-1_7

If the space devoted in these pages to all protagonists was to be proportional to their status within the history of astronomy, Copernicus would of course swamp all other contributors. However, he never wrote an explicit line on Other Worlds, being merely a sober-minded mathematician, not a physicist and philosopher, even less a metaphysician; and while a Churchman, not a theologian. The two real innovators, as far as Plurality is concerned, were Cusanus and Bruno during the period we are presently concerned with; or even perhaps, during all of History. Nevertheless, in between Cusanus and Bruno, the Copernican system was born; the system, but not the revolution. Relatively few people discovered, and still fewer adopted, the revolutionary point within the Copernicus book; that the Earth had been demoted to the status of an unremarkable planet within a crowd of others. Bruno was one of the few who did, and this discovery was to play a major role in his own work, and in the present story.

The flow of ideas (or the lack of it) between Cusanus, Copernicus and Bruno has to be understood to make intelligible the interplay of the three chapters devoted to them. Copernicus was born a few years after the death of Cusanus, and Bruno similarly soon after Copernicus' demise. Copernicus seems to have been unaware of Cusanus; indeed, not a single line written by the German Cardinal had any relevance to his own life-task, the overhaul of the Ptolemaic system. As to Bruno, he began by reading Cusanus extensively, and largely shared his uniformitarian cosmology. Next, he learned about the Copernican system, and adopted it with extreme enthusiasm because it fitted perfectly within his own wholly metaphysical view of Nature. About Copernicus the painstaking mathematician, and about the technical problem of better fit between observations and predictions, Bruno could not have cared less: unlike Cusanus, he knew nothing of science, and less of mathematics. Even so, Bruno's concept of Plurality was to grow far more precise than that of Cusanus, and his picture of these Other Worlds hits so close to the modern one that we might elect to cut the present history short on February 17 1600, when Bruno climbed on the stake. This improvement had been made possible because of unavoidable consequences of the heliocentric system that Copernicus himself never perceived. Modern Plurality, actual and scientifically sound, is an edifice largely constructed by two metaphysicians with a geometer in between, and pretty little understanding between the three of them (Figure 7.1).

All of which explains the narrow limits of the Copernicus account to be found here. The questions to be answered are: To what extent was Copernicus himself convinced of Earth mediocrity? How much of the Peripatetic Earth-Heaven duality had he dropped? What were his basic assumptions, patent or hidden? What kind of proof did he offer, and how did his contemporaries react? And why was he not taken seriously except by a few, such as Bruno? A description of the Copernican set of epicycles is no more needed here than in the case of Ptolemy; but on the other hand, the backward Copernicus notions about locations of stars and nature of space are relevant. Of equal interest are his rather scanty comments on earthly and celestial mechanics.

Because the Copernicus life and works have been so extensively written about, and are today more familiar than those of the other actors met so far, no account will

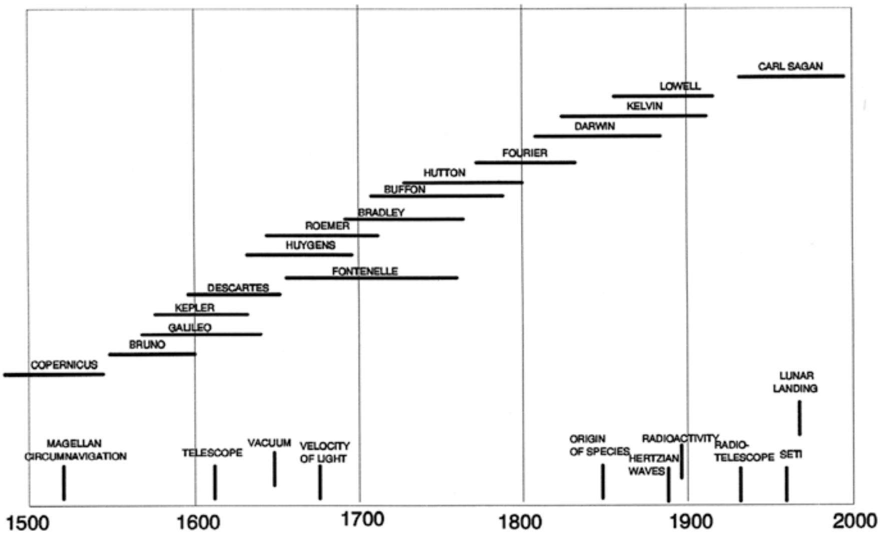

Figure 7.1 Chronology of the modern epoch

be given.[2] The Copernican system became known first through his own preliminary abstract, the *Commentariolus*, written before 1514, but only a few manuscript copies were circulated around. Second, his Lutheran disciple Rheticus wrote his own summary, the *Narratio Prima*, which was printed in 1540 and became at once reasonably well known. Finally, the full account was given by Copernicus himself in his *De Revolutionibus Orbium Celestium Libri VI*, printed in 1543 (his last year on Earth), but written or at least undertaken many years before. Copernicus had dreaded to publish what he understood quite well to be a dangerous concept, likely to generate serious trouble for the author. Times had changed indeed in between *Docta Ignorantia* and *De Revolutionibus*, because of those Wittenberg theses of Luther. However, it would be quite wrong to believe that the early objections against *De Revolutionibus* were primarily theological: Copernicus himself knew that he was very far from producing a closed case for Earth motion.

For our purpose, the *Commentariolus* is not helpful: it describes clearly what the Copernican system is, but does not give the Why. At the beginning, Copernicus lists seven assumptions and presents his own explicit program:

> There is no one center of all celestial circles and spheres. The center of the Earth is not the center of the Universe… Having set forth these assumptions, I shall endeavor briefly to show how uniformity of the motions can be saved in a systematic way. (Commentariolus, Rosen, 58).

[2] Arthur Koestler (1963) in his *Sleepwalkers* provides a highly-readable but misleading account of the life of the "Timid Canon." His description of *De Revolutionibus* as "the book nobody read" is a large overstatement. He is particularly difficult to follow when he pictures Copernicus as unconscious of the revolutionary character of his own theory. He is thoroughly demolished by E. Rosen's Copernicus as a Man and Contributor to the advancement of Science, *Vistas in Astronomy* 17 (1975).

There is no attempt to explain why these assumptions are made, nor to stress that they lead to results more exact than the traditional ones; Copernicus merely shows that they do save both the observed phenomena and the sacrosanct uniformity of circular motions. For him, the demonstration is essential, but is unlikely to shake the ground under anyone's feet. If he had not proceeded beyond the *Commentariolus,* his system would have remained one within a rich collection of oddities that had grown during the centuries after the rediscovery of the *Almagest*, none of which needs to be known today, except by specialists (for instance, the Fracastoro system; see Dreyer 1905, 296).

The *De Revolutionibus* exhibits a quite different scope. Admittedly, five out of the six Books are heavily technical and never read today except by historians of astronomy; these merely implement the *Commentariolus* program. But the first Book, intended for astronomers and laymen alike, explains both the author's aim and the reasons behind his assumptions. The *Narratio Prima* is also useful in this respect: Rheticus, gushing with youthful enthusiasm, often makes out the key points more pointedly than his master, and in a far-more vivid style; both will be quoted.

Raw Materials: Observations and Tradition

In order to understand the Copernicus undertaking, it is necessary to know the kind of material he had available when he started his work. This was of two kinds: actual observations, and the few surviving accounts (or rumors) about ancient theories which had let the Earth move.

Observations accessible to Copernicus were ancient or modern, and the last included some of his own. The *Almagest* had already run through several printed editions, and so had the *Alphonsine Tables*, which were still standard tools for specialists. Copernicus had the deepest regard for ancient observations, since they could not be considered as obsolete because of any sizeable technical improvements. Actually, his laborious efforts to account for them in the most respectful manner led him astray in several cases; for instance he never thought of dropping the old wholly spurious *trepidatio*. Kepler, as enthusiastic a Copernican as will ever be found, was to write that "Copernicus tried to interpret Ptolemy rather than Nature." (Kepler 1609, *Astronomia nova* quoted by Dreyer 1905, 313). However, Kepler himself was luckier, since he had on his bookshelves all the Tycho observations, which were far better than any available to Copernicus.

Which does not quite mean that observational astronomy remained in the same state of dereliction that had lasted through the dark ages. Efficient astrology and correct calendar keeping had both required up-to-date solar and planetary positions. In the fifteenth century, the most noticeable observer had been Johannes Muller of Königsberg, a village of Franconia; his name was italianized to Johannes de Monte-Regio, and for more lasting fame, latinized to Regiomontanus. As a mathematician he produced a trigonometry treatise, and much-needed tables of sines; as an astronomer, he built the first observatory worthy of the name within Western Europe, where he accumulated specimens of all extant astronomical instruments. These were but marginally better than those of Arab astronomers centuries before, except perhaps for mechanical clocks; still, they made possible a coherent observing program. His understanding of the Universe was still fully Ptolemaic, and he wrote a textbook titled *Epitome in Ptolemæi Almagestum* (see Dreyer 1909, 290).

Copernicus fully understood the need to extend observations up to his own day. He had a small tower built for an observatory near Frauenburg Cathedral, where he spent the later part of his life as Canon. In his *De Revolutionibus* he mentions or describes the instrument used for the Moon, the quadrant for the Sun and the armillary sphere for the stars.[3] Of his own observations, twenty-seven are mentioned in *De Revolutionibus*, and a few more in *Narratio*. Many were of the elementary type for which no instruments at all were needed: eclipses, occultations, dates of planetary conjunctions and of alignments between a planet and two stars. He was not primarily an observer, and made no improvements in accuracy; his own observations are unremarkable when compared with others of the same epoch. These Copernican undertakings were not actually required; the facts to be explained had been plain enough for two millennia. In the words of Rheticus, he had merely

> … so constructed anew the tables of declination, right ascensions, ascensional differences and the other tables belonging to this brand of science that they can be brought by the method of proportional parts into agreement with the observations of all ages. (*Narratio Prima,* Rosen, 110).

Errors in the *Alphonsine Tables* had become obvious enough, and were fairly well recognized at the time; by themselves they certainly required an overhaul of the Ptolemaic machinery but not an overthrow. Discrepancies between ancient and modern observations could have been taken care of largely by an updating of the main constants; for instance, the most vexing of them, the out-of-joint calendar could be eliminated simply by adjusting the length of the year. Nobody was proposing to throw the *Almagest* into the waste-paper basket.

Copernicus did not merely prize ancient data; he was also anxious to appear as respectful of tradition as any other humanist. He was himself a Greek scholar, having studied the language in Bologna and even translated some unremarkable Greek texts to Latin. He had the full support of Rheticus in this respect:

> For him, there is nothing better than walking in the footsteps of Ptolemy and following, as Ptolemy did, the ancients and those who were much older than himself… My teacher especially abhors what is alien to the mind of any honest man, particularly to philosophic nature; for he is far from thinking that he should rashly depart, in a lust for novelty, from the sound opinion of ancient philosophers except for good reasons and when the facts themselves coerce him. (*Narratio Prima,* Rosen, 187).

Copernicus himself never misses an opportunity to downplay the originality (but not the importance) of his own contribution, by quoting ancient authors who had proposed Earth motion. Admittedly, the material to quote from was pretty scarce; in his *Letter to Pope Paul III*, which serves as a *Preface* to *De Revolutionibus*, he writes: “First I found in Cicero that Hicetas (Hiketos) supposed the Earth to move. Later I discovered in Plutarch [Pseudo-Plutarch?] that certain others were of this opinion… Philolaos the Pythagorean believes that, like the Sun and Moon, it

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[3] For instance *The Instrument for Observing parallaxes* is described in *De Revolutionibus*, IV, 1. About the observatory, see e.g. the biography given by Rosen, *Three Treatises*, p. 340 ff.

revolves around the fire in an oblique circle. Heraclides of Pontus and Ekphantus the Pythagorean make the Earth move like a wheel in a rotation from west to east about its own center… Therefore I too began to consider the mobility of the Earth." (*De Rev.*, Rosen, 8; *MKM,* 151). And at another place, still within Book I, he alludes to

> Martianus Capella, the author of an encyclopedia, and to certain other Latin writers. For according to them, Venus and Mercury revolve around the Sun as their center. This is the reason, in their opinion, why these planets diverge no farther from the Sun than is permitted by the curvature of their revolutions. For they do not encircle the Earth, like the other planets…[4]

Here we may recognize the system of Heracleides.

The most interesting reference is not found in any printed text but in a stricken-out addition at the end of the Book I, in the happily preserved holograph manuscript of *De Revolutionibus*:

> … from these and similar causes, Philolaos regarded the Earth as movable. Some also say that Aristarchus of Samos, though not moved by the reasoning that Aristotle advances and rejects, was of the same view…[5]

The passage is tantalizing: Copernicus seems unaware of both Plutarch's *De Facie* and Archimedes' *Arenarius*, otherwise he might have been far more specific himself. Hence, he must have been referring to the Pseudo-Plutarch text already quoted: "Aristarchus places the Sun among the fixed stars, but lets the Earth move along the solar circle…" (Dreyer 1909, 139). Which had been extremely vague, and Copernicus probably failed to realize that the Aristarchus system had anticipated his own far more closely than those of Pythagoras or Heracleides; we do not know why the passage was struck out and never printed.[6] As to Oresme, he is never mentioned at all; the *Livre du Ciel et de la Terre* was available in French only, and had so far remained a manuscript. This is a pity, because the Copernicus notions about stars, star places and Space remained frankly backwards; in particular, he never placed the Sun among the stars. His innovative spirit left him stranded at the edge of this Solar System which he may be said to have created: before him, there was no such thing.

Tools and Aims

Having seen the raw materials from which Copernicus worked, one may describe the tools he used, together with his goals. Actually, tools and aims cannot be fully separated in this context: since he had decided from the start to employ only the

[4] *De Rev.*, Rosen, 16; *MKM*, 167. About Martianus Capella and his *Encyclopaedia*, see Dreyer 1909, 127.

[5] *De Rev.*, *MKM*, 173. The reference to Aristotle is *De Caelo*, II, 14. *Arenarius* was to be printed only in 1544; still, Copernicus might have seen a manuscript (Koyré 1961, III, Note 22)

[6] Koestler, systematically hostile to Copernicus, suggests (p. 205) that he was "confusing the trail" by not being more explicit about the only ancient system that had truly anticipated his own, but this appears unlikely.

traditional circles, he was to spend most of his productive years trying to make these obligatory circles fit as accurately as possible. The account of this lifelong effort occupies the major part of *De Revolutionibus,* and reads as hopelessly obsolete today; but, on the way, he accomplished far more.

First question: Why did Copernicus want an improved World machine? In complete contrast with both Cusanus and Bruno, he worked independently of any metaphysical system, and merely tried to describe Nature accurately. Which does not mean he was wholly free of metaphysical or even mystical postulates, as will soon be seen in his dithyrambic argument for putting the Sun in the center. He was also without interest in astrology, never mentioned in his works. However, adoption of heliocentrism did not mean that converts had to abandon this appealing art, as Copernicus disciples, both immediate and distant, will illustrate. In his *Narratio Prima*, Rheticus inserts (within a heavily-technical description of solar eccentricity) a paragraph entitled *The Kingdoms of the World change with the motion of the Eccentric* which seems strangely out of place:

> I shall add a prediction: We see that all kingdoms have had their beginnings when the center of the eccentric was at some special point in the small circle. Thus, when the eccentricity of the Sun was at its maximum, the Roman government became a monarchy; as the eccentricity decreased, Rome, too, declined.

The same fate befalls the Mohammedan empire, and next:

> We look forward to the coming of our Lord Jesus Christ when the center of the eccentric reaches the other boundary of mean value for it was in that position at the Creation of the World. This calculation does not differ much from the saying of Elijah who prophesied under divine inspiration that the World would endure only 6000 years during which time nearly two revolutions are completed. (*Narratio Prima*, Rosen, 122).

And Kepler himself will be permanently involved in astrology, at least as a moneymaking device.

Unlike astrology, an improved calendar definitely was a Copernicus goal. In his prefatory *Letter to Pope Paul III* he wrote:

> For not so long ago under Leo X the Lateran Council considered the problem of reforming the ecclesiastical calendar. The issue remained undecided then only because the lengths of the year and month and the motions of the Sun and Moon were regarded as not yet adequately measured. From that time on… I have directed my attention to a more precise study of these topics. (*De Rev.*, Rosen, 9; *MKM*, 152).

There is also the testimony of Rheticus: a protector and friend of Copernicus, Bishop Tiedemann Giese, had never "ceased urging my teacher whose accomplishment and insight he had known for many years, to take up this problem." The Rheticus account is of particular interest, as he goes on to explain that at first Copernicus

> had decided that he should imitate the Alphonsine Tables rather than Ptolemy, and compose tables with accurate rules but no proofs. In that way he would provoke no dispute among philosophers; common mathematicians would have a correct calculus of the motions…. And the Pythagorean principle would be observed that philosophy must be pursued in such a way that its inner secrets are reserved for learned men trained in mathematics etc. Then His Reverence [Bishop Giese] pointed out that such a work would be an incomplete gift to the world, unless my teacher set forth the reasons for his Tables, and the proofs upon which he relied. (*Narratio Prima*, Rosen, 192-3).

Copernicus had Pythagorean-like leanings towards secrecy; that is confirmed by himself in his Preface:

> I debated with myself for a long time whether to publish this volume or rather to follow the example of the Pythagoreans and certain others, who used to transmit philosophy's secrets only to kinsmen and friends, not in writing but by word of mouth. (*De Rev.*, Rosen, 5; *MKM,* 149).

Whatever early importance calendar reform or planetary tables may have had in drawing Copernicus attention to the need of repairing the Ptolemaic machine, he was soon to pursue other ambitions, and his goals grew more aesthetic. Not only greater accuracy, but also simplicity, coherence and harmony would have to be built into the new design; and it was to be assembled with perfect circles running at uniform speed, a basic requirement ever since Pythagoras, which Ptolemy had scandalously dropped through his invention of the equant; all these criteria formed a whole in the Copernicus mind. Today we are just as sensitive as he was to coherence and harmony, but perfect circles and eccentrics have joined equants in the scientific junkyard. The so-called Copernican system we are familiar with is actually the Keplerian version; our present proofs of Earth motion include some that Copernicus never dreamed about, and his own attempted ones are of mere historical interest. Still, they were to prove adequate for supporting the almost-modern view of Plurality that Bruno will enthusiastically endorse, long before Galileo, Newton and Bradley unearthed the physical evidence.

Copernicus' dedication to the spheres is shown by the very title he chose: these Orbs of which he describes the revolutions with the most minute care are nothing but the old spheres, already revamped by Ptolemy which he will refurbish once more after disassembly, cleaning-up and replacement of worn-out axles. How faithful he is to the spirit, if not to the letter, of the *Almagest* is imaginatively expressed by Rheticus:

> In my opinion, Ptolemy was not so bound and sworn to his own hypotheses that, were he permitted to return to life, upon seeing the royal road blocked and made impassable by the ruins of so many centuries, he would not seek another road upon land and sea to the construction of a sound science of celestial phenomena. (*Narratio Prima,* Rosen, 141).

Reliance on the circle is explicit; Copernicus gives to one of his chapters the title *The Motion of the heavenly bodies is uniform, eternal, and circular, or composed of circular motions.* And the arguments are those which had kept, ever since Pythagoras, the most persistent hold over human minds; indeed no other system of scientific explanation has yet lasted so long:

> … we must conclude that the motions of these bodies are ever circular or compounded of circles. For the irregularities themselves are subject to definite laws and recur at stated times, and this could not happen if the motions were not circular, for a circle alone can thus restore the place of a body as it was. (*De Rev*., Rosen, 2; *MKM,* 156-8).

The strength of that reasoning must be conceded, since our present decomposition of periodic motions into Fourier harmonics is of the same family, though not a linear descendant; and we use it with more caution, not conferring upon our component sines and cosines any physical reality.

For Copernicus, the need to resolve all irregularities into uniform circular motions was so strong that he decided to eliminate the equants; he blames

> … those again who have devised eccentric systems, though they appear to have well-nigh established the seeming motions by calculations agreeable to their assumptions, have yet made many admissions which seem to violate the first principle of uniformity in motion. (*De Rev*., Rosen, 7; *MKM*, 150).

Rheticus makes the same point even better:

> All these arrangements were shrewdly devised, like most of the work of antiquity, and would agree satisfactorily with the motions and appearances if we granted that the celestial circles admit an inequality about their centers, an essential property of circular motion. (*Narratio Prima,* Rosen, 137).

Copernicus had not been the first to hold the equant as a major blemish in Ptolemy's work: such an addition had proved enough to brand his system as a mere computing device with no physical reality. However, he was the first to eliminate this cumbersome tool, and for contemporary astronomers, the improvement was worthwhile. His laborious efforts to do without equants illustrate well his desire to build a true system, one that agreed to the physics of his day. According to our modern views, he had achieved nothing on this count, because he remained stuck with orbs, and never invented orbits, which are altogether different devices. Nobody before Kepler was to consider the actual trajectory of planets, i.e., the geometrical locus of the physical body, as worthy of attention.

A difficult question remains open: whether the orb itself was for him more than a calculating device. Did he still believe in crystalline spheres? Neither Copernicus nor Rheticus ever discusses the point explicitly. On the one hand, the Copernicus diagram presents well-separated planets, and solid spheres would have been free to nest within each other as in the Aristotelian system. On the other, the Earth (being reduced to a mere planet) now required a sphere of its own, which would have most catastrophically intersected the lunar one. We should have been able to fondle that heavenly crystal with our own hands, and we did nothing of the kind. Even worse, diurnal rotation meant that the Earth could not be rigidly attached to the said sphere, hence much of the mechanical point was lost. Which criticism is merely *a posteriori*: nobody bothered to present it at the time; altogether, Copernicus (like Ptolemy, his master) never worried about supporting devices for the planets. The first astronomer who explicitly operated without solid spheres was to be Tycho Brahe, who also rejected heliocentrism. As to the stellar sphere visualized by Copernicus, it warrants a separate discussion, to be given later.

Simplicity, Coherence, Harmony

So much for the spheres. What about the aesthetic aspects like simplicity, coherence and harmony? How essential a part of the Copernicus program were these features, and how successful was he in his approach?

Concerning simplicity, the answer is not simple, and a satisfactory one would require a full exposition of the system, out of place here. The issue of Ptolemy-Copernicus relative simplicity cannot be answered merely by looking at the familiar drawings; these are simplified diagrams prepared for the mere layman, in which epicycles, eccentrics and equants alike have been dropped. How many were needed? The *Commentariolus* concludes:

> Then Mercury runs on seven circles in all; Venus on five, the Earth on three, and round it the Moon on four; finally Mars, Jupiter and Saturn on five each. Altogether, therefore thirty-four circles suffice to explain the entire structure of the Universe and the entire ballet of the Planets. (*Commentariolus*, Rosen, 90).

In Ptolemaic astronomy, the number of actual circles had been an adjustable parameter, which bothered nobody; one of the most recent versions, by Georg von Peuerbach, had reduced it to 40. Thus, there was little improvement; worse, in the more-thorough *De Revolutionibus*, Copernicus increased his own complement to 48 (at least as counted by Koestler; Copernicus himself does not bother to give a grand total).

However, the mere number of circles is a misleading criterion if one wants to quantify simplicity: if not fewer circles, at least fewer independent *ad hoc* hypotheses were required. In this sense, the Copernican system truly proves simpler, and such a result could be perceived by sixteenth-century minds, although not by all of them. Plato had been the last philosopher to consider "those intricate traceries in the sky" as unworthy of notice; Eudoxus had already tried to model at least the most spectacular and baffling feature, the so called "major" or "first" inequality; this periodic retrogradation invariably takes place when Sun, Earth and planet are nearly aligned (see our figure 3.1). In an equally automatic manner, the three superior planets appear brightest when they reach the middle of their retrogradations; this fact had long been taken as a sign they were then closest to Earth, and the variation is particularly striking for Mars. Homocentrists and epicyclists alike had accounted for retrogradations and brightness changes by purely *ad hoc* spheres and circles independently built and running separately for each planet. Altogether, this major and most exasperating planetary idiosyncrasy had been represented, but never explained. Copernicus was the first to provide a true explanation, and a unique one at that; this was his masterstroke. In his system both retrogradations and brightness variations became automatic consequences of a single hypothesis: the yearly motion of the Earth around the Sun. And he was fully conscious of his own achievement: "We thus follow Nature, who producing nothing vain and superfluous often prefers to endow one cause with many effects."

His enthusiastic disciple will advertise this drastic advance even better, hitting the nail again and again, and (to make doubly safe), bringing in ancient authority:

> … mathematicians as well as physicians must agree with the statements emphasized by Galien here and there: Nature does nothing without a purpose…So wise is our Maker that each of his works has not one use but two or three or often more. Since we see that this one motion of the Earth satisfies an almost infinite number of appearances, should we not attribute to God, the Creator of Nature, that skill which we observe in the common makers of clocks? For they carefully avoid inserting in the mechanism any superfluous wheel or any whose purpose could be better served by another with a slight change of position. (*Narratio Prima,* Rosen, 137).

This unique and coherent explanation of planetary retrogradations was not the only major advantage of the new system. For the first time, the order and relative distances of planets could be reconstructed by geometry, and not merely fancied as before. As summarized by Copernicus himself, so far

> philosophers… adduce the fact that of objects moving with equal speed those farther distant move more slowly (as is proved in Euclid's Optics). They think that the Moon describes her path in the shortest time because nearest to the Earth she revolves in the smallest circle. Further they place Saturn who in the longest time describes the greatest orbit. Nearest than this is Jupiter, and Mars. Opinions differ as to Venus and Mercury, which unlike the others, do not altogether leave the Sun. Some place them beyond the Sun, as Plato in his Timaeus; others nearer than the Sun, as Ptolemy and many of the moderns. Alpetragius makes Venus nearer, and Mercury farther than the Sun. (*De Rev.*, Rosen, 28; *MKM*, 164).

That celestial palace had been built with stray blocks of marble and no mortar in between. As perceived today, ancient astronomers placing Mars, Jupiter and Saturn farthest had just made a lucky guess: if some planets are seen circling the sky vault more slowly than others, the true cause is not Euclidean perspective but the Keplerian laws, hence Newtonian attraction. Furthermore, the diameters of successive spheres had been fixed, at least by Peripatetics, from two arguments. First, one given sphere should contain its planet both at minimum and maximum distance, which gave the thickness; second, no vacuum was allowed in between spheres. Distances obtained in this way were complete fancy, and the fact that the diurnal (i.e. most rapid) motion was communicated to all spheres from the outer and largest one remained frankly embarrassing.

The Copernican mechanism was quite different: it formed a harmonious whole and not merely the order of the pieces, but the distance between them became logically and geometrically determined. There was for each planet only one size of the orb (orbit would be anachronistic) for which the Earth yearly motion produced the observed retrogradation; no additional degree of freedom was left to play with, no fine-tuning was any longer required. Again, Rheticus was the most eloquent advocate of the new system:

> Moreover, ye immortal gods, what dispute, what strife there has been until now over the position of the spheres of Venus and Mercury and their relation to the Sun. But the case is still before the judge. Is there anyone who does not see that it is very difficult and even impossible ever to settle this question while the common hypotheses are accepted? For what would prevent anyone from locating even Saturn below [i.e. closer than] the Sun, provided that he preserved the mutual proportion of the spheres and the epicycles… However, in the hypotheses of my teacher the sphere of each planet advances uniformly with the motion assigned to it by nature, and it completes its period without being forced into any inequality by the power of any higher sphere…[7]

[7] *Narratio Prima,* Rosen, 146. As a consequence, Copernicus obtains for the relative planetary distances almost the modern figures, an impressive achievement; let us give only the maximum distances, extracted from *Table 8,* p. 59 of A. Van Helden (1985):

Planet	Copernicus	Actual
Mercury	0.490	0.488
Venus	0.761	0.741
Earth	1.000	1.041
Mars	1.665	1.647
Jupiter	5.458	5.492
Saturn	9.700	9.987

However his absolute distances remained just as wrong as those of Ptolemy, because he simply adopted the solar distance of the *Almagest*, which is 20 times too small. No other course was possible before the telescopic era

Lastly, the Copernican system was not merely simpler than the Ptolemaic one, but also more coherent. Indeed, it was a global system, not a juxtaposition of mutually incompatible *ad hoc* explanations; the disastrous "I do not profess to be able to account for all motions at the same time" uttered by Ptolemy, leaves no relic. The improvement for the Moon was the most obvious one: not only was the new mechanism simpler, but also it did not produce the huge and patently-spurious change in apparent diameter predicted by Ptolemy. This was one case where internal coherence, and better fit with Nature, were evident to sixteenth-century minds. Unfortunately, it was also one that had no bearing on the geocentrism vs. heliocentrism issue. Trying to emulate the florid Rheticus style: whatever sort of ballet the Moon elected to dance, the Earth could still remain frozen in the center of the stage.

The Earth a Planet

So, all that pleasing heavenly harmony built into the Copernican system was inconclusive for the central problem: Earth motion. Copernicus had produced a fairly good case for all five visible planets revolving around the Sun, not for making the Earth the sixth of them. He fully believed, but did not prove (and could not possibly prove) that his system was any more true than the future Tychonian one, which was to combine planets circling Sun with Sun circling Earth; this possibility he does not seem to have considered. Indeed Tycho's system was often preferred to the Copernicus one until the beginning of the 18th century.

What are the specific Copernican arguments that brand the Earth as a planet? How did he make acceptable a motion of the ground we stand upon? How did he explain the venerable paradox of celestial bodies not falling down upon our heads? Copernicus began his account by stressing the sphericity of the Earth rather more than was warranted at the time. No doubt, he was following Ptolemy's old plan, and his chapter title *That the Earth Also is Spherical* was taken verbatim from *Almagest;* but, surely, his own readers had already heard of Magellan's trip through Pigafetta's account, published a few years before. The reason is that, for him, sphericity requires and explains rotation:

> Rotation is natural to a sphere, and by that very act its shape is expressed…" (*De Rev.*, Rosen, 17; *MKM*, 156). Why then hesitate to grant Earth that power of motion natural to its shape rather than suppose a gliding round of the whole Universe whose limits are unknown and unknowable? And why not grant that diurnal motion is only apparent in the Heavens but real in the Earth? It is but the saying of Aeneas in Virgile: "We sail forth from the harbor, and lands and cities retire. As the ship floats along in the calm, all eternal things seem to have the motion that is really that of the ship, while those within the ship feel that they and all of its contents are at rest. (*De Rev.,* Rosen, 25; *MKM*, 162).

Which is the third appearance of the moving-ship experiment; Copernicus knew Virgile well but neither Oresme nor Cusanus, and his description is much less specific than theirs. Today, we remain unimpressed by that "rotation natural to a sphere", and nevertheless applaud at the feeling behind the whole passage: the Earth is treated as merely one particular heavenly body, and the same mechanics, however deficient, apply everywhere. We are equally sensitive to the greater simplicity of the scheme:

> Consider first the diurnal rotation. By it the whole Universe save Earth alone and its contents appears to move very swiftly. Yet grant that Earth moves from West to East, and you will find, if you ponder it, that my conclusion is right. It is the vault of Heaven that contains all things, and why should not motion be attributed to the contained rather than to the container. (*De Rev*., Rosen, 20; *MKM,* 158).

Then Copernicus proceeds to quote the authority of Pythagoreans, whose actual scheme was very different, but who had been first to explain a patently obvious motion through a well-concealed one. Furthermore, he considers that not only do spheres rotate naturally, but also that smaller ones are bound to go faster

> … the bodies moving in smaller paths revolve more quickly than those many in larger paths. Thus Saturn, most distant of the planets, revolves in 30 years, and the Moon, nearest to Earth, compasses here circuit in a month. Lastly the Earth must be taken to go round in the course of a day and a night… (*De Rev*., Rosen, 22; *MKM,* 160).

In brief, the scheme involves two parallel continuous progressions in the spheres, from small to large and from fast to slow.

Far more was needed to prove Earth motion, or motions; here the main Copernicus weakness becomes apparent. He had with great success updated Ptolemy, but he was able to do very little about Aristotle. Earth could not be set in motion without novel, complete and coherent mechanics, in which field his own contribution was naught. Copernicus was not even aware of *impetus,* which might have helped. He gave a brief summary of the key Peripatetic notions: the heavy and light bodies, the natural rectilinear up or down motions of the four elements, and Earth at rest in the center of the Universe. Next, he quoted the *Almagest* passage against Earth motion: had the Earth been rotating

> … it would have been dissipated long ago … all living creatures and other heavy bodies free to move could not have remained on its surface…

He had pretty little to offer in guise of rebuttal:

> Now if one should say that the Earth moves, that is as much as to say that the motion is natural, not forced; and things which happen according to Nature produce the opposite effect of those due to force. Things subjected to any force, gradual or sudden must be disintegrated, and cannot long exist. But natural processes being adapted to their purpose work smoothly. Idle then is the fear of Ptolemy that the Earth and all thereon would be disintegrated by a natural rotation, a thing far different from an artificial act.

This objection comes from orthodox Peripatetism: Earth fails to fly apart not because centrifugal force is too weak, but because there is no kind of centrifugal force at all within any natural motion. Just the same, he was able to make a valid point none of his opponents had ever been able to counter: "Should he [Ptolemy] not fear even more for the Universe whose motion must be as much more rapid as the Heavens are greater than the Earth?" (*De Rev*., Rosen, 23; *MKM,*161).

Copernicus was well able to see that Earth rotation implied that motions cannot be merely straight or circular:

> We must admit the possibility of a double motion of objects which fall and rise in the Universe, namely the resultant of rectilinear and circular motion… Circular motion therefore may be combined with the rectilinear, just as a creature may be at once an animal and a horse. Aristotle's method of dividing simple motions in three classes, from the center, to the center and round the center is thus merely abstract reasoning… (*De Rev*., Rosen, 26; *MKM,* 163).

The composition of independent movements was a problem waiting for a solution, but Copernicus was not the one to find it. Up to this point, he has remained very far from any proof that Earth moves and Sun rests; here is at last an earnest attempt. In an often-quoted passage with obvious Neo-Platonic influences, Copernicus, having just described his own system of planetary spheres, proceeds:

> In the middle of all sits the Sun enthroned. In this most beautiful temple, could we place this luminary in any better position from which he can illuminate the whole at once? He is rightly called the Lamp, the Mind, the Ruler of the Universe; Hermes Trismegistus calls him the Visible God, Sophocle's Electra calls him the All Seeing. So the Sun sits upon a royal throne ruling his children the planets which circle around him. (De Rev., Rosen, 32; *MKM,* 169).

The language is far more grandiose than that of Oresme (who had merely handled a roasting jack), but the idea behind is the same, and has little to do with mechanics or geometry. Here goes Rheticus: the Sun must be in the center because

> …in human affairs the emperor needs not himself hurry from city to city in order to perform the duty imposed on him by God; and the heart does not move the head or feet or other parts of the body to sustain a living creature… God stationed in the center of the stage His governor of Nature, king of the entire universe, conspicuous by its divine splendor, the Sun. (*Narratio Prima,* Rosen, 139, 143).

Whether promoted to governor, king or emperor, the Sun has to be in the center, hence the Earth must be a planet. Therefore there are six of them, not five as of old, which is one more exciting consequence, and Rheticus is unstoppable:

> Who could have chosen a more suitable and more appropriate number than six? By what number could anyone more easily have persuaded mankind that the whole Universe was divided into spheres by God the Author and creator of the World? For the number six is honored beyond all others in the sacred prophecies of God and by the Pythagoreans… (*Narratio Prima,* Rosen, 147).

Copernicus himself had been free of all number mysticism, but Rheticus shows himself a true son of Pythagoras; and Kepler will prove even worse.

If the Earth is a mere planet, might planets be other Earths? Indeed, they are, and in more than one sense; here are found the two brief but sensible incursions of Copernicus in the realm of optics and physics. First, the planets are Earths, or Moons, as far as illumination is concerned; Copernicus believes himself to be following Plato, and derives an important consequence:

> If we agree with Plato in thinking that the planets themselves are dark bodies that do but reflect light from the Sun, it must follow that, if nearer than the Sun on account of their proximity to him, they would appear as half or partial circles … as with the waxing or waning Moon.[8]

[8] *De Rev.,* Rosen, 28; *MKM,* 165. When he attributes to Plato the idea that planets merely reflect sunlight, Copernicus may be alluding to a particularly obscure passage of *Timaeus* (p. 81). Plato first stresses that all planets "had been generated as living creatures"; next "God kindled a light which we now call the Sun, to the end that it might shine throughout the whole Heaven, and that all the living creatures entitled thereto might participate in Number, learning it from the revolution of the Same and the Similar."

This prediction, soon taken by opponents as a grave objection against heliocentrism, will turn into one of its greatest assets when Galileo actually observed these predicted shapes.

Second, in an even more important sense, planets are Earths because they are endowed with gravity:

> Since therefore there are more centers than one, we may discuss whether the center of the Universe is, or is not, the Earth's center of gravity. Now it seems to me gravity is but a natural inclination bestowed on the parts of the bodies by the Creator so as to combine the parts in the form of a sphere, and thus contribute to their unity and integrity. And we may believe this property present even in the Sun, Moon and Planets so that thereby they retain their spherical form notwithstanding their various paths. (*De Rev*., Rosen, 27; *MKM,* 164).

Hence, Copernicus adopted local gravity; furthermore, it was for him quasi-universal, while Plutarch had granted it to the Moon alone, and Oresme only to unspecified and somewhat virtual "other worlds." Copernicus had read neither, and did not need to: local gravity was an obligatory consequence of his own scheme. While it had still little to do with future gravitation, and could not be used to control celestial motions, his brand of gravity proved sufficient for Plurality: a planet with its own gravity is one that can be lived on.

However, Copernicus did not bestow on stars a similar gift, and the omission was deliberate, not due to distraction. Stars remained outside the whole scheme, and such was the greatest limitation of his cosmology, which must now be accounted for.

The Sun Not a Star

Even if he could not deliver a full proof, Copernicus believed the Earth to be a planet, and a common one to boot, noteworthy neither by position and velocity nor by illumination and gravity. However, he never took the Sun to be a mere star. As the above-quoted dithyramb has just shown, the Sun remained unique by virtue of its splendor and central position. The only common point with stars was immobility, but this analogy is never stressed; nowhere does one read that the Sun is fixed relative to the stars, or motionless like them. The Sun merely "sits in the middle of all", the stars no longer revolve and the heliocentric revolution stops at the frontier of the stellar sphere. Copernicus was not much concerned with stars, about which he wrote very little. Which was the attitude of a true specialist: his lifelong task had been to account in the most exact manner for all motions, but stars exhibited none, then why bother?

Still, he had to provide stars with a place of some sort, but he never managed to say whether they were located on the surface of a sphere, or within a thick one. The texts Rheticus and himself wrote on the subject are so brief that they can be quoted *in extenso*. The data consist first of the famous diagram given in his Chapter 10 *On the Order of Heavenly bodies* (reproduced p. 159); the outer circle bears the legend *Stellarum Fixarum Sphaera Immobilis*. By itself it does not prove that Copernicus confined his stars to the surface of a sphere, the drawing being far too schematic.

The thin planetary circles themselves do not represent planetary loci, but only the deferent circles from which the planets are allowed to disport themselves quite considerably. As to the text, it tells nothing more:

> Most distant of all is the sphere of the fixed stars, containing all things, being therefore itself immovable. It represents that to which the motion and position of all other bodies must be referred. (*De Rev.,* Rosen, 31; *MKM,*169).

There is also the title of his Chapter 1, *That the Universe is Spherical*, but what body, device or substance holds that spherical shape is never explained. Is it some kind of material or immaterial boundary? We do not know. In his refutation of the Ptolemy-Aristotle arguments, Copernicus wrote:

> They say too that outside the Heavens is no body, no space, not even void; in fact, absolutely nothing and therefore no room for the Heavens to expand. Yet, surely, it is strange that something can be held by nothing. Perhaps, indeed, it will be easier to understand that nothingness if we assume them to be infinite and bounded internally only by their concavity so that everything however great is contained in them while the Heavens remain immovable. For the fact that it moves is the principal argument by which men have inferred that the Universe is finite. Let us the leave to the Physicist the question whether the Universe is finite or not. (*De Rev.,* Rosen, 24; *MKM,* 162).

Hence, for Copernicus, this concavity is no external boundary of Nature, since Space and Heavens are allowed to proceed beyond; still, something concave may be in actual existence.

The Copernicus concept of stellar places is nowhere made any clearer. The immensity of Heavens relative to Earth is stressed again and again; the most specific passage is found after a discussion of planetary retrogradations induced by the Earth orbital motion: "…that there is no such phenomenon for the fixed stars proves their immeasurable [*immensum*] distance, compared to which even the size of the Earth's orbit is negligible and the parallactic effect unnoticeable." (*De Rev.,* Rosen, 33; *MKM,* 170). Which is strictly correct and clearly stated, but does not proceed beyond the point already made by Archimedes discussing Aristarchus. The question will acquire later considerable importance, as the lack of stellar parallaxes will be taken as a serious drawback of heliocentrism, particularly after Tycho's far-more accurate measurements still failed to show any; which failing was to be the main argument in favor of his own geocentric system. But three centuries later, the detection of actual stellar parallaxes by Bessel will provide the final vindication of Copernicus; most ironically, at a time when it was no longer needed, much like Foucault's pendulum did for the rotation of the Earth.

Rheticus is more definite, and shows that heliocentrism by itself did not kill anthropocentrism. His teacher had "…established by hypothesis that the sphere of the stars was created by God to be the region which would endorse within its confines the entire realm of Nature…this sphere was studded by God for our sake with a large number of twinkling stars…" (*Narratio Prima,* Rosen, 143). This image of a sphere "studded" by stars appears to locate them upon the surface. "If we follow my teacher, beyond the concave surface of the starry sphere, there will be nothing for us to investigate, except insofar as Holy Writ has vouchsafed us knowledge."

(*Narratio Prima*, Rosen, 144). Short and few as they are, these texts have been interpreted in very different manners; still, as far as Plurality is concerned, they present no ambiguity. Copernicus wisely decided that he could not measure stellar distances nor deduce their positions by pure geometry. He had no interest in their physical nature, much like Ptolemy his master; he never likened them to the Sun, nor connected them with it in any way. His Universe admitted a single center, exactly like the Aristotelian one, and there "sat the Sun enthroned"; no star was so honored. Planets were understood as centers of local gravity, but stars did not qualify. One solar planetary system had been revealed and painstakingly described; others were not to be thought of. A Plurality of Worlds in the sense of other Earths was limited to the five observed planets; it had nothing to do with the Cusanus concept. No sensible Copernican, having properly understood his Master, could believe in other stars with a planetary retinue of their own. In this sense, Kepler was fully orthodox, but, as we shall see, Bruno proved heretical.

The Copernicus Impact, or Lack of

For the historian, Copernicus presents a rare and fortunate case: the impact he had on colleagues is a truly-measured quantity, thanks to the work of Owen Gingerich. In his *Great Copernican Chase* (1992) and *The Book Nobody read* (2005), he has identified and carefully studied most of the surviving copies of *De Revolutionibus* including invaluable scribbles in the margins, some of them by Tycho himself! From his searches, we also learn that "Rheticus was so offended by the [Osiander] introduction that he struck it out in the copies that he distributed." (Gingerich 1992, p. 48).

Altogether, unlike the Cusanus cosmology, the Copernicus system was not ignored. Through his dedication to the Pope, he had insured that his book would go straight to Rome; and through the ministrations of Rheticus and some of his Protestant colleagues, it also went to Wittenberg where it was much discussed. Nevertheless, the overall impact remained (to say the least) muffled; not only during the next few years, but over the rest of a century that had still more than one half to run.

Copernicus was quite outspoken about the scandalous character of his main hypothesis. Before taking the plunge, he had hesitated for a long time; but, once committed, he did not mince words. The opening lines of the *Preface* are:

> I may well presume, most holy Father, that certain people as soon as they hear that in this book On the Revolutions of the Universe I ascribe movement to the earthly globe, will cry out that, holding such views, I should at once be hissed of the stage. (*De Rev.,* Rosen, 5; *MKM,* 149).

He braces for the shock, first from fellow astronomers:

> How I came to dare to conceive such motions of the Earth, contrary to the received opinion of the mathematicians, and indeed contrary to the impressions of the senses, is what your Holiness will rather expect to hear. (*De Rev.,* Rosen, 6; *MKM,* 150).

And, similarly, from ill-advised theologians:

It may fall out too that idle babblers, ignorant of mathematics may claim a right to pronounce a judgment on my work by reason of a certain passage of Scripture basely twisted to suit their purpose.

Which is the third apparition of Josuah in our book; it will not be the last. And he has a memorable precedent to recall:

…I well know that even Lactantius, a writer in other ways distinguished, but in no sense a mathematician, discourses in a most childish fashion touching the shape of the Earth, ridiculing even those who have stated the Earth to be a sphere… Mathematics are for mathematicians only. (*De Rev.,* Rosen, 9; *MKM,* 152).

He might have done even better, and maybe spared his Church unfathomable trouble, by quoting Augustine: "How much sorrow and pain these presumptuous Christians…".

What Copernicus did not anticipate was the rather moderate immediate reaction, even from theologians within or without his own Church; which did not justify the extreme reluctance he had shown before printing a work "kept in store not for nine years only, but to a fourth period of nine years." (*De Rev.,* Rosen, 6; *MKM,* 150). The main reason has nothing to do with himself nor with his text; it is Andreas Osiander's addition of a preliminary *Letter to the Reader Concerning the hypotheses of this Works*, actually a spurious and unsigned *Preface*. The story has often been told: Copernicus being seriously ill and Rheticus absent, the final printing supervision was left to Osiander, a Nuremberg Lutheran minister. Clearly out of theological prudence, he tried to blunt the Copernican edge enough to make it harmless:

For it is the duty of an astronomer to compose a history of celestial motions through careful and skillful observations. Then, turning to the cause of these motions or hypotheses about them, he must conceive and devise since he cannot in any way attain to the true causes, such hypotheses as, being assumed, enable the motions to be calculated correctly from the principles of geometry, for the future as well as for the past. The present author has performed these duties excellently. For these hypotheses need not be true nor even probable; if they provide a calculus consistent with the observations, that alone is sufficient… The astronomer will accept above all others the one which is easiest to grasp. The philosopher will perhaps rather seek the semblance of the truth. But neither of them will understand or state anything certain unless it has been revealed to him… (*De Rev*., Rosen, 3-4).

Which was fairly-well written, and came from a respectable Nominalist viewpoint, but still represented only the opinion of Osiander, not that of Copernicus, henceforward relegated to the role of a dealer in abstract geometry, incapable of shaking the ground from under our feet. Such an *ab initio* retraction was bound to appear as complete as that added by Oresme *in fine*. In the meanwhile, the poor author was safe from all earthly turmoils; as to his friends, they were furious at the imposture, but never managed to get their fury into clear print, and no readers were made any wiser. Still, professional astronomers (following Osiander's advice) felt free to use these convenient tools and sometimes referred to Copernicus as "a second Ptolemy." (Kuhn 1959, p. 186). They treated the Earth orb as just one more of them, and nobody had ever granted physical reality to all or even a few of the *Almagest* circles. The most tangible result was the publication of the *Prutenic*

Tables, printed in 1551 by Erasmus Rheinhold, a Wittenberg colleague of Rheticus. They proved distinctly better than the old *Alphonsine Tables*, which they quietly replaced, and were soon to be used for the Gregorian calendar reform. Even so, contemporaries could see as well as we do today that the gains had been due to (1) updated observations; (2) slightly better instruments; (3) much improved techniques of computation, e.g. Arabic numerals plus tables of sines; and ultimately (4) to the personal skill of Copernicus as an epicycle handler. None could be traced to heliocentrism.

A clear illustration of the way Copernicus was commonly used and abused is given by the English astronomer Thomas Blundeville in 1594:

> *Copernicus* … by way of supposition and not for that he thought so in deede… affirmeth that the Earth turneth about, and that the Sunne standeth still in the midst of the heauens, by helpe of which false supposition he hath made truer demonstrations of the motions & revolutions of the celestiall Spheares, then euver made before, as plainly appeareth in his booke *De Revolutionibus*… (quoted by Francis R. Johnson 1937, p. 208).

Nevertheless, a few readers did notice the discrepancy in tone between the false preface and the rest of the book; the Wittenberg scholars were first to react, as they may have been directly aware of Osiander's role. Anyway, Luther himself gave the mood as early as 1539, even before the printing of *Narratio Prima*; in his *Table notes* (actually taken by bystanders), he reacted just like Lactantius:

> People gave ear to an upstart astronomer who strove to show that the Earth revolves, not the Heavens or firmament, the Sun and the Moon…This fool wishes to reverse the entire science of astronomy; but sacred Scripture tells us that Josuah commanded the Sun to stand still, not the Earth.[9]

Fourth intervention of *Josuah, 10:13*; after Galileo, such knee-jerk reactions will become too numerous to quote. At Wittenberg, Rheticus seems to have stood alone in his wholehearted acceptance of the Copernican hypothesis, but he no longer published anything on the subject after leaving his Master. Philip Schwarzerde (better known under the Greek-form of his name Melanchton), lay Head of the establishment, reformer of education and author of many textbooks, some of them scientific, at once condemned "that Samartian astronomer, who sets the Earth in motion." (*Three Treatises*, Rosen, 400). Later, in his *Initia Doctrinae Physicae*, Melanchton brought together the common-sense arguments and those from Scripture:

> The eyes are witnesses that the Heavens revolve in the space of twenty-four hours. But certain men, either from the line of novelty, or to make a display of ingenuity, have concluded that the Earth moves, and they maintain that neither the eighth sphere nor the Sun revolves… Now it is a want of honesty and decency to assert such notions publicly, and the example is pernicious. It is the part of a good mind to accept the truth as revealed by God and to acquiesce in it.

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[9] Quoted by Kuhn (1959), 191. Contrary to what has sometimes been stated, Calvin seems to have made no attack on Copernicus (Oberman 2009, 139, 162), while Erasmus may have been favourable (see *Three Treatises*, Rosen, 358).

Next came a Scriptural quotation, to be later tiresomely repeated by Catholics and Protestants alike, that of *Ecclesiastes I: 4–5*: “The sun also ariseth, and the sun goeth down and hasteth to his place where he arose.” (Kuhn 1959, 191). But the Bible could equally-well be twisted in the opposite direction: did not *Job 9:6* say “Who shaketh the Earth out of her place and the pillars thereof tremble”, which made better sense by following Copernicus? (Quoted by Dreyer 1905, 353). However, Didacus Stuniga, the Toledo Augustinian monk who proposed this reading, attracted no followers.

Melanchton was one of the few writers of the time who condemned both heliocentrism and Plurality. He does not seem to have made any physical connection between the two issues, and his surviving arguments are solely theological:

> There is but one Son of God, our Lord Jesus Christ… He did not appear in other Worlds nor was he dead and resurrected there. Nor is it to be thought of that Christ was often dead and resurrected… In any other World, without the sacrifice of the Son of God, men could not be brought to eternal life. (Quoted as summarized by Mac Colley 1936, p. 413).

These troublesome problems (which Tempier had wholly failed to anticipate) were to induce voluminous discussions in the future.

On the Roman side, there seems to have been no official reaction to the Copernicus book, and Pope Paul III accepted the dedicatory *Letter* without recorded comment. One wonders at the reasons; Catholic authorities may have been misled by the Osiander *Letter*, which they had no reason to suspect: then, why bother about a treatise of pure mathematics? Moreover, with his reference to Lactantius, Copernicus held an argument that carried no weight for Protestants, but maybe embarrassed some thinking Catholics. Nobody seems to have remembered the Tempier decrees, and indeed, there was little reason to do so: the Bishop of Paris and his Committee had never been concerned with mathematics, Ptolemy nor Earth motion. It is merely by hindsight, and because we know of the seventeenth-century explosive developments, that we perceive today the alliance between those two key steps in the ultimate de-centering of Man: first, God being granted freedom to create other Worlds, and second the Earth acquiring freedom of motion. At the time, most Catholics must have felt heirs to centuries of Scholastic exegesis, while Scripture-based fundamentalism was a more Protestant attitude; nobody within all extant Churches felt any immediate or personal threat, and no steps were taken to refrain heliocentric propaganda. The change came with the Counter-Reform (of which both the Bruno and Galileo trials were clear episodes) and *De Revolutionibus* was to be put on the *Index* only in 1616, i.e. after the telescopic discoveries.

No conclusion on Copernicus is needed at this point; he never wrote anything about Plurality himself, none of his immediate readers saw the long-term implications of his work, and for all practical purposes the Earth remained unique. The actual revolution, that of the celestial orbs and much else besides, will be generated not by *De Revolutionibus* nor indeed by any other book-in-print, but by a commonplace device that had nothing to do with the world of the mind: the lowly glass lens.

Chapter 8
Giordano Bruno: Lame Compasses But Agile Pen

Thus is the excellence of God magnified and the greatness of His kingdom made manifest; he is glorified not in one but in countless Suns, not in a single Earth, a single World but in a thousand thousand, I say in an infinity of Worlds.

Giordano Bruno, *De l'infinito.*[1]


(left) Giordano Bruno, 19th century, from an engraving of 1578. Wikimedia Commons
(right) Statue of Giordano Bruno in Campo di Fiori, Rome, the place of his execution (1889). Wikimedia Commons

[1] Bruno (1584) *De l'Infinito Universo e Mondi,* translated by Dorothea Waley Singer as *On the Infinite Universe and Worlds* (hereafter *De l'Infinito*)*,* 246; in the accompanying *Giordano Bruno, his life and thought,* Singer gives a substantial biography, a study of his philosophy and cosmology, and particularly of his Italian cosmological works. Sources on Bruno have been his major works: Bruno (1584) *La Cena de le Ceneri* translated by Stanley L. Jaki as *The Ash Wednesday Supper* (hereafter *La Cena*), with very-valuable Introduction and Notes; Also, *The Cosmology of Giordano Bruno* by Paul-Henri Michel, *The Infinite in Giordano Bruno* by Sydney Greenberg, and Koyré (1957), mostly Chapt. II and III). See also *Jordani Bruni Opera latine conscripta*.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-41448-1_8

Less than a quarter of a century after Giordano Bruno's death on the pyre in 1600, he was already taken by Francis Bacon as a model of what the scientist should not be like. Bacon lists all the main philosophers of antiquity who "…invented systems of the Universe each according to his own fancy like so many arguments of plays… some were more elegant and probable, others harsh and unlikely. Nor in our own age has the practice entirely ceased." And he names Brunus (Bruno) together with half a dozen other moderns who "have come upon the stage with fresh stories neither honored by approbation nor elegant in argument." (Bacon 1622; This quote is reproduced or paraphrased by all authors dealing with Bruno). The hallowed father of the experimental method could not have been more correct in his overall estimate of Bruno, whose doctrines mostly proceeded from an unbounded imagination. However, elegant or not, the particular fancy Bruno concocted about the Universe structure happens to be correct, while Bacon himself (who never even endorsed Copernicus) remained flatly wrong.

At the end of that century of which Bruno had seen but a few days, Pierre Bayle's 1697 *Dictionnaire Historique et Critique*, which marks a milestone in the rationalist and tolerant approach to religion, presented an equally hostile picture in the article on Bruno:

> A man with a great mind, but one who made poor use of his lights; not only did he attack Aristotle's philosophy at a time when this could not be done without exciting thousands of troubles… but he also attacked the most important truths belonging to faith… a personage who in matters of Philosophy behaves as a knight errant…one says that he wrote books in which he affirmed there were many worlds, all eternal. (Bayle 1697).

What a sad contrast with Bayle's appreciation of Bacon himself, but a few pages distant: "One of the greatest minds of his century, and one of those who best understood the imperfect state of Philosophy."

One might go on. In a comprehensive *Histoire de la Science* (Daumas 1957, p. 457) Bruno is dismissed in four lines; and in Dreyer's 1905 *History of Astronomy*, he is granted twenty-five, on a par with Epicurus and Lucretius. In between, we learn with some amazement that a few earnest nineteenth-century Catholics tried to prove that Bruno had not really been burned. However, the same century also generated a wildly misguided surge of enthusiasm about Bruno taken as a paragon of materialistic atheism, martyred by obscurantist forces, and no less than 634 publications; plus at least two statues, one in the Rome *Campo dei Fiori* and the other in a quadrangle of the Naples University. All of which does not greatly help for unraveling Bruno's personality. Such a complex one defies the present author's powers of description, and he will take refuge (as usual) in quotations. First, from Bruno himself: "…a miserable wanderer…hated by the academics, the adversary of every accepted doctrine, praised by few, approved by none, pursued by all." (*De l'infinito*, 351). For a nutshell definition, try Edwin Arthur Burtt "An incorrigible intellectual radical" (Burtt 1954, p. 56); for a finely–chiseled epigraph, his modern translator Stanley Jaki: "a soaring poet, an exalted mystic, an ardent pantheist, an instructive catholic, a born philosopher, a wizard of mnemotechnics, a vitriolic critic, an amateur scientist, a muddled dreamer, a secretive cabalist, a dabbler in magic, a flamboyant reformer and an amorous rogue." (*Introduction* to *La Cena,* 9). Who solved that mysterious structure of the Universe to boot; not so bad for an amateur.

There is no question that Bruno cannot rank as a precursor of modern science on any count. He was not merely indifferent to precise observation or experimentation, but also actively hostile to mathematics. Whenever one tries today to follow his system of causes and explanations, he is found useless, or worse; in particular, he constantly promotes such a sweepingly animistic view of Nature that all antique hylozoism looks stale by comparison. And yet it was Bruno and no one else who invented the correct model of our local Universe: scattered, randomly located sun-stars, many with their own retinue of planets. The last century may have made the said Universe more complex by introducing additional hierarchies (e.g., galaxies as separate entities), but the Bruno model remains a permanent acquisition of science which risks no more obsolescence from future discoveries than the atomic structure of matter. Both have been refined; neither can be junked. Beyond the orbit of Saturn, where the most skilled ancient or modern geometers had failed, where Copernicus himself timidly stops his revolution, it is Bruno who succeeds; Bruno who distrusts mathematics as much as Epicurus had done; Bruno who invariably loses his way through the most elementary geometrical problem; Bruno whose few and lamentable diagrams are constantly absurd, or incoherent with his text, or both. And yet, when he pictures or locates the stars, he is always right where all professionals go wrong, and wrong in the most naive manner. This result he achieves led by the mind's eye alone and by no earthly one, being even less an observer than a mathematician. One wonders what would have been his reaction had he looked through Galileo's telescope, which he failed to do by a mere ten years, due to the zeal of the Holy Office. The speculation is idle: Bruno distrusted the senses just as much as reasoned logic. For him, the Universe was infinite and homogeneous because the Creator could not have failed to see (like himself) that such was the best scheme.

For these eternal truths, he never anticipated nor wanted any sort of human confirmation; still, he did not keep his fancies hidden away within a few manuscript pages, nor reserved for the ears of selected disciples. Unlike Copernicus, Bruno had neither Pythagorean leanings towards secrecy, nor any fear for himself. Throughout most of his knight-errant life, he preached and wrote the good news with an evangelic fervor, and a conviction of being in the right just as boundless as his Universe. And ultimately, he gave to his great vision the most striking publicity by his ultimate refusal to recant, and flamboyant public demise.

A general account of Bruno's philosophy will not be attempted any more than a biography. Cusanus' thought proves difficult enough for the scientist, but it is at least coherent; Bruno's is as complex and erratic as his life, and specialists despair of presenting a correct view. For Gentile "there is no unity, coherence or development in a philosophy that affirms at one time the doctrines of Parmenides and Heraclitus, the combination of Eleatic monism and Neoplatonism, the doctrine of the Universal Soul and the mechanistic theory of Democritus… and both the positive and negative positions in religion." (quoted by Greenberg 1978, p. 7). In such a complex case, "too many of Bruno's interpreters bestow their own individuality upon his philosophy so that Bruno will be found to appear as a materialist, an atheist, a pantheist, and sometimes in his true character, as an idealist." (Frith, quoted by Greenberg 1978, p. 5). Koyré makes the point more concisely: "Giordano Bruno, I am sorry to say, is not a very good philosopher; combining Lucretius with Cusanus does not produce a self-consistent mixture." (Koyré, 77. For a study of Cusanus and Bruno, see Védrine 1970, p. 211–223).

Thus, bad philosophy has produced good cosmology. In our Chapter 1, after discussing the two principal lines of thought about the structure of the Universe in the antique world, we concluded that the needed synthesis had never been tried. The Epicureans, heirs of the Atomists, had exhibited boundless naivety in their rejection of mathematical astronomy results, including the spherical Earth. Their opponents, heirs of Pythagoras and Plato, had shown equally simple minds when extrapolating its fully proven shape to utterly fanciful celestial spheres. Both sides had followed well-defined philosophical streams, recognized and approved by historians of thought. Here, at long last, we have with Bruno the unification we hoped for; woe! that synthesis comes from a thinker impossible to classify, in no way heir to any of the great schools, but a despicable syncretist. Worse, he cannot either be counted as a precursor of modern science, having completely missed the role of both mathematics and experimentation: he anticipates neither Kepler and Descartes, nor Galileo and Bacon. And, as an ultimate and damning touch of cosmic irony, not a single one of these great actors of our scientific revolution was to adopt, nor even to understand, Bruno's sweeping concept: Kepler and Bacon from blindness, Galileo and Descartes through prudence.[2]

If Bruno borrows from all and sundry, there is at least one school that he outspokenly rejects: Peripatetism, the dominant one in his own time. For him, Aristotle is the archenemy, far more so than Ptolemy whom he seldom if ever mentions: Ptolemy had been a mere mathematician, who did not claim to present a physical picture of the World. Aristotle, who had believed himself able to explain all of Nature, is attacked by Bruno in countless pages, often with brilliant wit. Still, one of Bruno's major inconsistencies is that he is unaware of actually borrowing a great deal from the Stagyrite: much of his language and argumentation, several basic creeds like indissolubility of form and matter, four elements out of five, and (most important), that animism which he was to develop in the most exuberant manner.

As far as cosmology is concerned, the main sources of Bruno are obvious enough, and he is quite explicit about them. First, Lucretius whom he quotes willingly; second, Copernicus on whom he will bestow apt praise but also some criticism:

> a man who in regard of natural judgment was far superior to Ptolemy, Hipparchus, Eudoxus; a man who had to liberate himself from some false presuppositions of the commonly accepted philosophy, or perhaps I should say blindness. But for all that, he did not move too much beyond them, being more intent in the study of mathematics than of Nature… (*Cena,* 56).

[2] Still, Bayle writes that "…*Monsieur Descartes a pris de lui quelques unes de ses idées*" (Mr. Descartes has taken from him some of his ideas). Indeed, Descartes (who stood poles apart from Bruno on all fundamentals) had read him, and some faint traces of Bruno may be looked for in his *Principia*.

And third, Cusanus, whose astronomical concepts he will adopt or reinvent; here is his qualified praise:

> This honest Cusan has known and understood much; he is indeed one of the remarkably talented men who has lived in our own world. As to the apprehension of truth however… he did not see the light continuously, openly and clearly… (*De l'infinito,* 307).

He will often refer to him as "the Cusan", and to himself as "the Nolan". Lastly, there is also in Bruno a strong Hermetic strand; some trace of Hermetism has already been found in Cusanus, and even in Copernicus.

Even so, on all essentials Bruno stands unsupported, and proud of his aloofness; unlike Copernicus, he does not take shelter behind ancient authority. When writing about Earth motion he adds:

> …it counts little for the Nolan that Copernicus, Niketas the Pythagorean from Syracuse, Heraclitus of Pontus, Ekphantus the Pythagorean, Plato in Timaeus … the divine Cusanus in the second book of his De Docta Ignorantia have said, taught and confirmed beforehand; because he [the Nolan] holds it for other specific and more solid principles by which not through authority but through real evidence and reason, he has this for as certain as anything else that can be had for certain. (*Cena,* 98).

Alas! Bruno is fully correct only about that lack of authority; for evidence of Earth motion, he adduced none and contributed himself very little reason but plenty of faith.

For all the authors we have met so far, the choice for or against Plurality had been a relatively minor issue. With Bruno the case is different: for the first (and last) time, Plurality holds the center of the stage. One would probably come closer to a correct picture of his thought by asserting this pivotal theme first, and deducing all non cosmological divagations as mere consequences. Quotations about cosmology may be collected in luxuriant abundance from most of his books, while in the case of Cusanus they were all found within a few nearly hidden pages. The most relevant lines come from the three major Italian dialogues; these were published in London during Bruno's most productive years in the retinue of the French ambassador to the court of Elizabeth I, in 1583–1585. All three take the form of a conversation between one Theophilo or Philotheo (i.e. the Friend of God, the standard mouthpiece of Bruno), and a few listeners, including one Burchio, simple-minded Peripatetic ancestor of the Simplicio in the Galilean *Dialogues*. The most readable Bruno's book is clearly *La Cena de le Ceneri* (*The Ash Wednesday Supper*), which includes some dialogue so vivid that some parts could well be acted on the stage: it comes from the same pen that produced a comedy*, Il Candelaio* (The Torchbearer), from which Molière was to borrow several scenes. The somewhat stiffer *De l'Infinito Universo e Mundi* (On the Infinite Universe and Worlds) is the most relevant one for our task, since it contains all the main points, only sampled in other works. The *De la Causa, Principio et Uno* (*On the Cause, Prime Origin and the One*) of 1584 ranks third in interest for the cosmologist. Next, the Latin poem *De innumerabilibus immenso et infigurabili* (*On the Innumerable, the Immense, the Formless)* was written in Helmstedt and printed in Frankfurt in 1591 (*Cena*, *Introduction* by Jaki, 19). This is his last book, since Bruno was jailed by the Inquisition in Venice before the end of that year; hence, his whole scientific output had been compressed within seven years. The *De innumerabilibus Immenso,* often considered his major work, is less accessible because of excessive length and lack of a full translation; while it presents no important concept not already developed in the *De l'infinito*, it does vividly illustrate a few points, and will be quoted only occasionally.

From Philosophy to Cosmology

We shall extract and discuss three main themes before reaching more technical points. They are Bruno's faith in an unlimited Divine Power, as spurred by the maximum Good, his rejection of mathematics and his universal animism. All three attitudes have since failed as guides for science, and the third must have already appeared strange to a few of his contemporaries. Still, such were his guidelines to the infinite, homogeneous universe.

The theme of unbridled Divine Power, able to fill a boundless space with other Worlds, has already been abundantly discussed in the previous chapters. The additional step of requiring God to do so in actual fact had been taken by Cusanus, although nobody seemed to have noticed. Hence, no truly original contribution is to be expected from Bruno on this count; still, one must show how he adopted and promoted the concept. He never mentioned the Tempier *decrees*, no more than Cusanus had done: three centuries of dust had accumulated. Even if they had become topical again, one doubts whether Bruno would have felt the need to quote any ecclesiastical authority; like Cusanus again, he had little use for Scripture to rest his world model upon. Neither did he show any interest in any of the Catholic-Protestant controversies prevalent in his own time.

The Maximum Good argument has always proved convenient for demonstrating either Plurality or Unicity, according to the argumentator's inner bent. To start with, *De l'Infinito* summarizes the view of Bruno's opponents, which has its roots in Plato:

> Unity is better than multiplicity…to perfection nothing can be added. If then this World is perfect, certainly there is no need for another to be added to it." And elsewhere: "Since unicity is better than multiplicity, *ceteris paribus*, why is the substance divided among four or six or let us say ten Earths, rather than forming a single great and perfect globe?…To perfection, nothing can be added. If this World is perfect, certainly there is no need for another to be added to it. (*De l'infinito,* 358).

However, the strongest objection to Plurality had long been a logical one, and remained an essential tenet of Peripatetism: God Himself cannot create whatever is not susceptible of creation, because He remains bound by logic (that is, the human brand):

> If there were an infinity of Worlds, or even more than one, this would be the case because God could fashion them thus, or rather because they could depend on God. But most true though this may be, it does not follow that these Worlds exist, for beside the active power of God there is needed the passive power of things…Insofar as concerneth the nature of the World, there cannot be more than one even though God can make more. (*De l'infinito,* 358–9).

Such a paltry view of Divine Omnipotence Bruno sweeps away with devastating efficiency. Here goes his Philotheo: "I ask you whether it is well that this World [i.e., just the visible one] exists?" The poor opponent cannot escape answering "It is very well", and the unavoidable conclusion falls.

> …just as it would be ill were this our space not filled, that is, were our World not to exist, then since the spaces are indistinguishable, it would be no less ill if the whole space were not filled. Thus we see that the Universe is of infinite size, and the Worlds therein without number. (*De l'infinito,* 256).

In these non-distinguishable spaces, we find a trace of the Cusanian principle. According to the Brunonian Gospel, here is the true concept of Divine Omnipotence:

> Why should we wish to assert that [Divine Goodness] would choose to be scarce, and to reduce itself to naught, for every finite thing is as naught in relation to the infinite? … Why wouldst thou that God should in power, in act, or in effect (which in Him are identical) be determined at the limit of the convexity of a sphere rather than he should be the undetermined limit of the boundless… (*De l'infinito*, 260–1).

Bruno has perused Cusanus, and acknowledges the fact on many occasions; but the German Cardinal is left far behind when Bruno sings the unbounded enthusiasm which the sight of this Universe he has just demonstrated induces in his heart. Despite much painful evidence of the contrary down here, everything is good for whoever takes the trouble to behold the whole picture:

> Here is the philosophy which sharpeneth the senses, satisfieth the soul, enlargeth the intellect and leadeth man to that true bliss …Since we are all subject to a perfect Power, we should not believe, suppose or hope otherwise than that even all issueth from good, so too all is good, through good, from good, by good means towards a good end. For a contrary view can be held only by one who considereth merely the present moment, even as the beauty of a building is not manifest to one who seeth but one small detail. (*De l'infinito*, 244).

At the end of a long but predictable road, we glimpse the silhouettes of Voltaire's Pangloss and Candide, serenely disputing on universal causes and consequences: "Consequently, those who ventured that everything is good have made a silly mistake; they should have said that everything is for the best." Thereupon the two Voltaire heroes will be caught under the most appalling cascade of hilarious disasters, at once interpreted as nicely fitting within the Plato-Bruno-Pangloss creed of universal underlying Good.

For the time being, no clouds are in sight; Bruno, convinced of being an orthodox Christian, has rediscovered Epicurean *ataraxia* through infinite Plurality. His Church will soon most pointedly disagree, but Bruno still has a few years to enjoy his newly found freedom. He does nor fear to bring in Democritus and Epicurus, nor to consider essential Change:

> We do not fear that by the violence of some erring spirit, or by the wrath of some thundering Jove, that which is accumulated in our World could become dispersed beyond this hollow sepulcher or cupola of the Heavens … There are no ends, boundaries, limits nor walls which can defraud or deprive us of the infinite multitude of things… Thus Democritus and Epicurus, who maintained that everything throughout infinity suffereth renewal and restoration, understood these matters more truly than those who would at all costs maintain belief in the immutability of the Universe. (*De l'infinito,* 245).

Quite soon, many will derive from the de-centering of their home planet a sense of crushing loss; and also (somewhat later), from the similar loss of that comforting immutability through Evolution. Still, Bruno shows that modern Plurality had been born not in pain, but in joy.

From his rediscovery of Atomism and Epicureanism, Bruno draws a staggeringly brilliant indictment not merely of Peripatetism, but of all those narrowly anthropocentric cosmologies that were stuffing the textbooks ever since that great reactionary, Plato, had made them respectable:

> Make then your forecasts, my lords astrologers with your slavish physicians, by means of those astrolabes by which you seek to discern the fantastic nine moving spheres; in these you finally imprison your own minds, so that you appear to me but as parrots in a cage, while I watch you dancing up and down, turning and hopping within those circles. We know that the Supreme Ruler cannot have a seat so narrow, so miserable a throne, so straight a tribunal, so scanty a court, so small and feeble a simulacrum that a phantasm can bring to birth, a dream shatter, a delusion restore, a chimera disperse, a calamity diminish, a misdeed abolish, and a thought renew it again, so that indeed with a puff of air it were brimful, and with a single gulp, it were emptied. On the contrary, we recognize a noble image, a marvelous conception, a supreme figure, an exalted shadow, an infinite representation of the represented infinity. A spectacle worthy of the excellence and supremacy of Him who transcendeth understanding, comprehension and grasp. Thus is the excellence of God magnified and the greatness of his kingdom made manifest; he is glorified not in one but in countless Suns; not in a single Earth, a single World, but in a thousand thousands, I say, in an infinity of Worlds. (*De l'infinito,* 245).

Whew! If true scientists proved able to write that kind of prose, superbly translated by Dorothea Waley Singer, Science would get a better hearing. Are most of us "slavish physicians" any more eloquent than those caged parrots?

However, the synthesis attempted by Bruno all by himself was bound to fail. From Plato, thinkers had to keep the geometrical view of Nature, and learn to use it properly. Pulverizing the spheres meant that one could do away with orbs, but orbits still had to be observed and described in mathematical terms. Here, he no longer shows the way, but just the reverse.

From Cusanus, Bruno had borrowed what we have called (for want of a better name) the Principle of Universal Indetermination. For the Nolan just as for the Cusan, perfect geometrical shapes or regularities cannot be found in the real world:

> First, as no one of the natural bodies is found to be perfectly round and consequently with an exact center, so among the sensible and physical motions which we see in natural bodies, there is none which would not differ by far from the perfectly circular and regular movement around some center, try as may those who … doctor up Nature to the point of making it a servant of Master Aristotle. (*Cena,* 111).

Consequently, even while adopting heliocentrism with enthusiasm, he felt far closer to Cusanus than to Copernicus. When discussing the Copernican Earth motions, he concludes.

> Although many have wearied themselves in trying to find the true rule of such motions, they did so in vain… because none of these motions is in fact regular and capable of being worked upon by the geometrical file. (*Cena,* 165).

Still, there is a sorry difference with the Cusanian attitude. Cusanus had been a competent mathematician, but one who thought mathematics simply irrelevant to the description of the Universe; in a like way, every astronomer who happens to be a musician does not feel called to support the harmony of the spheres.[3] However, Bruno, who lacks mathematical training, repeatedly tries to explain his meaning in problems involving perspective, apparent diameters, the horizon etc… with diagrams, seven of them in *Cena.* The result is rather disastrous; for instance, he manages to demonstrate that a small luminous body can illuminate more than half of a bigger spherical one, provided the distance is large enough! Also, that an even larger opaque body, placed in between, would not produce occultation (*Cena,* 106-7). This particular demonstration is not pointless: it fits within an attempt to explain why his putative planets around distant stars cannot be seen. Which is all the more unfortunate, because he has presented, in other places, perfectly sensible arguments as to why such planets remain invisible: they are just too small and too far away. Whenever plain common sense is adequate, Bruno shows plenty of it; his model of the Universe, soon to be discussed, is not just derived from Divine Omnipotence, but does save the main phenomena. However, when ruler and dividers are required, he is lost, and does not realize his own ineptitude.

Consequently, Bruno follows next to nothing of the technical demonstrations that form the core of *De Revolutionibus*. Which does not prevent him from perceiving the two most profound points: Copernicus had been too much of a geometer, and his elaborate epicyclic machinery was of little help in understanding Nature; but at the same time, Copernicus had truly believed in the Earth as one more planet. Bruno knows nothing of the Osiander episode, but guesses the truth just from the tone of the spurious *Preface* added to *De Revolutionibus*, and prints it with characteristic vigor: "… a certain epistle attached to it by I do not know what ignorant and presumptuous jackass." (*Cena,* 95). Altogether, his lack of mathematical ability has served him well, by enabling him to discard from the Copernicus book precisely those elaborate geometrical parts that were not to stand the test of time. And those of us who truly feel physicists, i.e. students of Nature, cannot help applauding Bruno when he writes:

> Reflected and direct rays, acute and obtuse angles, perpendicular, incident, oblique and horizontal lines, larger and smaller arcs, such and such an aspect are mathematical circumstances and not natural causes. One thing is to play with geometry, and another is to prove with nature. (*Cena,* 150).

Most excellently said! Today, almost all astronomers (including the present author) have never bothered to read more than that first book of *De Revolutionibus*. The reason why they do not is that Kepler made obsolete all the five other books at one stroke, while Bruno (stuck with his strictly-qualitative approach inherited from Epicurus and Cusanus) never even felt the need for a Kepler.

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[3] Examples of both attitudes about music: Kepler devotes immense effort to Pythagorean fancies in his *Harmonia Mundi*; but Huygens, who also displays in *Cosmotheoros* a vivid interest in music, has no place for Pythagoras when he considers planetary motions.

However, we cannot find any redeeming point within Bruno's universal animism. Here he outruns Aristotle: his entire World mechanism is powered by living forces. Such is probably the main reason why he was so completely forgotten during the mechanical age that was soon to rise. For Descartes, every animal became a machine; for Bruno, every machine had been an animal. The animist descriptions of celestial bodies (in fact, of all bodies) are so frequent and so precise that they cannot be mistaken for analogies: they are explanations. For Bruno, the Earth is not like a living creature, it is one. So are all other planets and stars, such is the grand master plan, Animism and Plurality are intimately connected as automatic consequences of Universal Good:

> There must be innumerable individuals, those great animals, whereof one is our Earth, the divine mother who has given birth to us, doth nourish us and moreover will receive us back; and to contain the innumerable bodies there is needed an infinite space. Nevertheless, it is well that there should be, since there can be innumerable Worlds similar to our own, even as our World hath achieved and doth achieve existence, and it is well that it should exist.

And the fundamental similarity of Earth and other bodies resulting from their common animal nature is stressed again and again:

> As our Earth is constituted by her own members, undergoeth changes, with flux and reflux of her parts, as we have seen happeneth to animals whose humors and parts suffer continual alteration and motion, so also the other stars are constituted by their members which are similarly affected." (*De l'infinito,* 257 and 331).

In *De l'Infinito*, one Fracastoro, both astronomer and physician, is usually given the task of elaborating on the animist theme, with properly stupefying results; within stars,

> these dissimilar parts must be understood to be disposed according to their various and diverse complexions of rocks, pools, streams, springs seas, sands, metals, caverns, mountains, plains and other similar sorts of composite bodies, sites and shapes; in the same fashion among animals the parts are named heterogeneous according to the diverse and varied complexions of bones, intestines, veins, arteries, flesh, nerves, lungs members of one or another shape presenting their excrescences, hollows, caves, waters, spirits fires, with the accidents corresponding to all meteoritic impressions such as catarrhs, inflammations, stones, vertigoes, fevers and innumerable other dispositions and qualities corresponding to mists, rains snows, heats, lightnings, thunderbolts, thunders, earthquakes and winds, tempests, torrid or that toss sea-weed. (*De l'infinito*, 314-5).

Brunonian animism is in itself a sizeable subject, not to be properly treated here. An analysis is given for instance by Paul-Henri Michel (1973) in his *Living Universe* chapter; from many quotations, he is able to show that such celestial animals have been given (a) a soul of their own; (b) bodies with internal heat (obvious enough in the Earth's case); (c) organs (as quoted above); (d) sexes, Suns being male, and Earths female; (e) intelligence: "Do you think that this soul is sensitive? Not only sensitive, replies the Nolan, but also intelligent; not only intelligent as ours, but perhaps more so." (*Cena,* 116; quoted by Michel 1973, 262). To crown the picture, Space is just as much alive as the stars themselves: "Moreover, I say that this infinite immensity is an animal, though it hath no determined form nor perception of exterior things for it is imbued with all soul and embraces all life and it is the whole of life." (*De l'infinito*, 300). From which premises, Bruno's character Philotheo proceeds to show that the Peripatic absolute lightness or heaviness concepts are absurd;

we applaud the conclusion but shrink from the argument. Michel's summary: "In Bruno's mind, the life of celestial bodies is not a legend, a symbol or a metaphor, but one of the theorems of his physics, and the fundamental axiom of his astrobiology." (Michel 1973, 300).

A last question emerges: Here is a disciple of the Atomist and Epicurean creeds, who (as we shall see later) fully endorses atoms; how is he able to fit in his essential teleology? The answer is: he just does, and out of his many doctrinal inconsistencies, that is perhaps the worst: "I do not adhere so much to the concepts of Democritus. I do not accept his impious elements. On the other hand, I recognize the existence of a high fatherly spirit through which all these elements are governed." (Bruno, *De Immenso* V, 3, quoted by Michel 1973, 257). Similarly, under the different Parisian climate, Gassendi will soon erect a Christian form of atomism, but with little success. Alas! Bruno had tried to make his atoms respectable by providing them with intelligent design and purpose, but all to no avail. The Holy Office was to unmask these poorly-disguised converts as heretics, i.e. worse than mere pagans by far, and to act accordingly.

The Infinite Homogeneous Universe

The Lucretius-Cusanus principle of universal homogeneity is central in the Brunonian thought, and already appears in the introductory epistle of *De l'Infinito*:

> We are no more circumferential to those others than they are to us; they are no more central to us that we to them. Just as we do tread our star and are contained in our heaven so also are they. (*De l'infinito*, 244).

However, the same principle will achieve with Bruno far greater precision and clarity when stressed in different contexts, and chiefly by application to well-chosen special cases. Poor geometer as he is, he hits upon a fortunate analogy between the illusory horizon seen from the two-dimensional surface of the Earth, and the appearance of a celestial vault when all three dimensions are considered. Both illusions similarly arise from the weakness of the senses:

> No corporeal sense can perceive the infinite… our sense perception … confesseth its own feebleness and inadequacy by the impression it giveth of a finite horizon, an impression moreover which is ever changing. Since then we have the experience that sense perception deceiveth us concerning the surface of this globe on which we live, much more should we hold suspect the impression it gives thus of a limit to the starry sphere. (*De l'infinito*, 251).

That much had been established in the *First Dialog*; in the second, Bruno proceeds further, because such an illusion is universal, and not peculiar to Earth dwellers:

> Thus we on Earth say that the Earth is the center … so without doubt those who inhabit the Moon believe themselves to be at the center [of a great horizon] that encircleth the Earth, the Sun and the other stars, and that is the boundary of the radii of their own horizon. Thus the Earth no more than any other World is at the center… the same is true of all other bodies, these may all be regarded either as centers or as points on the circumference, as poles or zeniths and so forth. The Earth is central only to our own surrounding space. (*De l'infinito*, 280).

This simple and excellent comparison with our familiar horizon line seems never to have been formulated before. The analogy will prove adequate not merely to the problem at hand, to wit that an unbounded model of the Universe does save the appearances of the celestial vault; it has a great future of its own as a pedagogical device for introducing a fourth dimension starting from our homely three, and we commonly speak nowadays of "hyperspheres" and "cosmological horizons," which were still in the distant future. The more immediate progress (compared to Lucretius and Cusanus, who had both remained unspecific), is this application of the Cosmological principle to our familiar Moon: for any Lunar dweller, the scenery is bound to appear similar to the one we see on Earth. The theme will soon be developed (with the help of impeccable geometry) by Kepler in his *Somnium*; and the Keplerian picture was to be so definitive that after him nobody is found worth quoting before Armstrong and Aldrin within the Apollo 11 project. Who will merely confirm.

Bruno demonstrates again and again the same felicitous ability to visualise the celestial scene from diverse vantage points. The results he wants to establish look quite elementary, unless one remembers where all his opponents were stuck. For instance

> Just as from Earth (itself a Moon) the diverse parts of the Moon appear, some more, some less bright, so from the Moon (itself another Earth) can the diverse parts of this Earth be distinguished by the variety and difference of the portions of her surface. Moreover, just as if the Moon were at a greater distance from us, then the diameter of the opaque parts would fail while the bright parts would tend to unite for us and shrink in our view, giving us the impression of a smaller body of uniform brightness, similar also would be the appearance of our Earth as seen from the Moon if the distance between them were greater. (*De l'infinito*, 312-3).

Here Bruno does fairly well, because he merely applies common experience: a given object, placed at increasing distances, loses all recognisable features, and becomes a mere point; but whenever he attempts to geometrize the same concepts, the result is a complete muddle: see e.g. the diagram in *Cena,* Fig. 1 p. 103: a highly-confused attempt to demonstrate that by going further away, we may see more of the Earth but in less detail.

Bruno still pursues the same thought when he presents his own version of the ship experiment. In *De l'infinito*, he merely stresses visual scenery:

> If we suppose a person within a moving ship in the midst of waters who knoweth not that the water is in [relative] motion nor seeth the shores…he would be unaware of the motion of the ship. For this reason… I am able to believe that if I were in the Sun, the Moon or any other star, I should always imagine myself to be at the center of a motionless world around which would seem to revolve the whole surrounding universe.[4]

[4] *De l'infinito*, 311. In *Cena*, 122, Bruno discusses almost adequately the fall of a stone aboard a moving ship, but without making any new point compared to Copernicus. His discussion is roughly correct because no geometry is involved: it is enough to start from the *a priori* feeling that the motions are the same within the ship. Bruno seems to be understanding motion in terms analogous to those of *impetus* theory: "…the stone which leaves the hand of the one supported by the ship, and consequently moves with its motion, has such an impressed virtue which is not had by the other who is outside the ship…" He provides a nice engraving of a sixteenth century warship under full sail; a hard wind is blowing, making the sea is so choppy that the experiment would never work due to ship rolling.

Furthermore, he is even capable of describing correctly the visual appearance of an Earth-Moon trip: all terrestrial features progressively vanish while the lunar ones become more distinct. (*De Immenso* IV, 3; quoted by Michel 1973, 185). In the same vein, he describes the view from Venus, with Earth and Moon both shrunk to brilliant points; unfortunately, he has misunderstood Copernicus to the extent of believing Mercury a satellite of Venus! In *Cena*, he shows (for once, with a quasi-understandable diagram) the absence of any solid reason for believing stars to be fixed:

> And therefore, they should not be called fixed stars as if they truly kept the same equal distances from us and among themselves, but because their motion is not perceptible to us… Therefore if with some among these stars there occurs a variety of approach this cannot be known except through very long observations which have not yet begun nor have been pursued because nobody believed in nor searched for a presupposed such motion. (*Cena,* 146-8).

Here Bruno was quite correct, and even prescient, where all professionals remained wrong: the individual proper motions of a few among the brightest stars might have been detected at the time by comparing positions with those of Hipparchus and C°; but any sort of heavenly variance was anathema to Peripatetics, and nobody looked for such changes. The actual detection of stellar proper motions will had to wait for Halley in 1718.

The direct consequence of properly-understood celestial perspective is not merely a shattering of the spheres, but the dissolution of all limits, hence an infinite geometry of the Universe: if Space is homogeneous, it must be filled with stars *ad infinitum*. Where Copernicus had been timid and ambiguous, Bruno is fearless and outspoken. He asks the question:

> Where is the World? Where is the Universe? Aristotle replieth that it is in itself. The convex surface of the primal heaven is universal space, which being the primal container is by naught contained. For, position in space is no other than the surfaces and limits of the containing body, so that he who has no containing body has no position in space. What then doest thou mean, O Aristotle, by this phrase that "space is within itself"? What will be thy conclusion concerning that which is beyond the World? If thou sayest there is nothing, then the Heaven and the World will certainly not be anywhere. (*De l'Infinito*, 251-2).

Here Bruno does not refer to Augustine, who had been much worried about that very point, and its consequences for Plurality.

The most efficient tool in the case remained the Lucretian arrow that had lain rusting for sixteen centuries, as far as surviving texts go. Here, it is back in service: Bruno quotes the *De Natura Rerum* passage discussed in our Chapter I: "Suppose that someone made his way to its uttermost boundary and threw a flying dart…" His own answer is clear:

> …it is impossible that I can, with any true meaning, assert that there existeth such a sphere, boundary or limit, beyond which is neither body nor empty space, even though God be there. For Divinity has not as aim to fill space nor therefore doeth it by means appertain to the nature of divinity that it should be the boundary of a body.

Burchio (the asinine Peripatetic) is not cowed:

> If a person would stretch out his hand beyond the convex sphere of heaven, the hand would occupy no position in space, nor any place and in consequence, would not exist. (*De l'Infinito*, 252-3).

Which must have been the standard doctrine in Bruno's time, however nutty it sounds today.

Actually, Bruno was not first to locate stars at infinite distances: in England, he may have met the astronomer Thomas Digges, and read his 1576 *Perfit Description of the Cælestiall Orbes*; this contained both a translation of *Book I* in *De Revolutionibus* and speculations about star places by Digges himself. Owen Gingerich (1975, p. 180), argues that he is probably responsible for Bruno's conversion to Copernicus. Digges will be briefly discussed in the Kepler chapter, and his Universe model is pictured in Figure 8.1.

Just like Oresme (whom he ignores) Bruno is in a good position to stress infinitude as a more natural assumption:

> To call the Universe boundless as we have done, bringeth the mind to rest, while the contrary doth multiply innumerable difficulties and inconveniences. (*De l'Infinito,* 234).

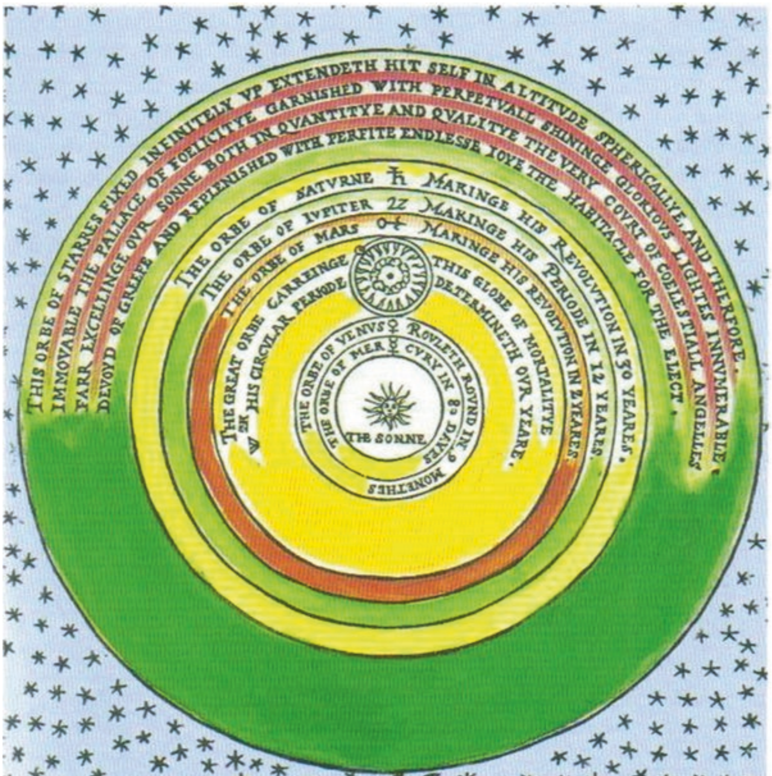

Figure 8.1 The World according to Thomas Digges (1576). It is copernician, but stars extend to infinity. Wikimedia Commons

He heaps ridicule onto his opponents, while unmasking their central error:

> For the difficulty proceedeth from the method and from an unfitting hypothesis, namely the weight and immobility of the Earth, the position of the *primum mobile* with the other seven eight or nine spheres, on which are implanted, plastered, nailed, knotted, glued, sculptured or painted the stars, and that these reside not in the same space as our own star, named by us Earth. But you shall hear that her space, shape and nature are neither more nor less elementary than those of the other stars, nor is she of a nature less apt to motion than each of those other divine living creatures. (*De Infinito,* 361).

Motion of the Earth is the key point; if Bruno is able to approximate our present model of the Universe, it is because he stands on the shoulders of Copernicus, while Cusanus did not.

We are now ready to understand how much of *De Revolutionibus* Bruno actually used, and what his Universe, and his brand of Plurality, looked like.

The Solar System and Sundry Others

What does our own solar system look like, according to Bruno? Roughly as one might expect from a follower of Copernicus with no mathematical training. The qualitative features are present, and often intelligently stressed; the quantitative ones are painfully distorted. Bruno's many mistakes need not detain us here; the unrewarding nature of such a task has been well expressed by the nineteenth century astronomer Giovanni Schiaparelli: Bruno "gives his confused and indefinite ideas, which are put forward in even more confused sentences, explanations wrapped in such great obscurity that I believe it would be a hopeless task to try and clarify them." (Schiaparelli, quoted by Michel 1973, 197). Altogether, Bruno's errors in his reading of Copernicus were many; but it is of greater importance that he upheld the physical reality of the Copernican system in no uncertain terms. Some had thought that

> …Copernicus presumably was not of the opinion that the Earth moved, for this is inconvenient and impossible; but that he attributed such motion to the Earth rather than to the eighth sphere for the sake of easier calculations… But it is certain that Copernicus meant what he said, and proved it with all its efforts… (*Cena,* 95).

Let us now cross the bounds of our Solar system. At once, Bruno is found proceeding beyond Copernicus, and passing even Cusanus for whom all celestial bodies had been "stars." Bruno is far more definite in his description, and correctly differentiates Suns and Earths through two independent criteria: their different motions, and their physical nature. This basic distinction is already made in the *Introductory Epistle*:

> …it will be propounded that every star hath motion even as hath our own [the Earth], and those others [the planets] which are so near to us that we can sensibly perceive the difference in their orbits and in their motions; but those suns [the stars], bodies in which fire doth predominate, move differently to the Earths in which water predominateth; thus may be understood whence is derived the light diffused by the stars [all celestial bodies] of which some glow of themselves [actual stars] and others by reflection [planets]. (*De l'Infinito,* 238. Clearly, this Bruno's remark applies both within and without our Solar System).

Such is the program, and it will be implemented throughout *De l'Infinito*. The geometrical disposition of the Universe is first delineated with uncharacteristic clarity:

> There are then innumerable Suns, and an infinite number of Earths revolve around these Suns, just as the seven we can observe revolve around this Sun which is close to us… around [the stars] revolve Earths both larger and smaller than our own. (*De l'Infinito,* 304-6).

Clearly, this Bruno remark applies both within and without our Solar System. Here, the Cusanian cosmological principle has been applied in definitive manner, both within our own solar system, and throughout the Universe. To make up that count of seven, the Earth and Moon had been included among these planets that "we can observe"; the Earth is unremarkable as to size and position, while that Sun glorified by Copernicus as "Lamp, Mind, Ruler of the Universe" is demoted to "this Sun which is close to us." Altogether, the Bruno geometry of the Universe proves far better than that of Copernicus.

From now on, Plurality takes the modern form: these other Worlds about which so much ink had been spilled, or wax scratched, are no longer black boxes closed to human inspection as they had been for the Atomists; neither are they mere thought experiments granted to Divine Omnipotence, as fancied by Scholastics. They are, and have ever remained since, geometrically well-defined groups of Earths circulating around our familiar stars. They are real; they are knowable; they have become a subject for science. Not bad, for a thorough non-scientist.

One major hitch remains: these Earths are not visible. Bruno at once frankly asks the question:

> Why then do we not see the other bright bodies which are Earths circling around the bright bodies, which are Suns?… The reason is that we can discern only the largest Suns, immense bodies; but we do not discern the Earths, because, being much smaller they are invisible to us on account of either greater distance or smaller size. (*De l'Infinito,* 304).

Here, Bruno is not merely sensible, he is prophetic as well. Rheticus and Kepler, both good mathematicians and Copernicus disciples, remained stuck with Pythagorean fancies, and never consented to increase the complement of planets beyond six. For Kepler, Number Six was to be God-chosen; his conviction proved so strong that, even with a telescope in his hand revealing countless new stars, he categorically refused the mere possibility of new planets. Bruno had no telescope, and spent little time sky-watching; but he was at least free of any numerological *a priori*, and saw plainly enough that the fancied Universe had been so far limited by our power of vision alone. Only Huygens, a full century later, will quantify Bruno's vision, with the help of impeccable optics and mathematics.

Unfortunately, Bruno next goes astray by trying to prove the existence of invisible planets within our home system, and even contradicts his own argument against occultations, already mentioned:

> Often we hear that the Sun has been partially eclipsed though the Moon hath not been interpolated… There may be innumerable watery luminous bodies… circulating around the Sun besides those visible to us. (*De l'Infinito* 304).

This argument is inherited from very primitive times, indeed from Anaxagoras and the Pythagoreans; but it had long become obsolete since better analysis of lunar motions had made all solar eclipses accountable from the Moon alone. Here, Bruno is relying on old wives tales.

Why are other planetary systems invisible? Bruno's explanations are alternately valid, when he relies on plain good sense, or just foolish when he ventures too far. On the sensible side, he likens planets around stars to small boats circling some large ship, or to a swarm of birds flying around a tree. (*De Immenso*, I, 3*,* quoted by Michel 1973, 238). From a long distance, we discern only the ship or the tree, which does not imply that birds or boats do not exist. Unfortunately, he also tries to explain why planets never eclipse their central star through a hair-raising geometrical analysis. He also calls in the laws of reflection; but he is no more optician than geometer. When he writes that other planets may be invisible "because they have little watery surface, or because such watery surface is not turned towards us and opposed to the Sun" (*De l'Infinito,* 304), he proves nothing. Admittedly, most people had hazy notions about such points, which will be cleared by Galileo; the limpid Oresme discussion was forgotten, and the *Diaries* of Leonardo Vinci remained unpublished.

So much for the invisibility; Bruno next discusses the difference between watery and fiery bodies: "all Earths vent the same amount of heat, and all Suns the same amount." (*De l'Infinito*, 305). His Universe is nicely staged with multiple turnspits, not just one as for Oresme and Copernicus. Next comes a most practical question:

> How shall I distinguish fiery bodies from Earths? Because fiery bodies are fixed, and Earths in motion; because fiery bodies scintillate, and Earths do not… They say that the appearance of scintillation is caused by the great distance from us…If that were so… the small stars, which are more remote, would scintillate more than the larger ones, which are nearer to us. (*De l'Infinito*, 306).

In fine, Bruno leaves the reader with the impression that stars scintillate because they are fiery, and he is caught in a tangled web of correct facts and wrong interpretations. Indeed, stars do scintillate, while our planets do not, and Aristotle had known as much. Bruno understands the main point, i.e. that stars are hot and Sun-like and planets cold and Earth-like; however, the true (and purely atmospheric) cause of scintillation is quite complex, and would not be unraveled before Arago. The final explanation has nothing to do with stars being hot and fiery, but is due to their small apparent diameter, compared to planets. Even so, Nature had planted a valuable naked-eye hint about stars and planets being different creatures; this was picked up and understood, from wrong arguments, as indicating a physical difference between them, and Bruno seems to be the first who presents the point explicitly.

Next, if planets are cold, why are the five familiar ones visible at all? Cusanus had still thought necessary to enclose Earth, Moon, Sun and all planets within their own spheres of fire; Bruno quotes his lines about the Earth being no more vile than others, and also about the Sun harboring a kind of Earth in its center. By contrast, the Brunonian explanation looks quite modern, at least at first glance:

> There are then two sorts of bright bodies: fiery bodies which give their own primary light, and aqueous or crystalline bodies which give reflected or secondary light.

He attempts to prove it by sensible considerations applicable to the Earth case:

> Every shining body doth illuminate the space around itself. Indeed, though the Earth be bright owing to the rays of the Sun striking her crystalline surface, yet her light cannot be perceived by us, or by anyone on its surface, but only by those who are opposite thereto. (*De l'Infinito*, 309-310).

The ensuing discussion uses faulty optics, but the errors are unimportant compared to Bruno's correct overall vision: the Earth, seen from afar, would be no different from any other planet.

Nevertheless, it will soon be seen, when studying Bruno's cosmochemistry, that he has preserved something of the Cusanian concept: his Earths and Suns are still mixtures of earthly and fiery particles, but in different proportions; thus, both can be inhabited.

Now is a good time to stop and ponder about Bruno's specific achievement and ask two connected questions: When and why did he adopt Copernicanism at all? And (more significantly) why did that event take place at that particular epoch in history? About the first no certain answer is available. One does not know at what age Bruno first read *De Revolutionibus*, and how much of his basic creed had been formed before. Clearly, he remained indifferent to those technical advantages that have stood the test of time: better fit to observations and automatic explanation of the major anomalies were for him but mathematical tricks. With his visceral hostility to epicycles, a few more or a few less could not matter. Truly, he adopted Copernicus with such enthusiasm only because his system offered just the features he had wanted *a priori*. If your starting assumption is a boundless homogeneous space, it has to be filled at infinitum with Suns and Earths. Other Suns are found easily enough to be the visible stars, since these are manifestly fixed, not orbiting; hence the most natural way to fill up that space is to do it with Copernican, not Ptolemaic, systems.[5]

Objection: for Bruno's purpose, all that professional geometry Copernicus had put in was irrelevant, and his simplistic diagram was quite good enough: thus, he might just as well have started from the Aristarchus system. Answer: by the time he wrote, heliocentrism meant Copernicus; all astronomers and some educated people knew of the hypothesis through *De Revolutionibus* and/or used the *Prutenic Tables;* hence Bruno was bound to hail Copernicus as the champion of heliocentrism. Still, today the question cannot be avoided: would Aristarchus have been able to set him on his course? The whole Bruno cosmological achievement is so independent of the Scientific Renaissance epistemological context, that very little change would have been required to make it arise in the Hellenistic or Roman era. Conceivably, if a few atoms somewhere had congregated differently, some late Epicurean (having chanced to read both Plutarch and Aristarchus), might have come up with a similar scheme; and, by rejecting all trace of intelligent design, forged a far better approximation of

[5] Nevertheless, the bizarre choice of filling up space *ad infinitum* with Ptolemaic systems had been already taken by the 14th century Jewish philosopher Hasdai ben Abraham Crescas, in an attempted refutation of Aristotle (quoted by Mc Colley 1936, 401).

modern Plurality. Such speculations are empty, within our own World anyway; however, some day, we may find it most informative to learn how things have turned out aboard some of the Other Ones.

Clearly, Bruno's contribution to the understanding of our own solar system has been nil: by the time he wrote, a few other thinkers had been converted to heliocentrism, and grasped the details far better than he did. Where Bruno stands alone is in his simultaneous adoption of Copernicanism and Plurality. Again, he is at the meeting point of these two currents of thought inherited from the Atomists on one side, and from Plato and the ancient astronomers on the other. His syncretism, together with his lack of mathematics, is precisely what enabled him to make the good choice by picking up from both schools just the proper materials to build the correct model of the Universe. On one side, Copernicus "more intent in the study of mathematics than of nature" could not rid himself of these spheres, all so nicely polished and pleasing to handle for the Platonic-type of mind, just as differential equations are today. On the other, the world-picture of Lucretius (or Cusanus) had remained a diffuse mess unconnected with the very real achievements of geometrical astronomy. From the first, Bruno adopts a (so-to-say) qualitative brand of geometry, wisely drops the hopeless epicycles and fits the result within the homogeneous universe of the second. Thus equipped, he shows that the World may be both boundless and acentric, and still open to exploration by competent geometers. Dropping the Peripatetic singular center does not mean no centers anywhere; dropping limits does not imply no meaningful relative positions, dropping quintessence, no speculations about cosmic chemistry; and, above all, dropping Man's unique role, opened up possibilities with which we are not yet through.

How does Bruno justify and locate his many solar systems? His initial reason had been aesthetic and metaphysical: "it would be no less ill if the whole space were not filled…."; nevertheless he does show, in many places, that his model is compatible with observations. He even finds the right words to present a Universe that stretches to infinity as a consequence of Earth motion; his original contribution starts precisely where Copernicus had stopped. Listen to Philotheo:

> Beyond this imagined edge of the Heaven there is always an ethereal region with Worlds, stars, Earths, Suns… The bodies said to belong to the eighth sphere nevertheless differ from one another by their greater or smaller distances from our Earth's surface no less than the bodies in the other seven spheres, for the argument resteth solely on the utterly false assumption of the fixity of our Earth…. But, because we have recognized the motion of the Earth, we know that these Worlds are not equidistant from our own. (De l'Infinito, 298-9).

There is subtle irony behind these lines. At exactly the same time, Tycho Brahe, the most accurate astronomical observer so far and a thoroughly competent geometer, was rejecting Earth motion because he was unable to detect stellar parallax, thus implementing exactly the reverse argument. Bruno has just been saying: since the Earth moves, I have no need of a solid stellar sphere as supporting device, hence stars are also free to move and scattered at different distances. While, in essence, Tycho argued: I cannot detect any star motion at all, and in particular not the annual apparent one that ought to show up in the Copernican model; therefore the Earth does not move either, my system must remain geocentric, and I keep the starry sphere. In his own convoluted way, Bruno also was trying to save the phenomena, but he was not even aware of the latest and most precise observations available; and cared little for precision anyway. Tycho's argument was truly Baconian, while Bruno used only observations from the mind's eye. Thus, at the crucial time when the make-up of Heavens passed from primitive to modern form, the first truly advanced astronomical observations played no role at all, or rather, an adverse one. Not only was the Bruno expansion of the World achieved from arguments that might well have arisen in Hellenistic times; it was also independent of the largest technical progress in the field since Antiquity.

Brunonian Mechanics and Chemistry

As far as the mere description went, the Brunonian system has just looked fairly modern. The next question is: How does it work? How does Bruno understand motion, gravity, and material structure of these similar Worlds? Here, he is found far closer to the Peripatetics than he would admit, and anticipating none of the future solutions. His unquestionable contribution is universal homogeneity: what goes on down here must take place everywhere; but he has very little to propose in the way of new devices for explaining these works of Nature. Except for his universal animism, a grotesque amplification of the antique concept.

First, Bruno's view of gravity. He quotes or summarizes the relevant passages of *De Cælo*, particularly the one where Aristotle had syllogized that other Earths, if actual, would move towards each other; which did not happen; ergo "there can be but one Earth, one center, one mid-point, one horizon, one World." (*De l'Infinito,* 330). Here, Bruno refers to a passage of *De Cælo*, I, VIII, 73. Bruno substitutes a polycentric concept: each of his Worlds has his own center of local gravity. He has never read Oresme, and his descriptions of motion under the influence of these centers are less precise than those of the Bishop of Lisieux. However, Oresme's other Worlds had remained rather hazy, and their existence purely hypothetical; for Bruno, they are actual, and identified with other Suns and Earths:

> There are certain determined definite centers, namely the Suns, fiery bodies around which revolve all planets, Earths and waters, even as one sees the seven wandering planets take their course around our Sun…Each of these Worlds is a center toward which convergeth every one of its own parts; towards it every kindred thing does tend just as the part of this our star [the Earth]. (*De l'Infinito*, 322-3).

Copernicus had been ready to grant local gravity to the visible planets; Bruno extends the gift to all heavenly bodies, hence endorses universal local gravity. The language is Peripatetic, he constantly refers to the opposition between natural and forced motion. Sample:

> As the particles of our Earth tend toward our whole Earth, so do the particles of another Earth tend similarly toward her. So, also only by constraint and against their nature could the particles of that Earth which we call the Moon, with the waters thereof, be brought to move to this Earth, or the particles of this Earth move toward the Moon.

Next, he attempts to solve the interesting half-way case:

> If a rock were in mid-air, equidistant from two Earths, how may we believe that it would remain fixed, and would it determine to approach one rather than another of the containing bodies…Since the form of the rock is such that it is no more turned toward the one than to the other, the rock would remain unmoved, unable to resolve on motion toward the one than toward the other… But if one is more kindred, congenial or similar or more calculated to preserve it, the rock will determine to take the shortest and direct way to join that. (*De l'Infinito,* 336).

Oresme had considered exactly the same problem within his hypothetical Worlds, and treated it as a question of pure mechanics: the "portion of Earth" had been likened to a piece of iron between two magnets, the equilibrium declared unstable, analogous to that of a sword on its point, and to be broken by strictly mechanical factors. With Bruno, everything is a matter of will, determination and congeniality; his kinematics are reasonable, but his dynamics are hopeless.

Here are a few more illustrations out of many. Bruno has just repeated that "as the center of another Earth is not the center of ours, and circumference of our Earth is not theirs." We could not agree more; but why is that so? Because "just as my soul is not yours, similarly my weight and that of my inward parts constituteth not your body nor your weight." (*De l'Infinito,* 333). In the same vein, the point that nothing is light or heavy, absolutely speaking, is rather well made, but what is the cause? Weight and lightness are mere consequences of position relative to natural places: "The head on [one's] own body is not heavy; but the head of another [person] laid on top will be heavy, the reason being that the latter is not in his natural position." (*De l'Infinito,* 366). For Bruno, motion of any object is invariably a consequence of inner forces and desires; the rule is universal, and applies to all celestial bodies who

> have for principle of intrinsic motion their own proper nature, their own proper soul, their own proper intellect … Wholly mistaken are those who say that the magnet pulls the iron, the amber the straw, the lignite the feather, the sun the sunflower; rather, in the iron there is a sense which is awakened by a spiritual force diffused from the magnet…[etc.] (*Cena,* 149).

Action at a distance will remain a puzzle to the most mechanically minded scientists for a long time; but Bruno goes as far as refusing any cause of motion external to the moved body. His sensible discussion of an equilibrium half-way between two Earths should not mislead us: if that stone remains hanging in mid-air *ad infinitum*, this is solely because it wants to.

After motion, matter; after mechanics, chemistry. What is the Brunonian concept of matter, celestial or not? A strange brew, since he keeps four elements out of five, but rejects their segregation according to natural place, an essential tenet of Aristotle; and simultaneously endorses atoms and fits them within an Universe not merely intelligently designed but also alive and intelligent down to its most minute components. None of Bruno's choices had been quite new, and none was preserved by posterity; but the important point here is that he held matter to be the same everywhere, just like the Atomists had done. That view we have since not merely endorsed but checked with extreme accuracy, a feat that was still declared impossible by Auguste Comte in the nineteenth century; Plurality, or its attributes, seems to fare badly in the hands of system-makers. Understanding Bruno's very peculiar brand of atomism is not simple, as it shows frequent incoherence (For a study of Brunonian matter, see Michel 1973, Chapter V). Still, the rejection of the fifth essence is clear:

> They therefore err who describe the outer surrounding bright bodies as certain fifth essences, certain divine corporeal substances of a nature contrary from that of the brightest bodies which are near to us. (*De l'Infinito,* 310).

He endorses the four remaining elements but refuses them local segregation; they are mixed throughout the Universe, and only their abundance varies:

> Everyone of those bodies, stars, worlds and eternal lights is composed of what is named earth, water, air and fire. Those in the substance of whose composition fire does predominate will be called Sun, bright in itself; if water doth predominate, we give the name telluric body, Moon or such like, which shineth by borrowed light. (*De l'Infinito,* 314).

Hence, the four nesting terrestrial spheres of earth, water, air and fires are disposed of, just like the adamantine spheres that had supported planets. We applaud; but the arguments with which Bruno derives this new state of things are such as we may expect from him: why are celestial bodies heterogeneous? because they are animals. Oresme had got rid of the same spheres with his neat thought-experiment implementing a "tile or copper pipe."

The question of what Bruno exactly means by his atoms is difficult. They are for him a deeper reality underlying the four elements, and they explain both change and permanency. While all sensible objects exhibit only finite size and motion, atoms are free to flow:

> Bodies are therefore constantly dispersed, and constantly reassembled… particles of elementary earth may wander through the ethereal region and may traverse most space now to this body now to that… atoms have an infinite course and infinite motion…

Worlds in this respect behave just like ourselves:

> We suffer perpetual transmutation whereby we receive a perpetual flow of fresh atoms, and those that we have received previously are for ever leaving us. (*De l'Infinito,* 284-5).

There are obvious similarities with the Democritean Worlds, forever forming and dissolving, but also a basic opposition in the underlying causes, and there is no need to feel afraid of Nature:

> Every such World is eternal though dissoluble; albeit if I mistake not, the inevitability of such eternity dependeth on an external maintaining and provident Being and not an intrinsic power, and self sufficiency." (*De l'Infinito,* 323).

Such Worlds are now fully Christian: Atoms, yes, Chance, no.

Are the Bruno-type physics and cosmochemistry adequate to sustain modern Plurality? Of course not; none of his explanations are still acceptable, and most of them vanished during the century after his death. Still, we are indebted to him for the first clumsy attempt at developing the concept of universal homogeneity inherited from the Atomists, and that is a lasting contribution. If interstellar communication becomes practical some day, we may be able to agree with our correspondents (or even, to understand them) on one central point: the laws of Nature are the same everywhere. But they might ask as the plainest of all questions: How did you manage to understand universal homogeneity? And which of your scientists did it? We would be driven to confess: Bruno; and he was not even one.

The Plurality of Inhabited Worlds

Bruno did not merely stock space with Earth-like planets; at once, he put inhabitants in charge. That is the concept for which he has remained most famous, and here may stand one of the reasons for his ultimate disaster at the hands of the Inquisition; we do not know for sure. Actually, he went only a little way beyond Cusanus; still, there is no question that he did hold the opinion, and taught it in far more open and dangerous fashion than anybody had done before. Furthermore, inhabited planets and stars did not merely fit within his system of Universal Good: they were a necessary consequence. And while the scheme will soon become immensely popular, for more than two centuries no one will ever manage to provide it with a better reason than the Good; in which line also, the Nolan was just following the Cusan.

To the direct question “Are the other Worlds inhabited like our own? “, here is Bruno’s answer:

> If not exactly as our own, and if not more nobly, at least no less inhabited, and no less nobly. For it is impossible that… these innumerable Worlds, manifestly as like to our own or yet more magnificent, should be destitute of similar and even superior inhabitants; for all are either themselves Suns or the Sun does diffuse to them no less than to us those most divine and fertilizing rays… (*De l’Infinito,* 323).

The scale of nobility theme had been developed by Cusanus, and Bruno also follows him when putting life on Suns; but he makes a clear distinction between planets and Suns, and fits both places with different species. The dialogue proceeds:

> Do you believe that fiery Worlds are inhabited even as are watery bodies? – Neither more nor less. – But what animals could live in fire? – You must not regard these Worlds as compounded of identical parts… (*De l’Infinito,* 306).

This is where the theme of chemical identity between Suns and Earths is developed, and it leads to the introduction of life on stars:

> …the Sun containeth particles of water even as our Earth containeth particles of fire. Therefore, as in this most frigid body primarily cold and dark, there dwell animals which live by the heat and the light of the Sun, so in that most torrid and shining body there are beings which can vegetate by aid of the chill from the surrounding bodies… (*De l’Infinito,* 309).

Ludicrous? Remember Marco Polo and his Indians hard-boiling their eggs in the rivers, all from solar heat; and think of Herschel and Arago, who did not reject life on the Sun!

Bruno is more specific than Cusanus on one important point. In line with his repeated attempts to explain the invisibility of other planetary systems, he shows rather sensibly that if Earth dwellers do not perceive signs of life or change in any other celestial body, that does not prove anything since the reverse is also true:

> …for rising of vapors and exhalations, successions of winds, rains, snows thunder, sterility, fertility, inundations birth, death, if these take place in the other stars, they similarly are not perceptible to us; only the stars themselves are perceptible to us owing to the continuous splendor which from a surface either of fire or water or cloud they send forth into wide space. Similarly our own star is perceptible to inhabitants of other stars by reason of the splendor which she diffuseth. (*De l’Infinito,* 312).

Here, Bruno has been anticipated by Plutarch, and his argument appears today rather elementary. However, all his opponents were convinced that "absence of evidence is evidence of absence" (inverting a present-day slogan), which had been the central tenet in all anthropocentric cosmologies. In fact, Bruno is presenting the reciprocal viewpoint of Aliens looking down at Humans, which is at the root of many of our *ETI* discussions today. Cusanus had mentioned vague mutual "influences" between stars, Earth included; Bruno is more precise, as he is plainly considering light and vision.

Bruno is most interesting when he tackles in a similar vein the communication problem, which Cusanus had merely sketched to deplore the absence of any common language. He proceeds farther: for him, actual communication may be the better scheme. First, an objection from Albertino, the Aristotelian:

> The Plurality of Worlds is outside all reason, for there would be in them no civil nature which consisteth in civil intercourse. And the Gods, who had created diverse Worlds would have done ill in that they had not contrived that the citizens thereof should have commerce with one another. (*De l'Infinito,* 359).

Philotheo's answer shows that he has read Cusanus, but he also treads new ground:

> We reply that there is no need of this courteous exchange of intercourse between the various Worlds … It is best for the living creatures of this World that nature hath distributed their diverse kinds throughout seas and mountains. And if by human artifice there has befallen traffic among them, good is not so much added to them as removed since communication tendeth rather to redouble vices than to augment virtues. (*De l'Infinito,* 375).

To understand the nature of those vices, one must turn to *Cena*, where Bruno uses allegoric language, but nevertheless clearly alludes to Columbus and the human disasters following the discovery of the New World. The conquerors have been

> …disturbing the peace of others…confusing that which provident Nature keeps separate…propagating with violence new follies, planting unheard of stupidities…showing new instruments and skills to let people tyrannize and assassinate each other…[6]

Among all of Bruno's ideas, this is the most prescient. Today, the reader almost feels he is attending a colloquium on *Life in the Universe*. Questions of biological contamination from Mars samples or from the Moon are becoming topical and technical. The possibility of intelligence contamination is already being asked, and may rise to prominence sooner or later. The effect on humans of the reception of alien radio signals is, to say the least, hard to predict. Should we prove wiser indeed in not "confusing that which provident Nature keeps separate"?

Another Bruno question has a similarly modern ring: how did these separate Worlds came to be inhabited in the first place? The Aristotelian again starts the ball rolling with the objection:

[6] *Cena,* 59. While the Bartholomeo de las Casas *Brevissima Relacion de la Destruccion de las Indias* had been published in 1552, this humane and frankly-modern Brunonian view of the West Indies human disasters was, to say the least, not prevalent at the time when he wrote.

> A plurality of individuals cannot arise from a single one except…by generation. But those who maintain the existence of a Plurality of Worlds of the same matter and kind of form, do not assert that one is transformed into another, or is generated from another. (*De l'Infinito*, 359).

Bruno answers:

> We reply that this is not universally true. For, by the act of a single efficient cause, there are produced from one mass many and diverse vessels of various forms and innumerable shapes. I leave aside that if there should come to pass the destruction of a World followed by the renewal thereof, then the production therein of animals alike perfect and imperfect would occur without an original act of generation, by the mere force and innate vigor of Nature. (*De l'Infinito*, 376).

The tone of this passage is unusual, as only natural causes are brought into play; remarkably, for once, these causes are efficient, not final. The absence of any Scriptural reference, and the far-worse explicit exclusion of an original "act of generation", are striking; and indeed, must have later struck the Inquisitors. On the basis of this paragraph alone, we might declare that Bruno, true descendant of the physiologers, anticipates the modern view of Life arising naturally wherever and whenever the physico-chemical conditions happen to be right. Let us resist the temptation, refuse to read too much within a few lines, and remember his overall finalist concept of Nature, well stressed in so many places: Bruno was neither wanting nor fated to make Vortex King.

While the Nolan's cosmology was not ignored, unlike the Cusanian one, he similarly had no direct followers; thus, he plays a central role in the history of Plurality only with the wisdom of hindsight. His most famous anticipation has not been subjected to the test of observation: we have not so far seen "animals alike perfect or imperfect" on other planetary systems. As to this inter-World "courteous exchange of intercourse", desirable or not, we are only talking about it. Galileo, who recanted, is the archetypal martyr of science; Bruno, who stood fast, is held to have been martyred for non-scientific reasons. Actually, these questions cannot be easily separated; according to Owen Gingerich, "Bruno's plan was to restore the integral unity of science, philosophy and religion" (Gingerich 1975, p. 189), and this goal is precisely what proved unacceptable to the Inquisitors. Altogether, while the details of Bruno's nine years in jail and final burning are fairly well known, some of the essential documents concerning his trial have vanished. We do know that eight heretical propositions were extracted from his works, and that he ultimately refused to disown them; in the final sentence, the judges "…condemn reprobate and prohibit all thine aforesaid and thy other books and writings as heretical and erroneous and containing many heresies and errors." All were to be publicly burned and placed on the *Index*, but the propositions themselves are lost.

Still, it is known that in his jail and about three years before his end, he had been "admonished to relinquish the vanities concerning diverse Worlds" (Singer, *Introduction* to *De l'Infinito*, 173 and 177), and it is unlikely that such a capital point was dropped *in fine*. Moreover, Galileo (who never refers to Bruno) provides indirect evidence, through the extreme care with which he handled Plurality: he must have felt it to be explosive stuff. On the other hand, if Bruno's writings about these "diverse Worlds" were indeed thrown against him, he might have tried a simple-enough rejoinder: Cusanus had been as much of a Pluralist as himself, without ever becoming suspect of heresy, and what about Tempier? However, that is mere speculation. Other damning points were not hard to find in Bruno's works: he had taught a brand of pantheism plus transmigration of souls, was a suspected magician and (most horrible to confess) had written delirious praise of that abominable heretic, Queen Elisabeth, to whom he applied the intolerable epithet "divine." (Singer, *Introduction* to *De l'Infinito*, 126). The worse indictments may have been unconnected with his views of the physical world.

Neither the immediate judgement of his Church and of most contemporaries, nor the lack of verification of his most daring views should prevent us from granting Bruno his place in cosmology. The main reason why scientists show so much reticence in his case is that this "miserable wanderer, hated by all academics" never managed to achieve anything according to standard rules, past, present or future. Bayle's opinion has shown that not even Bruno's demolition of Peripatetism was held to his credit in the dawning mechanical age: by then, his own animist guidelines had already become absurd. However, the present refusal to discuss him within histories of science means attributing to sheer luck the invention of the true Universe model; Bruno just happened to stumble upon the right path, but used none of the approved tools to clear away the ancient thorns. Copernicus and Kepler made countless mistakes, but wielded circles and ellipses with professional skill; but how can we take seriously a fellow like Bruno, who tackles from pure wishful thinking a field that we know full well must be treated objectively and, moreover, is mathematical to the core?

How much did he achieve? Carried along by an unquenchable imagination that had nothing to do with standard scientific quest, Bruno erected from a jumble of Cusanian and Copernican blocks that most weird edifice, multi-storied like Breughel's *Tower of Babel* but more incredible by far, irregular, asymmetric, incoherent, never completed, bizarre, just as bereft of Olympian guidance, Platonic good, Peripatetic logic and Epicurean *ataraxia* as of Biblical hints or Christian love; and worthy of notice on a single count: it happens to be the real World, the one we are stuck with, and in.

Chapter 9
Galileo Galilei: Technicians Oust Metaphysicians

Me thinkes my diligent Galileo hath done more in his three-fold discoverie then Magellane in openinge the streightes to the South Sea, or the dutch men that were eaten by beares in Nova Zembla. I am sure with more ease and saftie to him selfe, and more pleasure to mee.

Sir William Lower
(*Letter to Thomas Harriot*, June 21 1610)[1]

Galileo, frontispiece of his *Opere* (1656). Galileo points to a heliocentric Solar system with a phase of Venus, Jupiter and satellites, etc. One of the muses holds a telescope. The images on the left allude to Galileo's discoveries in physics. Bibliothèque de l'Observatoire de Paris

[1] Quoted by Johnson (1937), 228.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
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Stagehands Invade The Stage

At about the time Bishop Tempier was posting his Decrees, some humble glassmaker whose name is forgotten must have made a bizarre discovery: small lumps of glass with coarsely rounded surfaces were able to improve the fading eyesight of old people. About the circumstances, nothing is known; the place may have been Northern Italy, perhaps Venice with an active glassmaking industry, and the first recorded use of spectacles is close to 1280.[2] There is no explanation of why it happened at this particular time; Roman glass would have been perfectly adequate, at least for a start. Anyway, the use of lenses spread rapidly, but the rare theoreticians of optics paid no attention at all; concave mirrors as focusing or magnifying devices had been known and studied ever since Euclid, but lenses were seldom written about. No effort was made to explain their properties, and there was a total lack of speculations about further uses. For three more centuries they remained familiar only to unlettered artisans; with the world of the mind, they had simply no relation. Nevertheless, the invention of spectacles marks a turning point, because widespread manufacture led to improved glassmaking and polishing techniques; the objective of a telescope will require a far-more accurate lens than a common magnifier.

Thus, with a modest stretch of imagination but not of verisimilitude, we may fancy Bishop Tempier in his old age poring over those condemned Averroist texts through a pair of spectacles. However, if he ever did, he cannot have seen any connection: lenses remained tools for daily life, just like walking sticks, and nothing more. And yet, far more than any argument born out of pagan or heretical logic, these small pieces of glass were fated to "unthrone Zeus and make the Vortex King", also creating unfathomable trouble for his Biblical successor in the process. Far more than Copernicus himself, they have induced that universal revolution to which the name of Copernicus has become attached. And if lenses have not yet made these other Worlds quite visible, they have at least shown the search for them to be a rational human effort. Lenses, and their modern offspring, have implemented the transition of Plurality from virtual to actual, and its passage from metaphysics to science. With or without spectacles, Tempier and all thinkers of his time had been blind to the future solution of the problem. The central question, other Worlds or none, would ultimately be settled by observation, not by argumentation. Which meant letting in a wholly new crowd: rough artisans devoid of learning, uncouth fellows with callous hands and coarse minds who spoke no Latin, set no syllogisms, and had never fought out the pros and cons of "God makes out of necessity everything that comes from Him." And, as a distant and very minor consequence, after the *Plurality of Worlds* of St. J. Dick (1982), one of them is writing the present History.

[2] The surviving medieval texts have been thoroughly discussed by Edward Rosen (1956). Many antique lenses (mostly of rock crystal or precious stones) have been found, but few hard facts are known about their methods of manufacture or use, except as plain magnifiers; see e.g. articles by H. Taylor, *British Journal of Physical Optics*, **30**, 1–3 and 97–103, (1930). Robert Temple (2000) gives in *The Crystal Sun* a popular history.

To such universal blindness, can we find a present-day parallel? Philosophical speculation about the origin, place, role and meaning of Man in the Universe is nowadays as luxuriantly active as ever; more so indeed if the issue is quantified by weight of printed paper. If more scientists are alive today than existed during all of history, can the metaphysical-theological crowd stand far behind? Surely, the homes and offices of our most abstruse thinkers must be as full of small up-to-date gadgetry as those of the more technically minded. Radios, televisions, computers and smartphones are today as widespread as spectacles ever were, or still are; and just as void of interest to philosophers or theologians whose main purpose in life is to find the meaning of it. Yet such toys may well bring in the answer, or as much of an answer as will ever be available from an unintelligent Universe. Life and Intelligence are such complex phenomena that they will never be intelligible themselves as long as several independent samples have not been studied. In the future, within perhaps less time than the seven centuries separating us from Tempier, we might have either A) established communication with other similarly developed Worlds, or B) established that none exist or survive, or C) vanished ourselves. Present-day technology clearly has the potential ability of proving the existence of other intelligent beings; if it consistently fails to do so, then this negative result may prove the most relevant one ever found in the attempt to understand ourselves.

Let us stay within the essential seventeenth century; as put by Bertrand Russell: "In 1700, the mental outlook of educated men was completely modern; in 1600…, still largely medieval". From our more-specific viewpoint, it dawns with the telescope and sets with Savery's steam engine. Galileo's main contribution to the Plurality theme is distinct in kind from all others met so far. He proved a highly original mathematician and physicist in his own right, served by a brilliant writer and caustic polemist; still, he would have contributed to Plurality nothing but more scholarly arguments piled up over the old ones and soon forgotten, had he not learned about this novel use of lenses, and been ready and able to polish better ones. He confesses as much in his *Sidereus Nuncius* (*The Starry messenger*),[3] the small hastily-written book that he rushed into print in the spring of 1610:

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[3] Galileo probably meant more modestly *The Message from the Stars*, but many readers, first of all Kepler, took him to be advertising himself as *The Messenger from the Stars.* Quotations will be from the Stillman Drake translation *The Starry Messenger* in *Discoveries and Opinions of Galileo* (1957, hereafter *Starry Messenger*). These *Discoveries* (here quoted as *Discoveries*) also contain translations of the *Letters on Sunspots*, of the *Letter to the Grand Duchess Christina* (1615, published in 1636), and extracts of *Il Saggiatore* (1623, *The Assayer*). Also available now is *The Sidereal Messenger,* translation by A.V. Van Helden (2015), with an *Introduction, Notes,* and a *Conclusion on the reception of Sidereus Nuncius*, a very complete *Bibliography*, and excellent reproductions of the original Galileo drawings.

Other main texts used here are:

Dialogo sopra i due massimi sistemi del mondo (1632), translated by Stillman Drake as *Dialogue Concerning the Two Chief World Systems* (referred to as Dialogue);

Discorsi e Dimostrazioni Matematiche Intorno a Due Nuove Scienze (1638), translated by H. Crew & A. de Salvio as *Dialogues Concerning Two New Sciences* (referred to as *Discourse*, to avoid confusion;

> About ten months ago a report reached me that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the observer, were distinctly seen as if nearby… (*Starry Messenger*, 29).

The history of the telescope before Galileo is a fascinating and far from closed subject; still, we know that the art of melting homogeneous glass and grinding true spheres had long been progressing by trial and error. A kind of natural selection had been at work throughout, with little or no help from intelligent design; glass pieces must have been manipulated like pebbles and flints two million years before, and the record of the process is just as thoroughly lost. The oldest extant drawings of glass-polishing machines are those of Leonardo da Vinci. Given enough time, two more-or-less decent lenses must have happened to fall in line with the eye of some quick-witted beholder; one is tempted to say that chance was bound to produce the result sooner or later. Thus, the whole Scientific Revolution was on, for better or worse, with the end nowhere in sight.

At which point Intelligence nevertheless enters the stage, and Galileo's account of his own role is definitely not in terms of blind forces, quite the opposite. After summarizing his first astronomical discoveries, he writes with justifiable pride that.

> All these new facts were discovered and observed by me not many days ago with the help of a spyglass which I devised after being first illuminated by divine Grace." (*Starry Messenger*, 28).

One may elect to locate at this exact point the transition from medieval to Renaissance science: inspiration from God is still at the root of all knowledge, but it now merely guides Man in the building of some lowly device that will unveil Nature. All scientific-instrument designers (there are myriads of us by now) will understand and share Galileo's feeling, and the present author has not seldom felt illuminated in seemingly like manner; unfortunately, not by sufficient Grace since the outcome has never been any kind of revolution but merely trouble with the funding agencies.

The shocked reaction to this thoroughly novel method of work, the use of aided senses, might rank a study in itself. Galileo's colleagues did respond in two opposite manners; some just refused to look, and Galileo wrote to Kepler:

Discorso delle Comete (1619) translated by Stillman Drake in *The Controversy on the comets of 1618; The Astronomical Balance*, Lothario Sarsi (1619); *Letter* by Mario Guiducci (1620); *The Assayer*, by G. Galilei (1623); *Appendix to the Hyperaspistes* (an answer to the Assayer), by J. Kepler (1625).

Available from gallica.bnf.fr (2005): *Opere di Galileo Galilei* (de Duciis, Bologna, 1656, 2 vol., and Barbera, Firenze, 1890–1909, 20 vol.*).*

Out of the myriads of books about Galileo, we have particularly used *Galileo at work, his scientific biography, by* Stillman Drake; and *The Crime of Galileo* by *Dialogo, Discorsi, Il Saggiatore.*Giorgio de Santillana, which provides a non-partisan and most-readable study of the theological conflict. *Telescopes, Tides and Tactics*, an imaginary Galilean dialogue by Stillman Drake (University of Chicago, 1953) is a guide to Galilean thought. The bizarre and totally negative view of Galileo by Koestler in his *Sleepwalkers* is impossible to follow.

> What would you say of the learned here who, replete with the pertinacity of the asp, have steadfastly refused to cast a glance through the telescope? What shall we make of this? Shall we laugh or shall we cry?" (*Letter to Kepler*: quoted by Santillana 1955, 9, and by Burtt 1954, 77).

This graphic scene was to catch popular imagination, and has since been narrated or painted countless times. For others, all these pretended novelties were but old stuff, in particular to their Master:

> Having an [Aristotle] text fetched, he found a certain place where the reason is given why stars in the sky can be seen during daytime from the bottom of a very deep well; here you have the well which represents the tube; here, the gross vapors from whence the invention of lenses is taken… (*Dialogue*, 109).

One truly feels entering the modern era and scientists have not changed one bit since: just attend any Conference.

However, such was only the immediate answer, say within a few months. On a longer time scale, after early unbelievers (for instance the Jesuit astronomer Clavius) had built *optick tubes* of their own and confirmed Galileo, the weight of direct evidence grew overwhelming, and provoked that tidal wave of opinion we call the Copernican revolution. The new astronomy and its philosophical implications overflowed from the schools, and became a common issue within the reading public; no amount of learned disputation would have induced the same upheaval. In particular, the topic of Plurality became a familiar one in literature, poetry and on the stage, and more active than during any later period, even the recent one afflicted by the flying saucer craze.

Perhaps the greatest irony is that no telescope had yet shown these other Worlds, in the sense of complete packages with life and intelligence aboard. The situation has not changed since, and pure speculation still prevails today. Our present outlook is not unlike the pre-1609 one about putative Earth-like bodies, but with one difference: before the unheralded landing of that *Sidereus Nuncius* on a stupefied planet, nobody had given a thought to improving cosmology through technology. Starting with the Milesians, and ending with Copernicus and Bruno, the actual structure of the Universe had been not so badly unraveled through logical, mathematical and theological arguments applied to primitive observations; but the power of future discoveries was not even considered. In total contrast, there is no greater commonplace today; scientists, schoolchildren or men-in-the-street alike are convinced that the limits of our material abilities a mere century from now are unpredictable. Moreover, it is the contention of a solid group of astronomers that the tool for solving Plurality is already at hand: present radio-telescopes are adequate, and we need only the will to use them in earnest. If a more exact parallel between past and present is looked for, it will be found in these few pregnant months of the summer and fall of *annus mirabilis* 1609, when Galileo after "having prepared a tube of lead at the ends of which I fitted two glass lenses" (*Starry Messenger*, 29), had not yet tried to aim it at the Heavens.

The Galilean View of Nature

If rumor of that Dutch invention had never reached Galileo's ear, he would still stand out as one of the most creative figures of science. His decisive contribution not merely to specific problems like the fall of graves, the motion of projectiles and the resistance of solid bodies, but also to all epistemology, would remain the same. These points are merely mentioned here; still, if three centuries later we might perhaps be able to detect Other Worlds, it is because all sciences have developed in the Galilean manner, not merely thanks to his telescope. However, for the present purpose, it is enough to understand how Galileo's concept of Nature affected his own view of Plurality. The plain fact is that he was to remain most discreet on the subject; one must understand why.

The two major works of Galileo were written late in his life. The *Dialogue concerning the two Chief Word Systems* appeared in 1632, and provoked his disaster at the hands of the Church. *The Discourse concerning two new Sciences* of 1638, which contains his most important contributions to physics, was written in the subsequent period of at home quiet enforced by the Inquisition. However, it is clear from minor texts and extant *Letters* that the whole Galilean method had taken shape early in his life. He had formulated a mathematical view of Nature, rejected Peripatetic categories and final causes, decided on figurative reading of Scripture and adopted heliocentrism long before he became, by accident, involved in applied optics. In the words of E.A. Burtt "Viewed as a whole, Galileo's method can be analyzed into three steps, intuition or resolution, demonstration and experiment, using in each case his own favorite terms." (Burtt 1954, 81). If we are willing to add: experiment or observation, we have the path he followed to his own system of the World. He had long believed in the physical truth of heliocentrism, which made the Earth a mere planet, without any proofs from telescopic observations. Burtt again: "…in order to be able to demonstrate to his opponents the truth of his conclusions, he had been forced to prove them by a variety of experiments, though to satisfy his own mind alone, he had never felt it necessary to make any." (Burtt 1954, 76).

The main Galilean contribution to science is mathematical mechanics. In his often-quoted words,

> Philosophy is written in this grand book… which cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles and other geometrical figures… (*Il Saggiatore,* in *Discoveries,* 237).

And in the *Discourses*, page after page of closely-knit geometrical demonstrations establish that the definitive way to introduce mathematics in Nature had been found; a crucial achievement after two millennia of Pythagorean ramblings, by no means obsolete at the time, as the case of Kepler will soon show. A greater change in scientific thinking is hard to point out throughout History; and Galileo shows total awareness of his accomplishment, plus immense pride as a consequence. Even more striking perhaps is the clear view that his own work is only a starting point:

> My purpose is to set forth a very new science dealing with a very ancient subject. There is, in nature, perhaps nothing older than motion, concerning which the books written by philosophers are neither few nor small; nevertheless I have discovered by experiment some properties of it which are worth knowing, and which have not hitherto been either observed or demonstrated… And what I consider more important, there have been opened up to this vast and most excellent science, of which my work is merely the beginning, ways and means by which other minds more acute than mine will explore its remote corners… (*Dialogue,* 153).

As the Chapter 11 will show, even Descartes (both mathematician and philosopher) will totally miss the point of the Galilean approach.

That much being granted, one has to admit that the lack of a mathematical treatment of the system of the World ranks as the weakest part of Galileo's work. His heliocentrism remained qualitative, and if he wisely showed no interest in Copernican epicycles, he remained just as blind to Keplerian ellipses. Thus it is only through the contributions of Kepler and Newton that the mathematizing of Science had any consequence for Plurality; within Galileo's own time, it induced none.

The name of Galileo is the one that comes to mind whenever one thinks of the overthrow of Aristotle. His rejection of all Peripatetic qualities, and of their teleologic dressing, is unequivocal, and often expressed with biting irony. Take for instance these hallowed concepts of Perfection and Nobility which, ever since Plato, had been responsible for so many crimes against Reason. For Galileo, they are nothing but empty words:

> For my own part, never having read the pedigrees and patents of nobility of shapes, I do not know which of them are more, and which are less noble, nor do I know their rank in perfection. I believe that in a way all shapes are ancient and noble… except insofar as for building walls a square shape is more perfect than the circular, and for wagon wheels, the circle is more perfect than the triangle. (*Il Saggiatore*, 263).

Moreover,

> What greater stupidity can be imagined than that of calling jewels, silver and gold precious and earth and soil base?… If there was as great a scarcity of soil as of jewels or precious metals, there would not be a prince who would not spend a bushel of diamonds and rubies, and a cartload of gold just to have enough earth to plant a jasmine in a little pot, or to sow an orange seed and watch it sprout, grow and produce its handsome leaves, its fragrant flowers and fine fruit. (*Dialogue,* 59).

In a similar vein he dispatches incorruptibility, and its supposed connection with the spherical form:

> For if the round body is incorruptible, then incorruptibility must subsist in the parts that depart from roundness. For instance, there exists within a cube a perfectly round ball, incorruptible as such; corruptibility then resides in the corners… Within the parts towards the corners, there are also smaller balls… Thus in the end, resolving the whole cube into innumerable balls, you must admit it to be incorruptible. (*Dialogue,* 84).

The key point is not that Galileo drops scholastic terminology, but that he truly explicitly abandons all final causes, and the World becomes a machine solely actuated by efficient ones. Furthermore, these last being often difficult to unravel, Galileo is usually willing to forget about the Why, and concentrate on the How, a wise and prophetic attitude but one for which Descartes will take him to task. That is not all: as seen in the case of motion, he is ready to admit that even such a limited objective is for himself out of reach, but that his successors may do better if they follow his guidelines. Burtt: “In an age where uncontrolled speculation was the order of the day, we find a man with sufficient self-restraint to leave certain ultimate questions unsolved as beyond the realm of positive science. This touch of agnosticism in Galileo strikes one familiar with thought-currents of his generation as a mark of genius superior even to his marvelous constructive achievements.” (Burtt 1954, 101). Here we have the explanation of what his attitude relative to Plurality will be: Other Earths, yes, I can see them; alien Beings, animals or men, I can’t, hence I keep silent.

Within the traditional array of final causes, the one most universally invoked, Man, is no longer of any use. For Galileo, anthropocentrism was dead long before he received the news from Holland. The point often recurs in the *Dialogue*; to give but one example, here goes Simplicio, the Peripatetic quasi-simpleton, during the *First Day* i.e. at a stage when the telescope has not yet entered the discussion:

> For the celestial bodies, that is the Sun, Moon and the other stars which are ordained to have no other use than that of service to the Earth, need nothing more than motion and light to achieve their end.

Answers Sagredo, the intelligent bystander:

> Has Nature then produced and directed all these enormous, perfect and most noble celestial bodies, invariant, eternal and divine, for no other purpose than to serve the changeable, transitory and mortal Earth? To serve that which you call the dregs of the Universe, the sink of uncleanness? (*Dialogue,* 59).

The demise of anthropocentrism, within science anyway, clearly begins with Galileo, but the reaction was to be much delayed. In the immediate future, the issue played a pivotal but often hidden role during the anti-galilean counter-attack. Here is but one explicit case: in 1615, at the onset of the first difficulties with the Church, Galileo’s disciple Benedetto Castelli interviews the Archbishop of Pisa:

> He took for me but a single reason from his stock, omitting all others, and the substance of it was since all created things are made for the service of man, it clearly follows as a necessary consequence that the Earth could not move like the stars… these opinions were folly and madness… they deserve condemnation. (*Letter to the Grand Duchess*, in *Discoveries,* 157; henceforward referred to as *Letter GD*).

Rejection of finality is an ambitious goal, but immensely difficult to achieve in practice. A tricky question, which soon arises when Man is shelved away from his central place, is the origin of knowledge. Why does the Universe happen to be (more-or-less) intelligible? Galileo seems to be first to provide the essence of the modern scientific answer:

> Nature did not make human brains first, and then construct things according to their capacity of understanding, but she made things in her own fashion and then so constructed the human understanding that it, though at the price of great exertion, might ferret out a few of her secrets. (Quoted by Burtt 1954, 78, from *Opere* 1890-1909*,* VII, 341 and I, 288).

However, one must beware of transforming Galileo into a materialist; Burtt again: "by his free use of the word Nature, Galileo does not mean to deny an ultimate religious interpretation of things." (Burtt 1954, 82). Hence, for him, and despite all the achievements of human intellect, God may still do infinitely better, and for good reason, he being the Creator: **"**

> …the way in which God knows the infinite propositions of which we know some few is exceedingly more excellent than ours. Our method proceeds with reasoning by steps from one conclusion to another, while His is one of simple intuition. (*Dialogue*, 104).

Was Galileo prudent enough? Not quite; in the list of eight specific points which were to be found unacceptable by the Papal Commission, one reads "That he asserted some equality between the Divine and the human minds in geometrical matters." (*Dialogue*, 477, *Note* by St. Drake).

Galileo's God, no longer the automatic final Cause, as he had been for Aristotle and Plato, remains the ultimate efficient one while acting in the most orthodox Christian manner. Despite the revolution he brings to cosmology, Galileo does not venture into cosmogony. Did he accept literally the Genesis story? He never says, but that would be surprising, because another important aspect of Galilean thought is manifest in his sensible and well-argued plea for a figurative reading of Scripture. To the subject, he devoted in 1615 a complete small treatise, the *Letter to the Grand Duchess Christina*, which deals with the use of Biblical quotations in matters of science. Through this remarkable text, Galileo made the development of science ultimately possible within the Christian West, just as much as Aquinas had done. He was not the first Renaissance thinker to feel the need for a change in the way of reading the Holy Books, but five years after the telescopic discoveries the issue had become topical. Opponents of heliocentrism (and of Galileo personally) had been stirring trouble, in particular by throwing at him those well-thumbed pages of the *Bible*, plus some new ones freshly uncovered for the occasion. Their avowed purpose (in which they were to succeed eighteen years later) was to obtain official condemnation of the new doctrine. The battle which had not followed *De Revolutionibus*, mostly because of its purely-mathematical character, was at last opening. Galileo wrote in Italian, with devastating wit, no preface by any Osiander shielded him, and fast-multiplying telescopes were unveiling sights never mentioned in Scripture to whoever was daring to risk his eye behind a lens.

Today, we are mostly struck by the impeccable Catholic orthodoxy of Galileo's *Letter*. He shows without ambiguity his total respect not merely of "our Faith against the stability of which there is no danger whatever that any valid and effective doctrine can ever arise" (*Letter GD,* 189), but also of its self-chosen interpreters on Earth, those "grave and wise theologians who are solely competent to interpret [scriptural] passages according to their true meaning." (*Letter GD,* 203). However, on the way, he makes several dangerous points with his usual efficiency, and does take the risk to quote (very aptly, as seen today) Jerome, Tertullian and Augustine; from the last he reproduces extensive passages, some discussed here in Chapter 4. His more specific arguments concerning Earth motion will be treated later; here we are concerned with the general trend. Ever since the time of Chrysostomos, there had been no greater objection to Plurality in the West than Biblical fundamentalism. For Galileo

> In expounding the Bible, if one were always to confine oneself to the unadorned grammatical meaning, one might fall into error… it would be necessary to assign to God feet, hands and eyes, as well as corporeal and human affections such as anger, repentance, hatred…These propositions uttered by the Holy Ghost were set down in that manner by the sacred scribes in order to accommodate them to the capacities of the common people who are rude and unlearned… (*Letter GD,* 181-2).

For Galileo, the aim of Scripture is not provide us with ready-made science, and he makes the point through a striking epigram:

> The intention of the Holy Ghost is to teach us how one goes to Heaven, not how Heaven goes. (*Letter GD,* 186).

But he stands as firm as Aquinas had ever done on the fundamental compatibility between Nature and Scripture: when both are interpreted correctly, contradiction is impossible. Any apparent clash is the outcome of faulty exegesis or poor natural philosophy or both, and will ultimately be resolved. Furthermore,

> I do not feel obliged to believe that the same God who has endowed us with senses, reason and intellect has intended us to forgo their use … This must be especially true in those sciences of which but the faintest trace is to be found in the Bible. Of astronomy, for instance, so little is found that none of the planets except Venus are so much as mentioned, and this only once or twice under the name of Lucifer. (*Letter GD,* 186).

However, while willing to grant that human students of Nature can eventually go wrong, Galileo puts most of the burden in the lap of the exegetes:

> Nature…is inexorable and immutable, she never transgresses the laws imposed on her… [while] the Bible is not chained in every expression to conditions as strict as those which govern all physical effects. (*Letter GD*, 183).

And Galileo ends by shooting a barbed arrow, which must have produced painful wounds in high places:

> Certainly, no one doubts that the Supreme Pontiff has always an absolute power to approve or condemn; but it is not in the power of any created being to make things true or false, for this belongs to their own true nature and to the facts. (*Letter GD*, 210).

This is not the place to narrate the Galilean affair and trial.[4] As already noticed, the thirteenth-century Parisian turmoil and the Tempier *Decrees* were largely forgotten in Galileo's time; they are never mentioned by the accused or by his judges. Which is more easily understandable than in the case of Bruno, as these old *Decrees* had not been concerned with Earth motion at all. Still, the change of atmosphere within high Church circles is clear: Bishop Tempier had fought against human logic and for Divine Omnipotence, and for Christian orthodoxy against newfangled Peripatetic science. He and his assessors did not particularly mind if in the process they went far beyond a literal reading of the Bible, or for that matter, beyond any

[4] For discussions of the Galileo trial, see Gingerich (1982), *The Galileo Affair,* and Santillana (1955), *The Crime of Galileo*.

reading at all: in the Book, it had been impossible to find any trace of those Tempier-promoted *plures mundos*. Three and a half centuries later, Peripatetism had become so firmly embedded within Christian thought that the painful joints no longer even rankled. Galileo's judges believed themselves to be merely upholding the true reading of the Bible, which the resurgence of fundamentalism had made mandatory for Catholics (just as much for Protestants); but they were not conscious of actually defending Ptolemy and Aristotle who were, to say the least, not to be found in Scripture either.

So much for the past; what about the future? The immediate one was bleak indeed; the story of the Galileo-trial aftermath is too well known to be told here: the relative waning of Italian science, Descartes prevented from publishing his *Système du Monde* etc.… The subsequent evolution of the Church was to be extremely slow: Galileo's works were withdrawn from the Index only in 1835, and his view of Biblical exegesis became official Catholic doctrine in 1893, with the Leo XIII Encyclic *Providentissimus Deus*. The official Vatican rehabilitation of Galileo has been decided by John-Paul II only in 1984. Even so, long before the end of the seventeenth century, most Christian scientists, Catholics and Protestants alike, had found ways and means to accommodate religious beliefs with laboratory data and heliocentrism with Scripture. This outcome was an *a posteriori* vindication of Galileo's attitude; and the modern explosive growth of actual Plurality, replete with fancy Aliens, owes more to the *Letter to The Grand Duchess* than to the Tempier *Decrees*.

What remains to be proved is whether Galileo's long-term followers are truly showing in this respect "minds more acute than his own."

Heliocentrism Demonstrated?

The astronomical achievement of Galileo is twofold. He did more to establish the truth of heliocentrism than Copernicus himself, and he discovered completely new celestial bodies plus unexpected facts about the nature of old ones. Both accomplishments were to be taken as decisive arguments in favour of Plurality; however, far more so by his successors than by himself.

The early conversion of Galileo to heliocentrism is attested by a 1597 *Letter* to Kepler:

> Like you, I accepted the Copernican position several years ago, and discovered from thence the causes of many natural effects which are doubtless inexplicable by the current theories. I had written up many reasons and refutations of the subject, but I have not dared until now to bring them in the open… (quoted by Santillana 1955, 11).

Which he was to do much later, after the telescopic discoveries; but at the time of this *Letter*, he had already taken up the study of mechanics in connection with the problem of heliocentrism. His full demonstrations however were not to be made public before the *Dialogue* and the *Discourse*.

One starting point of Galileo's interest in mechanics may have been his desire to demonstrate the reality of Earth motion; ever since Ptolemy had formulated the main scientific objections, they had been mechanical in nature. Still, he never bothered about the Why of this motion, and not even much about the precise How; his interest in celestial kinematics and dynamics remained cursory. Demonstrating that the Earth was free to wander around merely meant for him that terrestrial projectiles fell in the same way whether the said Earth moved or not. Which he did in a quantitative manner, and he was unquestionably first to do so; hence our term of "Galilean system of reference" for one with a uniform translation, and within which everything takes place just as if it was immobile.

However, that Galileo proof remained negative; he was painfully aware that by such arguments he had merely shown that nobody could prove the Earth to be static nor central from known phenomena. Through most of his life he desperately searched for a positive proof; he even managed to get convinced that he had found one through his theory of the tides, which was mostly wrong. However, in the process, he was led to study with great care the fall of graves on Earth, and found the definitive laws of uniformly accelerated motion and of parabolic paths; alas, these had no bearing at all on the issue of Earth motion. An *Appendix* to the present chapter shows how narrowly he missed two experimental proofs. Altogether, he was never to take the key step, the one by which Newton later conclusively fused together the sub- and super-lunary worlds: treating Earth, Moon and planets themselves as mere projectiles.

Hence Galileo, when pretending to have found "many effects inexplicable by current theories" which favored Copernicus, overstates his case. Sure enough, he brings in the ship analogy for which he provides the definitive treatment, complete with stone dropped from the mast. Incidentally, one reads with some amusement that for Galileo (through Salviati, his mouthpiece), this ship remains strictly a thought-experiment: "Without experiment, I am sure that the effect will happen as I tell you, because it must happen that way"; while Simplicio the Peripatetic indignantly disagrees: "So you have not made a hundred tests, not even one! I shall retain my incredulity."[5] In any case that Ship had never convinced traditional geocentrists, for whom the refusal to admit the mediocrity of the human vantage point remained instinctive. A clear example is the conclusion of the famous 1615 *Letter* sent by Cardinal Bellarmine to Paolo Foscarini, disciple of Galileo and Copernican convert. The Cardinal has just given the first official (and ominous) view of the Copernican question formulated after the telescopic discoveries. He does not disdain to proffer his considered opinion on this humble technical point:

> …though it may appear to a voyager as if the shore were receding from the vessel on which he stands rather than the vessel from the shore, yet he knows this to be an illusion and is able to correct it, because he understands clearly that it is the ship that is in movement. But as to the Sun and the Earth, a wise man has no need to correct his judgment, for his experience tells him plainly that the Earth is standing still and that his eyes are not deceived when they

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[5] *Dialogue,* 145. Here also, Harriot had antedated Galileo; remember his "plummet [falling] downe from the toppe along by the maste even to the decke."

> report that the Sun, Moon and stars are in motion." (*Letter from Bellarmine to Foscarini,* quoted by Santillana 1955, 100).

The Cardinal had never pondered on the embarrassing case of Lactantius, and forgotten all about that Augustine warning.

The heliocentric system of Galileo remained crude. He never even alluded to epicycles, and the diagram he provided in the *Dialogue* (*Dialogue*, 323) did not differ from the crude one in the first chapter of *De Revolutionibus*, except for the addition of Jupiter's satellites. He showed no interest in the Keplerian orbits and laws either; to this surprising blindness, three reasons may be proposed. First, in Kepler's *Astronomia Nova*, which Galileo had received in 1609, the two first Keplerian laws were half-hidden behind laborious accounts of the many dead ends explored by Kepler. Second, the methods through which Kepler established celestial ellipses and Galileo terrestrial parabolas could not have been more different. The Keplerian laws had been thoroughly empirical; they were the result of long trial-and-error attempts (mostly error) through which groping Kepler fitted observed planetary positions to haphazardly chosen geometrical curves, all without theoretical guidance. By contrast, Galileo primarily treated projectile motion through thought experiments, and his conclusions were expressed in the forms of mathematical theorems; in the *Fourth Day* of *Discourse*, we read:

> A projectile which is carried by a uniform horizontal motion compounded with a naturally accelerated vertical motion describes a path which is a semi-parabola. (Theorem given in *Discourse, Fourth Day,* 245).

Altogether, neither of them (nor any of their readers before Newton) discovered that parabolas and ellipses being creatures very much of the same blood, their kinship might be worth studying.

Third, Galileo wanted so much planetary orbits to be circular that he never even alluded to the well-known anomalies, for which some geometrical device (either epicycles or ellipses) had to be brought in. For him, uniform circular motions remained self-explanatory, and in need of no external cause, just as they had been for Pythagoras and Plato, and for the same reasons: they were the only ones able to run eternally without messing-up the system of the World:

> Only circular motion can naturally suit bodies which are integral parts of the Universe… if there are any that do not move circularly, these are necessarily immovable, nothing but rest and circular motion being suitable for the preservation of order." (*Dialogue,* 32).

Here is seen how difficult it is in actual practice to get rid of teleologic thinking: such explanations ever keep creeping in. Altogether, Galileo contributed little to the description and understanding of planetary motions.

Here is one of the few attempts by Galileo to treat a problem of celestial mechanics: the fall to Earth of a body from the Moon orbit. Galileo, like Oresme, Copernicus and Bruno, endorsed polycentric gravity:

> …just as all parts of the Earth mutually co-operate to form its whole… the Sun, Moon and other World bodies are also round in shape merely by a concordant instinct and natural tendency of all their component parts… If at any time one of these parts were forcibly

> separated from the whole, is it not reasonable to believe that it would return spontaneously? (*Dialogue,* 33).

Galileo seems ready to treat the problem of the fall from the Moon's surface or, in others terms, the Moon-to-Earth voyage. But he did not do so, and was not even aware that Kepler had just described it in a qualitative (but essentially correct) manner in his *Somnium*. Galileo merely considered what would happen if "by divine Power, or by means of some angel a very large cannonball were miraculously transported there [at the distance of the Moon] and placed vertically over us and released." (*Dialogue,* 219). Next, he applied his own law of uniform acceleration (valid on the surface of the Earth) without giving a thought to any possible change in force or direction of gravity on the way; thus, he arrived at a grossly incorrect result, a fall time of 3 hours 22 minutes and 4 seconds.

However, Galileo also asked in the *Dialogue* a very profound question: Are the orbital speeds of the planets explainable from a single, and simple, hypothesis? Might the Divine Architect have initially fabricated all planets in the same place, and just dropped them? "Now, at what altitude and distance from the Sun would have been the place?" Galileo does not disclose his procedure, but one guesses that he must again have used uniform acceleration, and he concludes that for all planets "the size of the orbits and the velocities… agree so closely with those given by the computation that the matter is truly wonderful." (*Dialogue,* 29 and *Note* p. 471). Unlike the question, the answer was nonsense; without the inverse-square law, Galileo was not equipped to tackle the problem. The same applies to his renovated version of the hole-through-Earth experiment. Due to his familiarity with the pendulum, his language is more precise than those of Plutarch or Oresme, whom he both ignores; also, the stone is replaced by a cannonball, a doubtful improvement. Still, all he is able to do is to apply uniform acceleration/retardation during the downwards/upwards legs of the journey, and establish equality for the times of rise and fall; nothing essential has been added.

Altogether, Galileo had proved nothing so far; the best he could do for heliocentrism was to apply again the excellent but aging Ockham Razor:

> Who is going to believe that Nature, which by general agreement does not act by means of many things what it can do by means of so few, has chosen to make an immense number of extremely large bodies move with inconceivable velocities to achieve what could have been done by a moderate movement of one single body around its center? (*Dialogue*, 117).

Galilean terrestrial mechanics were to prove the essential tool in the unification of our own World and of the putative others; but only, given time.

The telescopic discoveries were more relevant, but still far less decisive than Galileo believed them to be. The first three, those alluded to by William Lower in his enthusiastic letter to his astronomer friend Thomas Harriot, were the satellites of Jupiter, the earthy nature of the Moon, and the myriads of new stars unveiled, in particular within the Milky Way; a little later were to come sunspots and the phases of Venus. All were more or less useful for establishing heliocentrism; but the physical nature of Moon, Sun, planets and stars being more specifically relevant to Plurality, it will be taken up later. The telescope finding that ever remained closer to Galileo's heart is not in doubt:

> But what surpasses all wonders by far and what particularly moves us to seek the attention of all astronomers and philosophers is the discovery of four wandering stars not known or observed by man before us. (*Starry Messenger*, 28).

Here, in his first page, *Sidereus Nuncius* manages to bring Galileo's astounding and still fresh discovery "observed by me not many days ago" to the help of Copernicus. Henceforward, anyone could watch a miniature Copernican system, with four small bodies revolving around a larger one, all in a common plane and with revolution periods increasing with orbit size. A few pages later Galileo stresses the second argument: for Peripatetics, the revolution of the Moon around a moving Earth had been hard to believe, as the Moon should have dropped behind. From now on,

> our own eyes show us four stars which wander around Jupiter as does the Moon around the Earth, while all together trace out a grand revolution about the Sun in the space of twelve years. (*Starry Messenger*, 57).

Q.E.D.: nobody had ever doubted that Jupiter was moving some way or other. When Galileo was to take up the matter again in the *Dialogue*, he had accumulated twenty-three years of observations, and accurately measured satellite periods, an important achievement in itself (see e.g. Drake 1955, 168, 194). No additional satellites had been found anywhere (all were to require far better telescopes) and he had no new points to make, even if many colleagues had confirmed his findings, and not a few had been converted; still, the argument was not decisive.

Neither will be the next one, drawn from the phases of Venus:

> Venus changes shape precisely as the Moon… [an observer looking right now] will see Venus circular in shape and very small… as it reaches its maximum departure from the Sun it will be semi-circular. Then it will pass into a horned shape, gradually becoming thinner…these things leave no room for doubt about the orbit of Venus. (*First Letter on Sunspots* in *Discoveries,* 93).

No doubt indeed, and opponents were soon convinced that Venus does revolve around the Sun: unlike the Jupiter satellites, phases for Venus had long been predicted as a necessary consequence of the Copernican model. Moreover, the quantitative agreement was striking: the Venus changes in apparent diameter coincided with those expected on the basis of Copernicus calculations.

However, throughout the history of geometry, necessary had never meant sufficient; there was still a way out, and a fairly sensible one too. At one stroke, the Galilean discoveries made Ptolemy obsolete, and he soon dropped out of the scene; but the far-more accurate and nevertheless geocentric system of Tycho Brahe seemed to have been invented precisely to cover that present contingency. Nothing that any telescope could show at the time had a chance of disproving it, since the Tycho system is kinematically identical to the Copernicus one: all relative planetary motions are the same. Both differ merely because Tycho holds the Earth fixed relative to the stars while Copernicus lets it move, and stabilizes the Sun. The main Tycho arguments were first the Scriptural one, to which he was very sensitive, and second the serious technical difficulty of absent stellar parallaxes. As stressed in our Bruno chapter, despite the much-improved accuracy of his instruments, Tycho had been unable to detect the yearly change in star position which the annual Earth motion should have induced. The solution for Copernicans had been decreeing a further large increase in the distance of the stars, but none felt happy about this step. The resulting immense empty gap between Saturn and the stars was useless, and appeared as a major blueprint error within any intelligently designed Universe. Simplicio:

> Nothing has been created in vain or is idle in the Universe. Now, when we see this beautiful order among the planets, they being arranged around the Earth at distances commensurate with their producing upon it their effects for our benefit, to what end would there be interposed… a vast space without anything in it, superfluous and vain? For the use and convenience of whom?

The answer of Salviati-Galileo is predictable enough, from his general premises; the Universe is God-created indeed, but not solely for Man:

> We take too much upon ourselves, Simplicio, when we will have it that merely taking care of us is the adequate work of Divine Wisdom and power, and the limit beyond which it creates and disposes of nothing. I should not like to have us it tie its hands so (*Dialogue*, 367);

which is theologically wise, but technically weak. Needless to say, Galileo thoroughly understood the parallax difficulty, and his discussion (which takes most of the *Third Day*) is a model of clear reasoning, and sometimes of Galilean humor, his opponents making the crudest mistakes in geometry. Still, he would have felt much better had his telescope disclosed that stellar parallactic motion implied by the Copernican model just as automatically as the phases of Venus. At least, he expected future astronomers to solve the problem: an additional and crucial argument

> may come from the fixed stars since by extremely accurate observations of these, there may be discovered these minimal changes that Copernicus took to be imperceptible. (*Dialogue*, 462)

Galileo even proposed a method to measure parallaxes, but it was never put in application and would not have succeeded anyhow. His prediction was to be fulfilled to the letter by Bessel, but only two hundred years later. In the early seventeenth century, the fact that the telescope had not shown parallaxes was clearly in favor of Tycho.

On the other hand, the telescope did establish that stellar apparent diameters were much smaller than hitherto believed; how this was done, and what the implications were for the stars themselves will be seen when studying Kepler. Hence, another early objection against Copernicus was somewhat alleviated: in his system, starting from the ancient estimates of stellar diameters, stars should have been larger than the Earth orbit, another hard-to-believe result. Still, no explicit disproof of Tycho could be expected from the argument, nor from any other at the time; this point, Galileo steadfastly refused to see, to the extant of never mentioning Tycho's system at all. The title of his *Dialogue* is revealing, since it mentions only two world systems, not three. The tactic was poor and his opponents were not fooled; after the rapid demise of the Ptolemaic model, a deadlock was to be established between the Tychonic and Copernican ones, which lasted for many years (Figure 9.1).

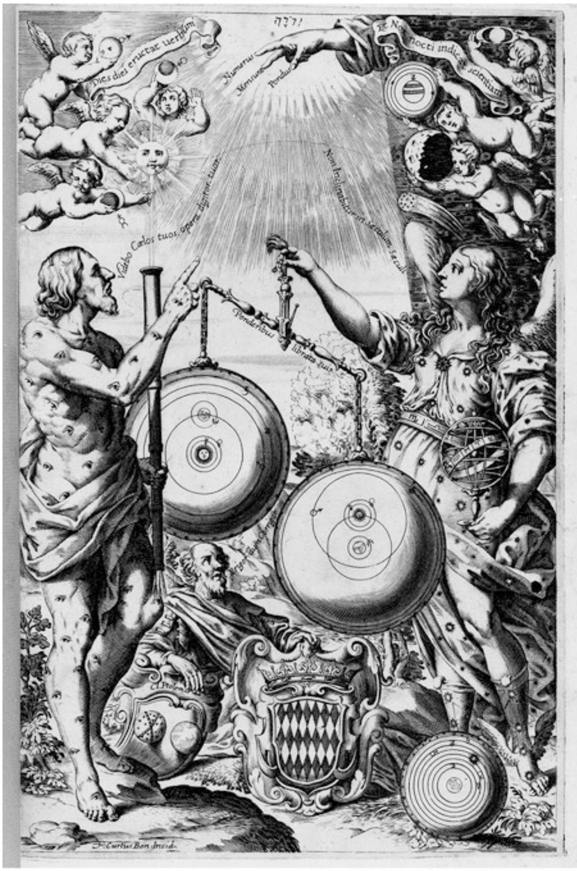

Figure 9.1 While Ptolemy and his World system are lying on the ground, the system of Tycho is preferred to that of Copernicus in this engraving of Riccioli's *Almagestum novum* (1651). Note the depictions of the Sun, Mars, Venus and Mercury with their crescents on the upper left, and of Saturn, Jupiter and satellites, the Moon and a comet on the upper right. The personage on the left is Argus with his hundred eyes, and that on the right Uranie with an armillary sphere. Bibliothèque de l'Observatoire de Paris

Moon and Planets Made Earthy

Mere geometry, even refined by the telescope, had failed to make the Earth a planet in the etymological sense, but Moon and planets were demonstrated to be Earth-like in appearance. Thus, the telescope immediately achieved more for Plurality than it did for heliocentrism, through disclosures about the physical nature of the Heavens. Galileo remained cautious about the ultimate consequences; obsessed with the issue of Earth motion, disciple of Copernicus the geometer but definitely not of Bruno the dreamer, he left some of his followers to draw the implications without endorsing them himself.

The shock and wonder of the Moon seen for the first time through any small amateur telescope is an experience still accessible today: it does rank as a true revelation. How much greater was it for Galileo! Here is the *Sidereus Nuncius* account:

> It is a very beautiful thing, and a most gratifying sight to behold the body of the Moon… We learn with all the certainty of sense evidence that the Moon is not robed in a smoothed

> and polished surface, but it is in fact rough and uneven, covered everywhere just like the Earth's surface by with huge prominences, deep valleys and chasms… (Starry Messenger, 28).

There follows the tale of an undreamed-of new country in the Heavens, more staggering than all the travel accounts written by Columbus, Vasco da Gama, Pigafetta or those unfortunate "dutch men eaten by beares." The key was the interpretation of the play of light and shadows, and the correct earthly analogies:

> There is a similar sight on Earth about sunrise when we behold the valleys not yet flooded by light though the mountains surrounding them are already ablaze with glowing splendor. (*Starry Messenger,* 32).

Within these first few nights of wonder, Galileo proceeded as far as we ever went before the Apollo landings, by measuring the elevations of mountains from their shadows, through faultless geometry served by accurate observations: "some mountains exceed four miles." (*Starry Messenger*, 41).

At this point, it is necessary to make a stop in order to gauge the magnitude of the Galilean achievement. Today, we risk to believe that, so many centuries after the Ionians and Plutarch had first proposed the scheme, an earthy-Moon was a familiar concept which a single glance through the crudest optick tube would instantly confirm. That would be to underestimate the strangeness of the hypothesis; even for enlightened minds, the notion of any other Earth in the Heavens was still difficult to grasp. The case of Thomas Harriot provides a clear example.

Harriot made valuable contributions to optics, algebra and geography, but published little. Through extant letters we know that he had built telescopes before Galileo; he used one to look at the Moon as early as July 1609, and some of his drawings have been preserved (shown on figure 9.2). Obviously, before getting a copy of *Sidereus Nuncius* (published in Mars 1610), Harriot understood not at all what he had been watching. His first drawing is not only poor but does not even look like any kind of map, while he had much interest in mapping new countries and some experience as a cartographer. He was not alone in this blindness; here is a letter he received from his disciple William Lower, reporting on his own observations (with another Harriot telescope):

> According as you wished, I have observed the Moone in all his changes. In the new I discover manifestlie the earthshine, a little before the Dichotomie, that spot which represents unto me the Man in the Moone (but without a head) is first to be seene, a little after near the brimme of the gibbous parts towards the upper corner appeare luminous parts like starres much brighter than the rest and the whole brimme along, lookes like unto the Description of Coasts in the dutch bookes of voyages, in the full she appeares like a tart my Cooke made me last Weeke, here a vaine of bright stuff and there of darke, and so confusedlie all over. I must confesse I can see none of this without my cylinder. (Dated February 6 1610, quoted by Stevens 1900, p.120).

Thus, exactly like Galileo, Lower observed the bright points within the dark region close to the terminator, a striking sight indeed; unlike him, he did not understand they were the tops of mountains. The allusion to the Dutch coast was no more intended as an explanation than the Man in the Moon, or that stale tart. As soon as

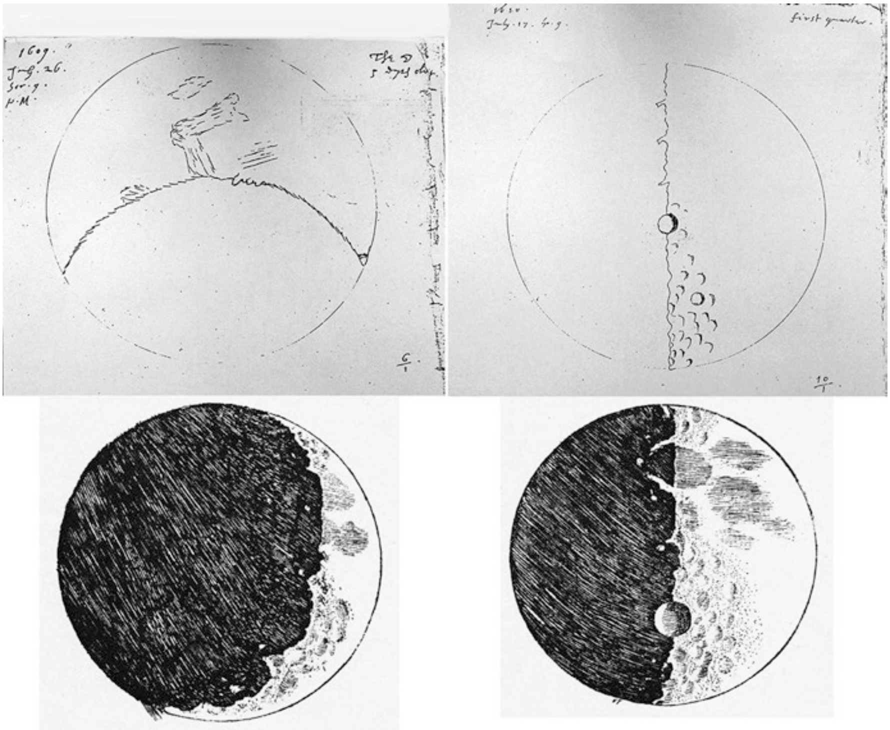

Figure 9.2 Top: two drawings of the Moon by Thomas Harriot, left on 26 July 1609, right on 17 July 1610 after Harriot has seen the *Sidereus Nuncius*: Galileo.Rice.edu/sci/harriot_moon.html. Bottom, two engravings by Galileo in *Sidereus Nuncius*, Wikimedia Commons

Sidereus Nuncius landed in England, Harriot understood what he had been so far only watching, and his own drawings improved accordingly. His immediate reaction is lost, but must have been as enthusiastic as that in the Lower *Letter*, here quoted before. As to Lower himself, he naively confessed that he had never understood the Moon from his own observations; "…in the moone I had formerlie observed a strange spotednesse all over, but had no conceite that anie parte thereof mighte be shadowes." (Quoted by T.F. Bloom, from Stevens 1900). The main explanation must be that Galileo's telescopes were much better than those of Harriot; as these last are all lost, no direct check is possible. Still, neither Lower nor his friend reacted to their first telescopic exposure as natural philosophers already familiar with the earthy-Moon notion. When he received *Sidereus Nuncius*, Kepler did not yet have a telescope for a check of his own; even so, his reaction (equally instant and enthusiastic) shows his line of thought to have been quite different. Avid reader of Plutarch, he had long been speculating about the true nature of the Moon, inhabitants included; he will deserve a thorough study in the next chapter.

There was far more to be seen, or fancied, in the Moon than mountains. Once the surface was proved roughly Earth-like in texture, why not seas, an atmosphere, and living actors to make use of these props? After Galileo's demonstration, overconfident why-nots seem to get as numerous as readers; and soon they will be mistaken for serious arguments. By a sudden inversion of popular feeling, universal teleology will be set to work, helping Plurality. So far the Heavens had been perceived as different in essence from the Earth, hence devoid of inhabitants; seen from now on as Earth-like, they must be overflowing with them! Within a few years after *Sidereus Nuncius*, it will no longer be possible to quote or list the enthusiastic observers who have actually seen in the sky every possible convenience for life; still less, count those who have read the astronomer reports, or comment on them. And Galileo is responsible for all that speculation; what does he say himself?

Sidereus Nuncius had been written in great haste after few actual observations through a still-primitive device, and at the time Galileo thought there might be some evidence for lunar seas and an atmosphere; however, on both issues, he expresses himself with caution. For instance, after making the correct point that mountains hiding behind one another near the edge of the disk would not prevent this edge from being seen as smoothly circular, he adds: "To the above explanation, another one may be added: namely that there exists around the body of the Moon just as around the Earth, a body of some substance, denser than the rest of the ether." He proceeds to explain, quite correctly again, and with a good explanatory diagram, that such an atmosphere would be most easily seen near the edge even if it is not "sufficiently opaque to prevent our seeing through"; but he does not pretend to have seen the effect. The same conditional language is used concerning seas:

> As to the large lunar spots, these are not seen to be…full of cavities and prominences; rather, they are even and uniform. Hence, if anyone wished to revive the old Pythagorean opinion that the Moon is like another Earth, its brighter parts might very fitly represent the surface of the land, and its darker regions that of the water. (*Starry Messenger,* 34).

By the time Galileo wrote his *Dialogue* he had accumulated twenty-three years of observations with slightly better telescopes, and undertaken a study of lunar optics. He now felt sure that there was neither an atmosphere nor water on the Moon, and his conclusion is still valid today: "I believe that the lunar globe is very different from the terrestrial, although in some points conformity is to be seen." (*Dialogue,* 62). Which has been the whole problem of planetary observations ever since; some degree of terrestrial analogy is invariably found, but how far does it go? Galileo proves happier in the balance he strikes than many of his successors. His Simplicio starts from the orthodox Peripatetic position: "I consider the Moon's sphere to be as smoothed and polished as a mirror" (*Dialogue,* 68), granting at most that it might have some inclusions like amber or crystal do. He is then driven through a Socratic-type discussion to confess that he had long known the true state of things, having "…seen the Moon by day among little whitish clouds and similar to them in appearance." (*Dialogue,* 68). Next, all three interlocutors perform a simple but decisive experiment: "Now please, take that mirror and let us go into that court…hang the mirror on that wall there, where the sun strikes it. Now let us withdraw into the shade…" (*Dialogue,* 72). The conclusion is inescapable: "If then the Moon were smooth as a mirror, only a very small part would show itself to the eyes of a particular person as illuminated by the Sun, although an entire hemisphere would be exposed to the sun's rays." (*Dialogue,* 75).

That first demonstration is only half of the story: a reciprocal point has to be made. Simplicio at first refuses to believe "that the Earth can reflect light of the Sun no less strongly than the Moon can. For to me it seems so dark and opaque that such an effect strikes me as quite impossible." (*Dialogue,* 87). Again the matter is settled by direct observations: "Yonder is the Moon, more than half full, and over there is a high wall where the Sun beats down. Come this way so that the Moon is seen beside the wall. Do you not see that if there is an advantage, it belongs to the wall?" (*Dialogue,* 89). A further consequence is the explanation of shadow-light, for which the most ludicrous interpretations were still current. Simplicio presents two: "This brightness which is observed on the balance of its disk outside the thin horn lighted by the Sun, I take to be its own natural light" (*Dialogue,* 69); alternately "it derives from the illumination of the sun itself which penetrates its whole body because the substance of the lunar globe is somewhat transparent… the interior drinking in and soaking up this light like a cloud or crystal makes the Moon visibly lighted." (*Dialogue*, 91). Galileo had long known the correct explanation from naked-eye observations; in *Sidereus Nuncius*, he professes to have discovered it "not just recently, but many years ago…yet it is rendered more evident and easier to observe with the aid of the telescope…" (*Starry Messenger,* 42). Still, he was merely the first to publish: Leonardo da Vinci, Mästlin (Kepler's teacher), and possibly others had understood shadow-light long before he did.

One important deduction is that the Earth seen from afar appears as bright as any other celestial body, and would not be distinguishable from these. Cusanus had made the same point, but without any demonstration or discussion of the involved optics. Does Galileo understand the fully general principle involved? He comes rather close, with a sort of cosmic law of action-and-reaction through the agency of light:

> From all this we conclude that reflection from the Earth is very powerful on the Moon. What is more important is that there follows from this another beautiful resemblance which is that if it is true that the planets act reciprocally upon the Earth by their motion and by their light, perhaps the Earth is no less potent in acting upon them by its own light, and possibly by its motion too. (*Dialogue,* 96).

The rest of the text shows that motion is here alluded to merely as the cause of changing perspective. This remains clumsy compared to the Cusanus formulation; moreover, as will be seen, Galileo grants equivalence of all viewpoints only within the solar system, never outside.

Anyway, correct optics soon dispose of lunar seas. A specific experiment is performed:

> Let us go into that hall, and pour a little water on the pavement. Tell me now, doesn't this wet brick look darker than the dry ones? Of course it does, and it looks so from every place but one; namely, where the reflection of light from that window strikes… (*Dialogue,* 98).

What a pity that Pieter de Hooch was not available as an illustrator: he would have rendered splendidly the dull brick floor and the tiny shining pool reflecting a window, with three elegant gentlemen looking down in rapt attention. The interpretation of telescopic appearances is, for Galileo, unambiguous:

> What is clearly seen on the Moon, is that the darker parts are all plains, with few rocks and ridges in them, though there are some. The brighter remainder is all full of rocks and mountains, round ridges and other shapes… (*Dialogue,* 68).

As for a possible atmosphere, it is no longer mentioned.

One cannot but contrast Galileo's sober-minded attitude with that of many successors: later selenographers were to dub those rough plains "seas" and the circular ridges "craters", showing in both cases undue haste through risky analogies with Earth. In the same vein three centuries later, not a few astronomers will disport themselves as equipped with much better telescopes but far weaker judgment, e.g. Flammarion and Lowell.

Let us now proceed beyond the Moon, and explore the planets. Galileo will soon prove that essential point which, ever since Plato, had remained a questionable hypothesis: planets are intrinsically dark, like the Earth. The question was not stressed in *Sidereus Nuncius*, because the author had been so much taken up by the Jupiter satellites that he did not discuss the planet itself. Nevertheless, he had already noticed that "the planets show their globes perfectly round and definitely bounded, looking like little moons, spherical and flooded all over with light." (*Starry Messenger,* 47). Next, late in 1610 Venus became observable, and in that letter to Julian of Medicis where he gives the first description of the phases, he already stressed as a second essential consequence of his discovery that "all planets are naturally dark." (*Letter to Julian of Medicis,* Jan. 1st 1611, in Michel 1966, 361). During the *Second Day* of *Dialogue*, the issue becomes an important one, and the implications are explicit:

> The six moving planets entirely lack light, like the Earth; therefore their essence resembles the Earth and differs from the Sun and the fixed stars. Hence the Earth moves and the Sun and the stellar sphere are motionless. (*Dialogue*, 267).

Such a demonstration of heliocentrism from physical arguments is subtle and indirect. Most of Galileo's opponents will concede soon enough some degree of physical likeness between Earth and planets; but the fact that the Tychonic system becomes highly-contrived as a consequence will dawn but slowly. Nevertheless, the argument was to play a major role in the later universal acceptance of Copernicus, which long antedated the three relevant astronomical or physical demonstrations, to wit: Bradley's aberration in 1725, Bessel's parallaxes in 1838 and Foucault's pendulum in 1851.

Galileo himself will never provide more detailed descriptions of planets: his telescopes were too poor to show anything beyond the phases of Venus, and the surface markings on Jupiter and Mars were discovered only after his death. Still, and even without a micrometer, he must have been able to form rough estimates of the apparent diameters; this is proved by his correct measurements of lunar shadows and of the positions of Jupiter satellites; also, by his detection of the changes in the apparent diameters of Mars and Venus. Hence, it is puzzling that he never gives figures for these diameters, as he would have immediately been enabled to deduce actual sizes for all planets. If a likeness in physical constitution between Earth and planets was felt to be a powerful argument for Copernicus, surely a similarity in size would have been an additional one? In any case, if Galileo ever made the calculation, he certainly used the Ptolemaic distance scale, which he had no reason to distrust. Hence, he must have underestimated the sizes of all planets by a factor of about 20, and on this count, the Jupiter diameter would be 0.6 times that of the Earth: our home planet is perceived as the largest one, though not prominently so. Neither Galileo nor any of his readers, opponents or converts alike, seems to make the point at the time. However, Kepler felt he had to increase these distances (see discussion by Koyré 1961, 348). The true dimensions of planets will become known a quarter of a century after Galileo's death when Cassini measured the solar parallax. Only then will Earth be demoted to a size as unremarkable as her rank had become after *De Revolutionibus*, and her surface after *Sidereus Nuncius*.

The telescope changed the understanding of the Sun as much as that of the Moon, and the philosophical implications were not less striking. Sunspots "which have come to disturb the Heavens and worse still the Peripatetic philosophy" (*Dialogue*, 53), played a role as important as lunar mountains in the overthrow of Aristotle. Corruption, so far a questionable privilege of Earth, became manifest even within that Sun which for Copernicus had still been "Lamp, Mind, Ruler of the Universe"; hence sunspots met with stiff resistance. A minor but useful property of those spots was that they also demonstrated solar rotation; so far no celestial body had shown anything of the kind, since the Moon had been visualized as non-rotating. Henceforward, on that count also, the Earth no longer stood as a unique body in the Copernican model; however, here we concentrate on the physical nature of the Sun.

Soon after this discovery, Galileo devoted to the subject his three 1613 *Letters to Mark Weseler on Sunspots*; the matter was urgent since his eyes were no longer the only ones equipped with telescopes. Sunspots had been observed by several people, including Thomas Harriot but who published nothing. They were also seen, but misunderstood, by Christopher Scheiner, a Jesuit astronomer; and the ensuing controversy was to have in the long run disastrous consequences for Galileo by earning him wholesale Jesuit hostility. Later he returned to the subject in the *Dialogue* with no appreciable perspective change. Galileo never reached the modern explanation of sunspots, because it could not be formulated before new tools had been brought in, spectroscopy in particular. Even so, he gave correct guidelines: with due caution, some kind of terrestrial analogy could be applied. Which is precisely what his opponents rejected at all cost, as for them spots were "vain illusions of the lenses" (*Dialogue*, 353), or "congeries of many minute stars which gather together in greater or smaller numbers to form spots of irregular or varying shapes." (*Letters on Sunspots,* in *Discoveries*, 141). Scheiner made them small additional planets orbiting the Sun; having been forced to grant reality to the "Medicean Stars" around Jupiter, Peripatetics took a few more of them as a lesser evil for their cause, since the Sun itself was left unblemished. Galileo was able to show conclusively that, just as in the case of the lunar "inclusions", such an hypothesis did not fit the telescopic observations: "The spots are in contact with the Sun's body… touching its surface they are moved either with it or upon it." (*Dialogue,* 54). Which was proved by the absence of parallax, and the changing perspective when spots reached the edge of the disk. Moreover, Galileo showed great insight when he wrote that "sunspots are at least as bright as the brightest part of the Moon." (*Letters on Sunspots*, in *Discoveries*, 92). A definitive demonstration will have to wait for William Herschel, then accurate photometry and the nineteenth century, but Scheiner had again been wrong, believing spots to be fully dark.

This was as far as the telescope could take anyone at the time; to proceed farther was to formulate chancy hypotheses. Those of Galileo were sensible; the appearances were

> exactly as would happen for someone who might observe from afar the motion of our clouds. These would appear to move with a very rapid and constant motion, carried around every twenty-four hours by the whirling of the Earth… along circles parallel to the equator, but somewhat varied by incidental movements caused in them by winds. (*Dialogue*, 346).

As to their substance "I liken the spots to clouds or smokes." (*Letters on Sunspots*, in *Discoveries*, 140). Which interpretation did not anticipate the true one: spots are not opaque bodies floating within a clear medium, but depressions in the surface of the chromosphere, within which cooler (hence darker) layers are unmasked. Still, Galileo understood that, among all possible terrestrial analogies, clouds gave the best ones, and deduced the most important physical consequence: "I think that the circumambient substance to be very fluid and yielding." (*Letters on Sunspots*, in *Discoveries*, 112). Within a World still filled to the brim with crystal spheres, the mere notion of a fluid Sun was a great progress. Moreover, the cloud hypothesis was expressed with intelligent caution:

> I do not assert on this account that the spots are clouds of the same material as ours, or aqueous vapors…I merely say that we have no knowledge of anything that more closely resembles them… I do not decide on this, and they may be of a thousand other things not perceived by us. (*Letters on Sunspots*, in *Discoveries*, 100).

And in a brief passage of the *Third Letter*, which goes far beyond the particular case of sunspots, Galileo summed up his greatest contribution to the unraveling of the physical nature of the Universe. Altogether, he had not merely discovered dark planets, lunar mountains or transient sunspots; he had invented a wholly new way of looking at celestial matters:

> The substances composing the Earth and the Moon seem to me to be equally unknown as do those of our elemental clouds and of sunspots. I do not see that in comprehending substances near at hand we have any advantage, except copious detail… When I ask what the substance of clouds may be and am told that it is a moist vapor, I shall wish to know in turn what vapor is. Per adventure, I shall be told that it is water… this fluid body which runs in our rivers, and which we constantly handle. But this final information about water is no more intimate than what I knew about clouds in the first place; it is merely closer at hand, and dependent on more of the senses. In the same way, I know no more about the true essences of the Earth and fire than about those of the Moon or Sun. (*Letters on Sunspots*, in *Discoveries*, 123).

This Galilean guideline was to permit the simultaneous growth of earthly and celestial physics, each shouldering the other, and to prove immensely successful.

The nature of the stars plays a minor role in Galileo's work; for him, they were unquestionably "so many Suns" (*Dialogue*, 327), but he never elaborated on the theme, for the sensible reason that he had not enough new facts to present. Just as in the case of the Sun, the far better telescopes of the next two centuries could do little as long as spectroscopes had not been hooked to their focal planes. Even so, in his understanding of stars, Galileo proceeded beyond Copernicus, and appeared somewhat closer to Cusanus and Bruno (both never mentioned), without however reaching any principle of universal homogeneity.

The view through that first telescope had been startling enough, and the shock is best conveyed through the immediate *Sidereus Nuncius* account:

> Surely, it is a great thing to increase the numerous host of fixed stars previously visible to the unaided vision, adding countless more which have never been seen, exposing them plainly to the eye in numbers ten times exceeding the old and familiar stars …These stars are so numerous as almost to surpass belief. (*Starry Messen*ger, 27 and 47)

They were to prove even more amazing than lunar mountains. The experience is such a commonplace today, a pair of field-glasses being adequate, that we risk missing the startlingly unexpected character of the original discovery. Again, William Lower comes to help; in that same *Letter* where he sings his enthusiasm for Galileo's discoveries, he recalls his own telescopic observations of the preceding winter, before the news from Galileo. He had looked at Pleiades, where the naked eye had always seen seven stars (figure 9.3):

> Through my cylinder I saw thes also plainelie and far asunder, and more than 7 to, but because I was prejudged with that number, I believed not myne eyes nor was carefull to observe hou manie; the next winter, now that you have opened myne eyes, you shall heare much from me of this argument. (quoted by Rosen, in Shirley 1974).

Here again *Sidereus Nuncius* (through a lost letter of Harriot) "opened his eyes"; Lower had first construed those bright points shown by his own telescope not as real stars, but merely as phantoms from the lenses.

As for Galileo himself, he takes particular pride in having solved the Milky Way mystery:

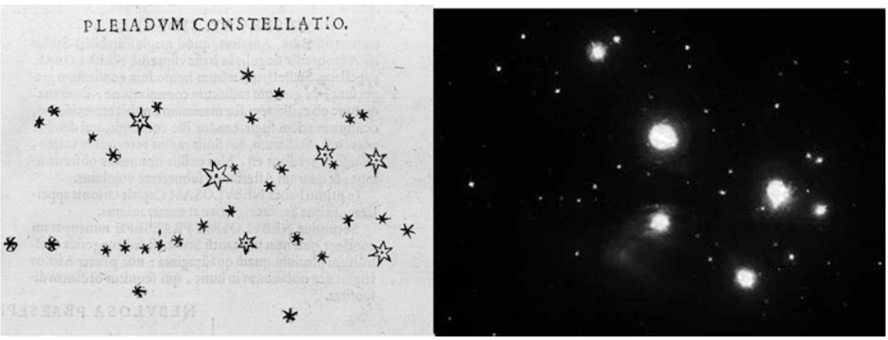

Figure 9.3 Left: Galileo in *Sidereus Nuncius,* Wikipedia Commons; right, Palomar Sky Survey

> all the disputes which have vexed philosophers through so many ages have been resolved, and we are at least free of wordy debates about it. The Galaxy is in fact nothing but a congeries of innumerable stars grouped together in clusters… (*Starry Messenger*, 49).

Ever since Democritus had first proposed the cloud of stars hypothesis, it had remained a minority view and devoid of proof. Still, Galileo is here (as often) over sanguine in gauging his own accomplishment. While he had settled the main point, endless "wordy debates" were to go on, telescope or no telescope; only in the twentieth century was the Galaxy fully delineated in its relation to the Solar System on the one hand, and to the Universe on the other.

About individual stars, the telescope had shown a single but bizarre new fact: "A telescope which is sufficiently powerful to magnify other objects a hundredfold is scarcely able to enlarge the stars four or five times." (*Starry Messenger*, 46. The magnification of 100 is meant for area). The technical question is complex, and a short discussion will be given with Kepler. But whatever were the optical causes (and those proffered by Galileo are not fully adequate), the outcome was a clear difference between planets, with their "globes round and definitely bounded" and all fixed stars, which are "never seen to be bounded by a circular periphery." (*Starry Messenger*, 47). Galileo felt stellar apparent diameters to be a critical issue, and devoted much thought and care to the matter. He never quoted their apparent diameters as having been actually measured with a telescope, and never even gave an upper bound; which shows remarkable restraint, and fair understanding of his instrumental limitations. Simply expressed, he did not know why his telescope gave imperfect images, but he understood that such images provided no clue for the real stellar diameters.

He did far better without a telescope at all, inventing a new technique of observation specifically for the stellar-diameter problem. So far, all astronomers had been stuck:

> …None of them, not even Tycho himself… ever set himself to determine and measure the apparent diameter of the stars, except the Sun and the Moon. I think that arbitrarily, and so to say by rule of thumb, someone among the most ancient astronomers stated that such and such was the case, and the later ones without any further experiment adhered to what the first one had declared. (*Dialogue,* 361).

The proposed experiment is striking because it might quite well have been performed by Euclid, possibly even by Thales: Galileo merely takes a thin cord, and tries to find the minimum distance at which it will hide a star from the naked eye. The rest is elementary geometry; still, one has to know the pupil diameter, and take it into proper account. In the description of his calibration procedure, Galileo displays his experimental skill more obviously than through his rather scant accounts of telescope construction or use. Anyway,

> by this very precise operation, I find that the apparent diameter of a star of the first magnitude, commonly believed to be two minutes, and even put at three by Tycho…is no more than five seconds. (*Dialogue*, 362; the figure looks somewhat optimistic).

This result is a remarkable advance, and bears simultaneously on the Copernican system and stellar nature. Stars may now be reduced to solar-like sizes, and the lack of stellar parallaxes becomes understandable:

> Assuming that a sixth magnitude star may be no larger than the Sun, one may deduce … that the distance of the fixed stars from us is sufficiently great to make quite imperceptible in them the annual motion of the Earth [the parallax]. (*Dialogue,* 359).

Having only an upper limit for diameters and a lower one for distances, Galileo cannot prove any star to be Sun-like in bulk; for such a result, photometry, spectroscopy and interferometry will ultimately be required. Hence, his assertion that stars are Suns largely remains an act of faith. For him, the Earth is one of the planets by virtue of analogous motions and being dark; likewise, the Sun is one of the stars because all are bright and at rest:

> Common sense says that motion ought to be deemed to belong to those which agree better in kind and essence with the bodies which unquestionably do move, and rest to those which differ most from them.

Galileo derides the notion of any universal center:

> I might very reasonably dispute whether there is in nature such a center, seeing that neither you nor anyone else has so far proved whether the Universe is finite and has a shape, or whether it is infinite or unbounded. (*Dialogue,* 319).

Hence, the champion of heliocentrism drops the Copernican notion of the Sun as a center for the Universe, which is a considerable improvement. Nevertheless, he remains, like Copernicus, a geometer at heart, and never indulges in those fortunate flights of fancy that had taken Cusanus and Bruno so far. Geometry did not yet establish star distances, let alone their spatial distribution, and any proposed solution could not help, being arbitrary:

> Now what shall we do, Simplicio, with the fixed stars? Do we want to sprinkle them through the immense abyss of the Universe at various distances from any predetermined point, or place them on a spherical surface? (*Dialogue,* 325).

The ensuing discussion (indeed, the whole *Dialogue*) pulverizes that Sphere, but what is the replacement?

> I do not believe that the stars are spread over a spherical surface at equal distances from one center; I suppose that their distances from us vary so much that some are two or three times as remote as others. (*Dialogue,* 383).

This Galilean solution is timid: geometry had not established the distance of any star, still less that they stretched to infinity, but it had not shown either that a range of two or three was the most that could be expected. No justification is presented, and these figures are just arbitrary. For Galileo, Space is unbounded, but Matter remains crowded within a small corner of it, where Man is conveniently placed to enjoy the show. Our Sun is no longer at a center in any geometrical sense, but remains a privileged star by virtue of its singular position.[6]

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[6] About the Galilean stellar distribution: Kepler adopts a similar model, and justifies it at length, but Galileo does nothing of the kind. Here one may differ from Koyré, who writes: "In the *Dialogues* indeed, Galileo tells, exactly like Kepler, that it is "absolutely impossible that [a new star] should have been infinitely higher than the fixed stars, for there is no such place in the Universe, and if there were, a star placed there would be invisible to us" (*Dialogue*, 290)." The Galileo quotation

The Sun also seems privileged in another respect: it remains the only star equipped with a planetary system. Galileo never alludes to the problem at all, just as he never writes the name of Bruno. In the joint issues of stellar distribution and of multiple planetary systems, his rejection of anthropocentrism fails him, because more powerful forces were operating; their nature will now be explored.

Planetary Dwellers? Neither Yes nor No

The Galilean discoveries launched that tidal wave of enthusiasm about Aliens that is still running today, after splitting into a pair of divergent wavelets: the flying-saucer popular delirium and the serious radio search. Galileo will be found far more sober-minded than many of his successors, immediate or distant. The attitude arose from his fundamental restraint about the scientific matters he believed not yet susceptible of proof, and also from the religious problems of the time. Bruno had gone to the stake only ten years before the Moon was unveiled as "just like the Earth, covered with huge prominences, deep valleys and chasms"; hence Galileo's prudence in adorning these places with a living complement is, to say the least, understandable. Still, there is no reason to tax him with hypocrisy on that count, and no conflict seems to have arisen in his own mind. His observations did not show inhabitants or artefacts in the Moon, and his deductions did not make their presence likely; thus, he felt no reason to deviate from Scripture.

The *Sidereus Nuncius* does not say a word about inhabitants nor habitability of Moon or planets, but speculation started right away. A 1616 letter from Giovanni Ciampoli, friend of Galileo, vividly paints the public response:

> One man amplifies, the next one alters, and what comes from the author's own mouth becomes so transformed in spreading that he will no longer recognize it as his own… Your opinion regarding the phenomena of light and shadow in the bright and dark spots of the Moon creates some analogy between the lunar globe and the Earth; somebody expounds on this and says that you place human inhabitants on the Moon; the next fellow starts to dispute how these can descended from Adam, or how they can come off Noah's Ark, and many other extravagances you never dreamed of. (*Letter* of Ciampoli, quoted by Drake in *Discoveries,* 158).

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by Koyré seems out of context. Kepler, through sensible arguments, had shown that no actual and finite star, placed at an infinite distance, would be visible (but his Sun-centred distribution is wrong just the same). Galileo, in the quoted passage, tackles the quite different problem of proving the error of those astronomers who had found for the famous 1572 supernova negative parallaxes, and were such poor geometers that they could not understand the absurdity of their result. When Galileo writes that "there is no such place in the Universe", he does not mean that the Universe is bounded in any way, but that geometry precludes any negative parallax from being meaningful. Despite the obvious similarity between their models, with stars filling the space between two concentric spheres, the positions of the two astronomers remain conceptually different: Galileo keeps an open mind, stressing the arbitrariness of all hypotheses, and not taking seriously himself that factor of "two or three" in stellar distances. Kepler is convinced to have fully proved that the Universe is closed and centred on our Sun, which differs in size from all other stars.

The most interesting early reaction is that of Thomaso Campanella, Dominican friar who wrote from a Holy-Office jail where he spent twenty-seven years. As early as January 1611, he shows in a private letter, quoted in part by Nicolson (1955, p. 255), an immense enthusiasm for the Galilean cause, and speculates that other planets might shelter inhabitants. Next, in his published *Defense of Galileo* (Campanella 1616), he is wholly concerned with the Scriptural arguments, and covers part of the same ground as the *Letter to the Grand Duchess*: "Scripture accommodates its discourse in syntax and meaning to the external senses of the common people." (Campanella 1616, 52). He recalls errors of the Fathers; for instance Augustine and Lactantius had "declared… that antipodes do not exist because the men thought to be there could not come from the loins of Adam." Should one admit the reasoning of the Fathers, "it follows that the truth disclosed by Columbus is discordant with, or contrary to, Divine Scripture." (Campanella 1616, 35). Campanella lists eleven current arguments against Galileo; the ninth is:

> If the four elements which form our World exist in the stars, it follows from the doctrine of Galileo that as Mohammed declared, there are many Worlds with lands, seas and with human inhabitants. However, Scripture speaks of only one World and one created Man… I pass without comment the opinion that Galileo has revived the heresy that Christ must make atonement for the men who inhabit the stars and die there again, just as formerly it was said that Christ must be crucified a second time in the Antipodes. (Campanella 1616, 8).

Campanella's own answer: "Galileo does not conceive of the existence of a Plurality of Worlds but of all Worlds or systems existing under one and within one immense Heaven." (Campanella 1616, 64). In short, Galileo had not revived External Plurality in any guise; he had merely "disclosed moons similar to planets… mutations of elements in heaven… clouds above the surface of the stars." (Campanella 1616, 65). He never says that Galileo (or himself) place dwellers over there, but merely that "if the inhabitants which may be in other stars are men, they did not originate from Adam and are not infected by his sin. Nor do these inhabitants need redemption unless they have committed some other sin." (Campanella 1616, 66). And he adds that "there cannot be found in the decrees of the Church a decree which prohibits belief in a Plurality of Worlds." (Campanella 1616, 65). He is wrong: he forgets Gratianus (see Chapter V, *The Bishop Tempier decrees*). On the other hand, he has an impressive point to make: "The articles promulgated by the University of Paris include among the errors to be corrected in Saint Thomas [Aquinas] the proposition that another Earth could not exist." (Campanella 1616, 66). Such appears to be the sole surviving allusion to the Tempier *decrees* from the post-*Sidereus Nuncius* tempest.

At least as early as 1613, Galileo began to issue cautionary warnings. In a private *Letter* to Prince Cesi, president of *Academia dei Lincei*, the problem of inhabited planets comes up: "If the question be put to me I will answer neither yes nor no." (Fahie 1903, 134, Note 2). In the case of the Moon, for which the telescopic evidence was more abundant, he soon showed himself quite definite; in a 1616 private letter, he reports on a conversation during which

> a discussion arose on the inequality of the lunar surface… in order to disprove the fact, [his interlocutor] argued that if the lunar superficies be unequal and mountainous, one may say as a consequence that, since Nature has made our Earth mountainous for the benefit of plants and animals beneficial to Man, so on the Moon there must be other plants and other animals beneficial to other intellectual creatures. Such a consequence, he said, being most false, therefore lunar mountains do not exist.

An impeccable chain of final causes indeed, proceeding to a fully logical conclusion, to which Galileo retorted:

> As to the inequalities of the Moon's surface, we have only to look through a telescope to be convinced of their existence; as to the "consequences", I said they are not only not necessary but absolutely false and impossible, for I was in a position to prove that neither men nor animals nor plants as on this Earth, nor anything at all like them can exist on the Moon. (quoted by Fahie 1903, 135).

The point will be more fully developed in the *Dialogue* sixteen years later; still, as early as 1616, Galileo had already mustered all his arguments against life on the Moon.

However, budding astrophysics did not develop in a free World or within a conceptual vacuum. The time was precisely that of the first difficulties with the Church: Cardinal Bellarmine, "Master of Controversial Questions" in the *Collegio Romano* (and one of Bruno's judges) was even then taking professional interest in the heliocentric doctrine. Hence, when Galileo stressed that he was able to demonstrate that there were no men on the Moon, he was well aware that any proof to the contrary might be inadvisable. Three years earlier, in his *Third Letter on Sunspots*, he had already stressed

> …as false and damnable the view of those who would put inhabitants on Jupiter, Venus, Saturn and the Moon, meaning by "inhabitants" animals like ours and men in particular. Moreover, I think I can prove this. If we could believe with any probability that there were living beings and vegetables in the Moon or any planet different not only from terrestrial ones, but remote from our wildest imaginings, I should for my part neither affirm nor deny it but should leave the decision to wiser men than I. (*Letter* in *Discoveries*, 137).

This passage illustrates well the prevalent situation: Galileo believes he holds sound technical arguments against lunar life, but had his conclusions been different, he would not have felt free to develop them; hence he is somewhat over-emphatic in his rejection of Life on the Moon. This prudent attitude had a fortunate consequence for him: Plurality was not to become an issue during the future trial; unlike in Bruno's case, we have the complete list of the opinions condemned by the Tribunal.

By the time Galileo writes the *Dialogue* in 1632, the storm has abated to a deceptive lull, and he feels able to leave in the background those religious points. He does it in rather astute fashion, as the sole mention of theological implications is put into Simplicio's mouth, and for once the good man is not made ridiculous. The starting point is the old Peripatetic refusal of heavenly changes, and the link with the central place of Man is explicitly made:

> Generations, mutations etc… which would occur say in the Moon, would be vain, and *natura nihil frustra fecit*… We see plainly that all generations and changes that occur on Earth are either directly or indirectly designed for the use, comfort and benefit of man. Horses are born to accommodate men; for the nutriment of horses, the earth produces hay

> and the clouds water it… Now of what use to the human race could generations ever be which might happen on the Moon or other planets? Unless you mean that there are men in the Moon who enjoy their fruits; an idea which if not mythical is impious. (*Dialogue,* 60).

Which is merely the old case built against Plurality by Platonic and Peripatetic thought: everything is made for Man, Man is alone, and the Holy Bible fully concurs. Galileo's answer combines scientific prudence with theological caution. He is careful not to deride the impiety argument and to dissociate it from Simplicio's implications. Sagredo:

> I do not know, nor do I suppose that herbs or plants or animals similar to ours are propagated on the Moon, or that rains or winds or thunderstorms occur there as on Earth; much less, that it is inhabited by men. Yet, I still do not see that it necessarily follows that since things similar to ours are not generated there, no alterations at all take place, or that there cannot be things that do change or are generated and dissolve; things not only different from ours, but so far from our conceptions as to be entirely unimaginable by us. (*Dialogue,* 62).

Different and hard to imagine, indeed.

A further passage of the *Dialogue* is of interest, because it reveals an aspect of Galileo's thought that nobody will follow before a long time: Plurality might proceed from efficient causes alone. Simplicio has just presented his strictly anthropocentric view of the Universe and Salviati, fully granting the said Universe to be the outcome of Divine Wisdom and Power, nevertheless refuses

> to have us tie its hands so. We should be quite content in the knowledge that God and Nature are so occupied in the government of human affairs that they could not apply themselves more to us if they had no other cares to attend to than those of the human race alone. I believe I can explain what I mean by a very appropriate and most noble example, derived from the action of the light of the Sun. For when the Sun draws up some vapors here or warms a plant there, it draws these and warms this as if it had nothing else to do. Even in ripening a bunch of grapes or perhaps just a single grape, it applies itself so effectively that it could not do more even if the goal of all its affairs were just the ripening of this one grape. That grape would be guilty of envy and pride if it believed or demanded that the action of the sun's rays should be employed upon itself alone… I cannot bring myself to believe that there may not be other things in the Universe dependent upon the infinity of [Divine] wisdom… It is brash for our feebleness to attempt the reason for God's actions, and to call everything in the Universe vain and superfluous which does not serve us." (*Dialogue*, 367-8).

Here God operates as the ultimate efficient cause fertilizing the entire Universe according to uniform principles, just like the Sun does. Galileo will never endorse Plurality, either in the form of other men within our solar system, or of similar systems erected around stars; still, he is implicitly formulating a view of universal Life arising from God's action that cannot be limited to our small corner of the Universe. For Galileo, the World is physically the same everywhere, and his long-term anticipation here is remarkable: the same efficient causes acting at any place are likely to induce the same kind of development; if that appetizing bunch of grapes ripens successfully on Earth, why not elsewhere? Galileo's immediate or more distant successors will prove ready to drop crudely anthropocentric causes, but not final ones. Sure enough, they will cram this new space, just made available, with whirls, whorls and worlds; however, their invoked explanation will not be that heat, light and gravitational attraction from the stars should induce everywhere like effects, but merely that the Universe looks more pleasing that way. For most of the next two centuries, the guideline will simply be: the fuller the better.

The situation will evolve but very slowly. The main telescope discovery, that of a basic similarity between Heaven and Earth, was bound to produce at first these unbridled speculations recorded by Ciampoli. An immense amount of paper was to be blackened on the subject with the ink of pure imagination, and serious speculation could not appear before the concepts of terrestrial and celestial evolution had been formulated. The telescopic Universe, while spreading out through Space, had remained for Galileo and his followers (even Huygens) as closely bound in Time as it had been for the Fathers of the Church. The second great revolution, the stretching of the traditional time scale, would not arise out of any sudden instrumental breakthrough within a few nights of sky-watching. Slow and laborious studies of strata, fossils and bone fragments by many different workers were to be required. The implications have never reached, even today, the degree of glaring obviousness provided by any instant telescopic observation. Reconstruction of the distant past remains a highly difficult and controversial business.

All these painstaking steps were needed before non-teleologic arguments could be effective for stationing dwellers within Heavens. Today, we still have to confess these Aliens as still "entirely unimaginable by us"; even so, we visualize them as the laborious but probable outcome of natural processes, like those grapes ripening in sunlight.

Plutarch, Galileo and Aliens

How closely had Plutarch anticipated Galileo about Life on Other Worlds? Did the telescope bring in truly novel arguments? Before studying the case, let us quote nearly in full the relevant parts of the *Dialogue*; here Simplicio keeps mum and the Florentine Salviati speaks for Galileo, while Sagredo the Venetian plays the intelligent *tertium quid*.

> SAGREDO: I am certain that a person born and raised in a huge forest among wild beasts and birds, and knowing nothing of the watery element, would never be able to frame in his imagination another world existing in nature differing from his, filled with animals which would travel without legs or fast-beating wings, and not upon its surface alone, like beasts upon the earth, but everywhere within its depths; and not only moving but stopping motionless wherever they pleased, a thing which birds in the air cannot do. And that men lived there too, and built palaces and cities, and travelled with such ease that without tiring themselves at all, they could proceed to far counties with their families and households and whole cities. Now as I say, I am sure that such a man himself could not, even with the liveliest imagination, ever picture to himself fishes, the ocean, ships, fleets and armadas. Thus and more so might it happen that in the Moon, separated from us by so much greater an interval, and made of materials perhaps much different from those on Earth, substances exist and actions occur which are not merely remote but completely beyond all our imaginings, lacking any resemblance to ours, and therefore being entirely unthinkable. For that which we imagine must be either something already seen, or a composite of things and parts of things seen at different times; such as sphinxes, sirens, chimeras, centaurs, etc…

SALVIATI: Many times have I given rein to my fancies about these things and my conclusion is that it is indeed possible to discover some things that do not and cannot exist on the Moon, but none which I believe can be and are there, except very generally; that is, things occupying it, acting and moving in it, perhaps in a very different way from ours, seeing and admiring the grandeur and beauty of the Universe and its Maker and Director and continually singing encomiums in His praise. I mean, in a word, doing what is so frequently decreed in the Holy Scriptures, namely a perpetual occupation of all creatures in praising God. (*Dialogue*, 61-2).

Thus, unlike most of his future followers, Galileo does not take the crucial step of deciding that such celestial dwellers are required as a necessary outcome of Divine Omnipotence; they remain for him a mere possibility, neither confirmed nor ruled out by the telescope, but definitely not in conflict with basic Christian creeds.

All that first discussion of extraterrestrial life had started from the issue of heavenly corruption; while only the Moon had been mentioned, the conclusions were applicable to all celestial bodies. Later in the *First Day*, conversation returns specifically to the lunar case, and watery seas have just been shown as very unlikely. Then:

SALVIATI: I consider the Moon very different from the Earth. Though I fancy to myself that its regions are not idle or dead, still I do not assert that life and motion exist there, and much less than plants, animals or other things similar to ours are generated there. Even if they were, they would be extremely diverse and far beyond all our imaginings. I am inclined to believe this because in the first place I think that the material of the lunar globe is not land and water, and this alone is enough to prevent generations and alterations similar to ours. But even supposing land and water on the Moon there are in any case two reasons that plants and animals similar to ours would not be produced there.

The first is that the varying aspects of the sun are so necessary for our various species that these could not exist at all without them. Now, the behavior of the Sun toward the Earth is much different from what it displays toward the Moon. As to daily illumination, we on Earth have for the most part twenty-four hours divided between day and night, but the same effect takes a month on the Moon… Now think what the action of the sun would be in the torrid zone if for fifteen days without pose it continued to beat down with its rays. It goes without saying that all the plants and herbs and animals would be destroyed; hence if any species existed there, they would be plants and animals very different from present ones.

In the second place, I am sure that there are no rains on the Moon, because if clouds collected in any part of it, as around the Earth, they would hide some of the things on the Moon which we see with the telescope. Briefly, the scene would alter in some respect; an effect I have never seen during long and diligent observations, having always discovered a very pure and uniform serenity.

SAGREDO. To this it might be replied that either there might be great dews, or that it rains there during its nights; that is, when the sun does not light it up.

SALVIATI. If from other appearances we had any signs that there were species similar to ours there, and only the occurrence of the rains was lacking, we should be able to find this or some other condition to take their place, as happens in Egypt by the inundations of the Nile. But finding no event whatever like ours, of the many that would be required to produce similar effects, there is no point in troubling to introduce one only, and even that one not from sure observation but because of mere possibility. Besides, if I were asked what my basic knowledge and natural reason told me regarding the production there of things similar to or different from ours, I should always reply: “Very different and entirely unimaginable by us", for this seems to me to fit with the richness of Nature, and the omnipotence of the Creator and Ruler. (*Dialogue*, 100-1).

How original is Galileo compared to Plutarch in his deductions? As far as lunar inhabitants were concerned, had the telescope provided him with wholly new proofs? Let us extract the most relevant lines from the above quotations, and parallel them with some Plutarchian ones from our Chapter 3.

PLUTARCH: Now Egyptians and troglodytes are all burned to a cinder… (Plutarch, *De Facie*, 161).

GALILEO: Now think what the action of the Sun would be if for fifteen days…

This first Galileo argument, the disastrous length of lunar days, had been fully pre-telescopic, and he does not proceed at all beyond Plutarch. Next:

PLUTARCH: Winds and clouds and rains without which plants cannot arise … cannot possibly be imagined as forming there. (*De Facie,* 161).

GALILEO: I am sure there are no rains on the Moon… clouds would hide some of the things we see with the telescope.

Here, the starting points are different but the conclusions are the same. Plutarch had deduced a cloudless Moon because it lay far above our highest mountains; thanks to the telescope, Galileo has observed the absence of clouds with his own eye. Both similarly conclude that no clouds means no rains, hence forms of life at best very different from any sample we know or fancy. Indeed:

PLUTARCH: They err those who demand that living beings be equipped just as those here. (*De Facie,* 177).

We have no comprehension of these creatures. (*De Facie,* 179).

They err those … who are blind to the diversity of Nature… (*De Facie,* 177).

GALILEO: Plants and animals are very different from present ones.

Very different and entirely unimaginable by us.

This seems to fit with the richness of Nature and the omnipotence of the Creator.

Here the parallel is exact. Both authors stress the immense variety of possible life forms, and the infirmity of human imagination; the first invokes plain Nature and the second a Creator. Either way, very little has been added since. Next:

PLUTARCH: Just as assuming that we were unable to approach the sea… if someone said that it supports in its depths many large animals… his statements would seem to us like a tissue of myths…such appears to be our relation to the Moon. (*De Facie,* 179).

GALILEO: A person born and raised in a huge forest… knowing nothing of the watery element…never able to frame in his imagination another world existing in nature… thus and more so might it happen than in the Moon…

Exactly the same pedagogical device is used in both cases, and no better one has ever been invented to wreck the anthropomorphic Universe; it had been much older than Plutarch, remember Xenophanes: "If horses, oxen and lions…" As to Galileo, he sees clearly enough that his telescope could not produce decisive observations about lunar life, but he does not realize that Plutarch, who had no telescope at all, closely anticipated him. Even so, *De Facie* had lain mostly forgotten for a millennium and a half while Galileo generated an instant revolution.[7] Soon, few readers will follow the *Dialogue* carefully enough to feel the need for any caution; most will prefer to "amplify, alter and expand." Believers in the most thorough form of Plurality, i.e. actual Aliens leading full lives of their own, will outnumber opponents within a few decades. The telescope did not provide them with any solid argument, but unlocked latent powers of imagination so far compressed within the crystal spheres. Are we any more factual today?

Appendix: Galileo's Missed Earth-Rotation Proofs

Throughout his life Galileo desperately searched for positive proofs of Earth rotation, and never found a correct one. A manifestation of Nature's irony in her dealings with poor scientists is that he had two conclusive demonstrations almost under his eyes and perceived neither of them.

The first might have come from the pendulum he was so familiar with. The Foucault pendulum, now displayed in all science museums, is a simple device that could conceivably have been invented through pure luck during antiquity. For a stand, the Roman Pantheon would have been just as adequate as the Parisian one in 1851, when the French government decided to give the experiment maximum publicity. Still, the observed rotation of the pendulum plane is small under most usual conditions and would have been noticed only by an able experimenter, particularly one looking for the effect. Perhaps, Archimedes (who did know about the Aristarchus system) would have been equal to the task? Such speculations seem rather empty; but in the case of Galileo, they are clearly not.

Galileo (1) was looking for proofs of Earth rotation, (2) considered the motion of projectiles on the surface of the Earth in connection with this problem, (3) used the pendulum in thought-experiments, (4) observed its motion with great care as his discovery of isochronism shows (for pendulum or related experiments of Galileo, see Drake 1955, 66–72), (5) was interested in keeping a pendulum operating for a very long time: he tried to develop a pendulum-driven clock. That famous lamp swinging in the cathedral of Pisa would not have been quite suitable as it hung, because of excessive damping; but a minor modification, merely replacing the candelabra by a small lead weight, would have made it so. From his profound thoughts sent to Benedetto Castelli, we know that the Archbishop of Pisa would have been nonplussed, but merely greasing the beadle's palm might have done the trick. More sensibly, the experiment could have been tried under less grand circumstances; altogether, Galileo passed unaware very close to a crucial demonstration. Complete analysis of the phenomenon is not simple, except

[7] In the next chapter we shall see that Kepler in his *Somnium* (written at about the same time as the *Dialogue*, but published posthumously two years later) develops the same theme as Galileo, with plenty of Keplerian imagination thrown in; but he is fully aware of *De Facie*, which even provides his starting point.

at the geographical Pole, and requires advanced mechanics; but the result itself is plain, as the oscillation-plane revolution period simply varies as the inverse sine of latitude. Anyway, at a given location, the mere fact that some rotation had been consistently observed in the proper direction would have been striking. We can play with the possible historical consequences, had the phenomenon been discovered by himself. What kind of twisted explanations would have been fabricated by Peripatetics? Would Cardinal Bellarmine have been induced to take the pendulum as that "real proof" he had been asking for? Would Galileo (and the Church) have been spared that disastrous trial?

In actual history, the effect was unquestionably observed soon after Galileo's demise by his disciple Vicenzio Viviani: "We observed that all pendulums suspended by a single wire deviate from the first vertical and always in the same direction."[8] While most of the *Accademia del Cimento* papers were published in 1667, this startling line was to be discovered only in a manuscript two centuries later, after Foucault had made his own experiment. It seems likely that Viviani must have guessed the true explanation, but never uttered a word about it, mere mention of Earth rotation being then taboo in Italy. Still, he was on perfectly safe ground when recommending that a two-wire suspension be used to eliminate such troublesome pendulum behavior. Indeed, a single-wire pendulum proves a poor tool for anyone interested in precise isochronism, or for most experiments of mechanics, since trivial perturbing forces soon transform the plane oscillation into an elliptical one anyway. Viviani's advice was either followed or rediscovered, the need being fairly obvious, and a pair of wires (or equivalent devices with knife-edges or flat springs), which constrain the oscillation to a stable plane, became universally used. Thus, at the precise time when the pendulum graduated to a routine laboratory tool, the rotating-Earth effect became masked through the use of proper experimental care! Even so, in 1666 Robert Hooke demonstrated before his Royal Society colleagues a single-wire pendulum operating either as plane or conical. But the goal was to show that the heavy bob followed circular or elliptical orbits, just like planets do, and the rotation of the Earth was no longer an immediate issue. (Kuhn 1959, 250–1).

As to Foucault, who knew nothing about Viviani, his own thinking started from an 1837 paper by Poisson in which the author had computed the easterly deviation of projectiles due to Earth rotation, and "…it appeared to me that the mass of a pendulum can be likened to that of a projectile which deviates to the right when it goes away from the observer, and necessarily in the opposite sense when returning to its starting point." (Foucault 1878, 382). Hence, even if Foucault himself was a pure experimenter, he had not taken his cue from some chance observation, but from a study of theoretical mechanics by a mathematician; still, he is fully responsible for having correctly guessed the key point: "The Pendulum has the advantage of accumulating effects, and of passing them from the realm of theory to that of observation."[9]

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[8] "Osservammo che tutti i penduli da un sol filo deviano dal primo verticale e sempre per medesimo verso." Unpublished account of work done at the *Accademia del Cimento*, quoted by J. Bertrand in *Introduction* to *Recueil des Travaux Scientifiques de Léon Foucault* (Foucault 1878) p XV.

[9] Léon Foucault (1851) *Comptes Rendus de l'Académie des Sciences* 32,135

Next he made the first test in his own basement, and got a positive result; but the full pendulum theory was only to be given much later in 1879 in the PhD thesis of Heike Kammelingh Onnes, the future discoverer of supraconductivity. The experiment was soon repeated at the Paris Observatory, then under the Parisian Pantheon dome, and all over the world; for instance, in the Reims and Amiens cathedrals, next in the Roman church of Saint Ignatius, Founder of the Jesuit Order (Tobin 2003, 145–149). Times had changed indeed.

The second experiment that Galileo missed is simply the free-fall of a body on the rotating Earth. Conceptually it is simpler than the pendulum one, but harder to perform and the result is less striking: a tiny deviation to the East of the impact point, compared to that expected from a check with a plumb line. In actual history, the effect was predicted by Newton and studied with increasing care first by Hooke, then by various workers, the last and most accurate tests being those of Hall, using the Harvard tower, in 1903.[10] At Harvard, with a height of 23 m, Hall computed a deviation 0.179 cm, and measured 0.149 cm on the average from about a thousand trials, with a probable error of 0.015 cm, i.e. ten times smaller. The sole novel point to be made here is that Galileo might easily have made an order-of-magnitude prediction, and presented the test at least as a thought experiment, and possibly as an actual one. Would he have attempted the actual experiment? Adequate technology had certainly been available in Renaissance Florence: Hall dropped his balls by burning threads, and caught them in a mixture of tallow and beeswax.

[10] E.H. Hall (1903) *Physical Review*, 17, 179–210 and 245–254, (1903). An up-to-date theoretical treatment, and most of the historical references are given by M.S. Tiersten & H. Soodak (2000) *American Journal of Physics*, 68, 129–142.

Chapter 10
Johannes Kepler: Servo-Controlled Planets Orbiting a Sun-God

If there are globes in the Heaven similar to our Earth, do we vie with them over who occupies the better portion of the Universe? For if their globes are nobler, we are not the noblest of rational creatures. Then how can all things be for mans' sake? How can we be the masters of God's handiwork? … This system of planets, on one of which we human dwell, is located in the very bosom of the World, around the heart of the Universe, that is, the Sun… We humans live on the globe which by right belongs to the primary rational creature, the noblest of the corporeal creatures.

Kepler, *Dissertatio*[1]

(Left) Portrait of Kepler, anonymous copy of a lost original from 1610, Benedictine monastery in Kremsmünster. Wikimedia Commons
(Right) Fontispiece of Kepler's *Rudolphine Tables* (1627). Wikimedia Commons

[1] *Dissertatio,* 43.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-41448-1_10

Kepler's Life and Books[2]

Within any history of science Johannes Kepler occupies a conspicuous place: his complex character and tangled life story are bound to make wonderful copy under any pen. The fascination he exerts on all readers arises from his capital contribution to all exact sciences while he is (in the words of Gerard Holton) "rooted in a time when animism, alchemy, astrology, numerology and witchcraft presented problems to be seriously argued." (Holton 1956, 340). Both his works and his life have been exhaustively studied by historians, and his rare case has even attracted a great novelist: Arthur Koestler (1963) in his *Sleepwalkers* has devoted two hundred pages, both highly readable and serious, to the Kepler phenomenon (in this unusual case, the novelist is not dismissed outright by historians). Hence, even minor incidents in his life are well documented, not the least by Kepler himself who often describes the chaotic path followed by his own thought, either in his books or in well-preserved letters. The case is one of excessive abundance of riches, but here the modest goal is to highlight some of the least-followed aspects of his work: his view of the nature of planets and stars, and of stellar geometry, necessary to understand his utter rejection of Cusanus' and Bruno's ideas. Needless to say, the essential contribution of Kepler to science is contained within his three astronomical Laws, which delineated the modern solar system and gave his cue to Newton; here they will be but summarily mentioned, since they do not play any role in his negative view of Plurality.

The Kepler books used here are (in chronological order of their writing):

Mysterium Cosmographicum (1595), translated by A.M. Duncan as The Secret of the Universe (referred to as Mysterium);

Ad Vitellionem Paralipomena quibus Astronomiae Pars Optica (1604), translated by W.H. Donahue as

Johannes Kepler Optics (referred to as *Paralipomena*);

Astronomia Nova (1609), translated by William Donahue as *Johannes Kepler New Astronomy* (referred to as *Astronomia Nova*);

Dissertatio cum nuncio sidereo (1610), translated by Edward Rosen as *Kepler's Conversation with Galileo's Sidereal Messenger* (referred to as Dissertatio);

Harmonices Mundi, (1619) translated by E.J. Aiton, A.M. Duncan & J.V. Field as *Harmony of the World* (referred to as *Harmonices Mundi*);

Epitomes Astronomiae Copernicanae (1621), books IV and V, translated by Ch. Glenn Wallis as *Epitome of Copernican Astronomy* (referred to as *Epitome*);

Somnium, seu Opus Posthumum de Astronomia Lunari (1634) translated by Edward Rosen as *Kepler's Somnium* (referred to as *Somnium*);

Johannes Kepler Gesammelte Werke (1938–2009) (referred to as *KGW*).

The most useful works about Kepler have been:

Caspar, M. (1959) *Kepler;*

Kepler, Four Hundred Years, a Conference edited by Arthur Beer & Peter Beer (1975) (referred to as *KFHY*);

Holton, G. (1956) *Johannes Kepler's Universe: its physics and metaphysics*;

Koyré, A. (1961) *The Astronomical Revolution, Copernicus-Kepler-Borelli*.

What are the main materials? Kepler's life will be found divided in three parts by two major events: his entry within Tycho Brahe's Prague team in 1600, and the day when he received *Sidereus Nuncius* ten years later. Long before the first, twenty-four years old Johannes Kepler (fresh offshoot of the Lutherian Tübingen University) was a math teacher at a school in Graz, and rather bored with the job, when he wrote his first book, the 1595 *Mysterium Cosmographicum*. Kepler had been converted to Copernicanism during his student days by his teacher Michael Mästlin, who himself did not dare to profess openly that dangerous creed. In the *Mysterium*, Kepler tried to go far beyond Copernicus by finding answers to these two questions: why are there six planets orbiting the Sun, and why are they spaced just so and not otherwise? all of which he wanted to deduce from pure geometry. Neither the questions nor the answers Kepler managed to wrangle from Nature and Plato, not counting God himself, make any sense today; and it must be admitted that he made few converts. Absurd as we hold it to be, the *Mysterium* nevertheless was to have far-reaching consequences, first for Kepler himself, and later for the history of astronomy. He sent a copy to Tycho Brahe who was unconvinced, as his own approach rested on reading graduated circles rather than Plato. Still, his attention was caught by this young hopeful who definitely could handle computations: Tycho wanted his own controversial planetary system solidly grounded on his voluminous observations, so far insufficiently reduced. As to Kepler himself, who until then had been unable to make any but the most primitive measurements, with hardly any instruments at all, he hoped exactly the same kind of demonstration for his own *Mysterium*. In hindsight, both quests were hopeless; but the outcome, five years later, was Kepler settling in Prague and the most famous and fruitful collaboration ever achieved between instrumentalist-observer and computer-theoretician. Also the briefest and most tempestuous, to be saved only by Tycho's sudden but opportune demise a year later, which left Kepler in somewhat disputed possession of a priceless store of numerical data; plus, as successor to Tycho, of the impressive title of Imperial Mathematician to Emperor Rudolf II. This meant a substantial salary, which was even sometimes actually paid.

The uncharacteristically stable ensuing situation lasted from 1601 to 1612, covering some of the most fruitful years of Kepler's life. His first publication is the 1606 *De Stella Nova*, describing a bright new star that had appeared two years before in Ophiucus. The book is nowadays considered relatively minor, as unveiling no essential novelty: while this star (widely studied today, and called "Kepler's supernova") did play a role in the overthrow of Peripatetic heavens, the 1572 "Tycho's supernova" had already shown the way by showing that the supralunar word was not perfect after all. Simultaneously, he went on with his reduction of the Tycho data in parallel with his own fancies, and published *Paralipomena* in 1604 *and Astronomia nova* in 1609, both dedicated to the Emperor. *Paralipomena* (subtitled *Astronomia Pars Optica*) is devoted to both laboratory and astronomical optics[2]; it contains the

[2] *Paralipomena* is a latinisation of the Greek term παραλιπομενα: things being left on the side. Kepler was modestly presenting his own work as a mere supplement to the 1270 encyclopedia of optics by the Polish optician Witelo (Vitellon), reprinted three times in the sixteenth century; which illustrates well the extremely slow progress of optics before his own time, and the total lack of new theoretical work before the invention of the telescope.

fundamental inverse-square-distance law for illumination, and the "Kepler Law" of proportionality between angles of incidence and refraction. This last, while only a small-angle approximation, proved adequate for understanding human vision, with real images forming on the retina; however, Kepler showed no interest yet in any lens outside the eye. The second part dealt e.g. with lunar and solar apparent diameters and their consequences for eclipses, with parallaxes, and with atmospheric refraction. That important and troublesome phenomenon was still very poorly understood and modeled, even by Tycho himself; but Kepler, hard at work on Mars, had an urgent need for accurate corrections (see Leen and van der Werf 2005). The book will be useful here for following his views of the Moon and of the light from stars.

Astronomia Nova is the outcome of work performed from the day Kepler joined Tycho, and has completely different scope, being concerned with planetary motions and their explanation from physical causes, a wholly new and pregnant concern. The full title uses the peculiar mixture of Latin and Greek beloved by Kepler: *Astronomia Nova seu Physica Coelestis ΑΙΤΙΟΛΟΓΗΤΟΣ* (concerned with causes). Tycho had entrusted the still-novice Kepler with the chore of analyzing the Mars observations of which his disciple Longomontanus had made neither head nor tail, and this choice proved a tremendous piece of luck. Because of its large eccentricity and proximity to Earth acting together, the Mars observed positions presented the largest departures from the models of Ptolemy, Copernicus and Tycho alike, which all relied on circular motions and epicycles. *Astronomia Nova* gives the first two *Laws*; and the story of the many Kepler trial-and-error attempts has been exhaustively followed (see in particular Koyré 1961, 117-265).

As soon as he had printed copies, Kepler sent one to Galileo, hoping for a favorable reaction from this eminent natural philosopher; actually, Galileo had not yet made a name for himself in astronomy, but his opinion was worth having, and Kepler knew him from a correspondence begun twelve years before to be a half-convert Copernican.[3] However, the answer never came; instead, less than a year later, in March 1610, the stupefied Kepler heard about the Galileo telescopic discoveries, at first by inaccurate word of mouth. He was left aghast by these four new planets said to be circling somewhere on the celestial vault. Were they orbiting the Sun? Unbelievable, his *Mysterium* having conclusively demonstrated the number of planets to be six. Or some other star, as Bruno had predicted? If so, an equally essential part of the Keplerian system, which left no room at all for such other planetary systems, was left in ruins. Happily, on April 8, *Sidereus Nuncius* brought relief and Kepler could breathe again: he had no *a priori* objections against bodies circling Jupiter, and felt quite ready to welcome them within his own solar system. Galileo, while (rightly) caring little about the *Mysterium* and (wrongly) about the two just-published Laws, had felt that some support from the Imperial Mathematician was still worth seeking: his own discoveries were yet far from generally accepted.

[3] The Kepler-Galileo correspondence is followed by Rosen in his *Note* 42, p. 59 of *Dissertatio*. *Fac-simile* reproductions of two letters exchanged in 1597 are given by L. Rosino, *Kepler and Galileo*, KFHY, 255.

Within eleven days, Kepler wrote his answer to Galileo; in May he had it published under the title *Dissertatio cum Nuncio Sidereo* (*Conversation with the Messenger from the Stars*) as a public Letter that was to play an important role in the passionate debates of that climacteric year, and be reprinted several times.

In his enthusiastic (and most-readable) *Dissertatio*, Kepler overflows with praise:

> I yearned to discuss with you, most accomplished Galileo, in a highly agreeable kind of discourse, the many undisclosed treasures of Jehovah the Creator, which He reveals to us one after another. For who is permitted to remain silent at the news of such momentous developments? Who is not filled with a surging love of God, pouring itself copiously forth through tongue and pen? (Dissertation, 12).

Kepler will achieve a considerable volume of such outpouring, since he instantly perceived that the *Messenger from the Stars* brought vital support to both Copernicus and himself; and he showed no jealousy of the telescope achievement. What makes both attitudes even more remarkable is that Kepler, by far the better optician of the two men (as he will very soon show) had no telescope, and could not readily construct one: unlike Galileo, he had neither manual skill, nor his own workshop nor a Mazzolini! All the resources at the service of the Imperial Astronomer, including those of the sizeable Bohemian glass industry, do not seem to have been of much help at this critical juncture. Galileo showed no haste in sending one of his instruments to Prague, being more interested in pleasing various grandees. In August Kepler finally received one of his telescopes from the Duke of Bavaria; he became able to check these incredible discoveries with his own eyes and immediately printed an account, the *Narratio de Jovis Satellitibus*; which confirmation of Galileo seems to have carried appreciable weight.

The most amazing part of the Kepler 1610 achievement may only be mentioned by straying from our main subject, but forgetting it altogether would be too painful for me, as an optician. Within August and September Kepler wrote his *Dioptrice*, a word he coined for the occasion. Despite the urgency of playing with his just-received telescope, he managed to produce the basic textbook of modern geometrical optics; he must have quite literally observed all night and written all day. Apart from the discovery of total reflection within a prism, the work is mostly theoretical and contains 141 theorems that cover the imaging properties of lenses. Kepler also proposed the use of converging eyepieces, far better tools than the diverging Galileo type, and universally used since for astronomical telescopes. And he wrote it all while still unable to do his own checking with decent lenses! Had he laid hands on a single pair, he would not have needed the Bavaria telescope.

The next two important books of Kepler were published while he was District Mathematician in Linz, as he had to leave Prague after the abdication of Emperor Rudolph II. The 1619 *Harmonices Mundi* (*Harmonies of the World*) gives the third Law, well hidden within a mess of further Pythagorean fancies. The problem of other solar systems, or the physical nature of planets are not considered; still, the text is valuable for whoever wants to understand the basis of Kepler's thought. The modest title of the 1618–1621 *Epitome Astronomiae Copernicanae* (*Summary of Copernican Astronomy*) is misleading: it risks being dismissed as merely a revamped Rheticus *Narratio Prima*, i.e. a handbook for non-specialists. In fact it gives a full description not of the Copernican system, but of the Keplerian one in its up-to-date version; this is also the place where his deductions about the nature of stars and planets are most fully described; we will follow them later.

The planetary position tables, the *Tabulae Rudolphinae*, had been one of Kepler's main goals from the days when he joined Tycho, but he was able to complete them only in 1627 after his discovery of a wonderful new tool: the Napier logarithms, which he perfected at once, even computing his own logarithm tables. Presently living scientists (at least the older ones) are able to understand Kepler's enthusiastic reaction to logarithms: right in the middle of their own careers, the computer happened, and they joyfully started writing their first programs. The *Rudolphinae* soon proved more accurate than the ageing *Prutenic,* but their reception followed exactly the same pattern: while welcomed and widely used, they were not taken as proving the reality of the planetary system from which they had been derived.

A special place must be granted to the last of Kepler's books, the 1630 *Somnium, seu Opus Posthumum de Astronomia Lunari* (*Dream or Posthumous Work on Lunar Astronomy*). From his student days, Kepler had read Plutarch, and toyed with the idea of following his path by writing a "lunar geography" which would also operate as a Copernican propaganda device: while giving an accurate description of all celestial appearances for an observer located on the surface of the Moon, the author would be presenting a good case for Earth rotation. Hence, telescopic discoveries did not initiate the project: they only made the subject topical, and must have attracted many more readers. Unlike his other, highly technical works, *Somnium* (despite the use of Latin), is written for the general public, and the lunar voyage theme became widely popular during the seventeenth century. In our own time, Fred Hoyle has been compared to Kepler, as being simultaneously a professional astronomer and a science-fiction author.

The Bases of Kepler's Thought

For a cameo portrait of Kepler and his view of Nature, follow Stanley Jaki: "The three major gems in his work on astronomy lay in a vast field of errors, of irrelevant data and details, of mystical fantasies, of useless speculations, of morbid detours of self analysis, and, last but not least, of an organismic and animistic conception of the world and its processes." (Jaki 1978, p. 26). And for a pithy account of his scientific method, Arthur Koestler: "With one eye, he was reading the thoughts of God; the other squinted enviously at Tycho's shining armillary spheres." (Koestler 1963*,* 278). Which epitome applies well both to the construction of his solar system (today revered by all astronomers) and to his negative view of Other Systems, in which he regressed beyond Cusanus and Bruno. Kepler the consummate geometer, the first astronomer of the times, believed to have thoroughly demolished the fancies of those two hazy dreamers with his own arguments that came solely from Faith, Reason and Observation. However, God's thought (ever notoriously difficult to read) had lately become even more so as the number of translations increased beyond control, and astronomers held no privileged one. We will be more surprised to find Kepler refuting Cusanus and Bruno by application of faultless geometry to a plain mistake in his own observations.

Clearly, there were for Kepler two Gods who (remarkably enough) never quarreled in his mind. To the first, revealed by the Holy Writ and more immediately by Luther, he will not turn for guidance in his scientific work. The second is "the Creator, who is the very source of geometry and, as Plato wrote "practises eternal geometry." (*Harmonices Mundi,* 1017). In the case of Plato also, more immediate intermediaries may be pointed at: even the frequent rhapsodic tone used by Kepler is characteristic of Renaissance Neo-Platonists (see Kuhn 1959, 209). His Sun

> is a fountain of light, rich in fruitful heat, most fair, limpid and pure to the sight, the source of vision, portrayer of all colors… king of the planets for his motion…heart of the World for his power, its eye for its beauty, and which alone we should judge worthy of the Most High God should He be pleased with a material domicile… (quoted by Kuhn, 131 from the translation by Burtt 1954, 59).

Kepler's Sun is clearly inherited from that Copernican "Lamp, Mind and Ruler of the Universe", and holds little in common with the physical body revealed by Galileo, with its shocking dirty spots.

The source of all knowledge is simple enough; natural laws are understandable to Man because

> God wanted us to perceive them when He created us in His image in order that we may take part in His own thoughts…Our knowledge [of numbers] is of the same kind as God's at least insofar as we can understand something of it in this mortal life. (*Letter to Mästlin*, April 9 1,599, quoted by Holton 1956, 351).

As put by Holton (1956, 350) "the investigation of Nature becomes an investigation of the thought of God, Whom we can apprehend through the language of mathematics." A reciprocal Kepler theorem seems to be that God, having fabricated a Man able to understand this material World, has thoughtfully modeled the said World for him. So much is perhaps never stated in full, but teleological and/or anthropocentric explanations are seldom far from Kepler's mind. Their strange and intimate mixture with geometrical arguments may be briefly followed. In the *Epitome*, Kepler wonders about planetary orbits sizes:

> [Question] Where do you judge that the beginning should be made in investigating the ratio of bodies?
>
> [Answer] From the Earth 1) as the home of the speculative creature, and 2) of the same image of God the Creator; 3) for we read in the Holy Book of Moses that in the beginning God created the Heaven and the Earth; 4) the sphere of the Earth is the middle figure between the planets… and even a geometrical mean proportional between the territories of the higher and the lower planets; 5) the very structure of these ratios cries in a loud voice that God the Creator in fitting the bodies and intervals to the solar body… made His beginning at the Earth. (*Epitome,* 873).

We have met in the thirteenth century much the same procedure: some devout Christian starts from Genesis, and fills in a few astronomical details Moses had just not bothered about. Here, the architecture of the Keplerian solar system is both geometric and anthropocentric; the modern readers tend to remember mostly the strikingly successful first line of cogitation and forget the second, because it never took Kepler very far.

However, the sizes of Earth and Sun had not been derivable from the Platonic solids; then, why are they just so and not otherwise? "By means of vision of the Sun. For the Earth was going to be the home of the speculative creature… [Q] How great does the diameter appear to be on the Earth?" Summarized, the answer is that ancient astronomers have shown this to be half a degree, i.e. 1/720 of the circumference; which causes a momentary hitch in the demonstration since "there is no geometrical cause for the division of a circle into 720 parts." Kepler will not be stopped long by such a paltry obstacle; the musical system of his *Harmonices* are brought in to help, in which the "least number which offers itself in the twofold scale of the octave … is 720." (*Epitome,* 874). Q.E.D., and all is for the best! The argument proceeds:

> [Q] The determination of what body follows closely? …
>
> [A] The Moon, a secondary planet 1) because this star has been assigned to the Earth as its private property, so that the Moon might help with the growth of earthly creatures and be observed by the speculative creature on Earth… the visible diameter of the Moon at its greater distance from Earth had to occupy 1/720 of the circumference, both on account of the number itself, as before, and also on account of the eclipses of the Sun, a spectacle ordained by the Creator in order that the speculative creature should thereby be taught concerning the rationale of the course of the stars.

Which result was most efficiently achieved "if the semi-diameters of the Sun and Moon were to appear equal at the greatest distance of each." (*Epitome,* 876). A fair summary is: (1) The Creator had located Earth first of all to please Man, but also to fit His own geometrical mean; (2) He chose the size of the Sun to please Kepler in person, and fit his *Harmonices*; (3) He sized and located the Moon in order to produce those splendid total eclipses (alas! Kepler himself never had the luck of watching one); and all along, He acted as a highly professional geometer.

However, Kepler's anthropocentrism is flexible enough to adopt some novelties. In his *Dissertatio*, i.e. within a few days of getting the news from the first telescope, he had already taken as "evident that these four new planets were ordained not primarily for us who live on the Earth, but obviously for the Jovian beings who dwell around Jupiter." (*Dissertatio,* 41). His fairly elaborate teleological demonstration will be followed later, with his views of the planets. Galileo himself would never have written that kind of stuff, and one can understand why he found the Imperial Astronomer so hard to follow. On nearly all counts, his thought proves far more modern than Kepler's; an illuminating comparison of the two personalities has been given by Stillman Drake (*KFHY*, 237–247). Here are some extracts:

> Kepler's program missed the mark because he thought that the new astronomy could be explained by recourse to old physics… Galileo's because he thought that the new physics could be supported by the ancient doctrine that celestial motions have no need of further explanations… There was no duplication of effort between them, and their labours revealed that at least two utterly different methods existed by which Man's understanding of the Universe could progress… Pure reason and the pursuit of metaphysical and aesthetic principles of harmony made astronomer Kepler into a physicist, while chance and personal ambition made the physicist Galileo into an astronomer. The benefit to Science from both events and their virtually simultaneous publication was enormous… Those two men were complementary in nearly every respect in the linking of astronomy.

Geometrical and teleological explanations are not the only ones to operate within Kepler's mind: whenever he tries to find causes for motions, he manages to use both animist and mechanical "forces"; however, a gradual progression from the first to the second is perceptible. First, the Earth is clearly endowed with a soul; here is the Koyré summary of Keplerian arguments from *Epitome*:

> 1) the perpetual, sensible subterranean heat; 2) the generation of metals, minerals and fossils; 3) the fire and light producing properties – cognate with the soul – possessed by certain products of Earth, such as sulphur, marcassites etc.…; 4 and 5) the formative power of Earth which produces animated beings such as flies, insects, marine monsters besides geometrical shapes such as snowflakes and crystals; 6) the perception by the Earth of celestial phenomena (aspects and relationships between angles) in accordance with which meteors (atmospheric phenomena), volcanic eruptions and so on are produced. (Koyré 1961, 291).

The Sun is similarly endowed, and all planets are gifted with souls, or rather "intelligences" but their action is far more elaborate than that of medieval angels which just pushed the planets around, and they prove almost understandable to the modern mind:

> It is not possible for the planetary globe to be carried around by an intelligence alone. For… mind is destitute of the animal power sufficient to cause movement… it is not heard or perceived by the irrational globe; even if mind were perceived the material globe would have no faculty of obeying or moving itself. (*Epitome,* 892).

In *Astronomica Nova* (p. 405), Kepler clarifies his meaning through the picturesque analogy of

> phenomena exhibited by the propulsion of boats. Imagine a cable or rope hanging high up across a river… and a pulley running along the rope, holding by another rope a skiff… If the ferryman fastens his rudder in the right manner, the skiff, carried crosswise by the simple force of the downward moving river, is transported from one bank to the other… In very much the same manner, the power moving out into the World through the species is a kind of rapid torrent which sweeps along all the planets… It is not itself suited to attracting bodies to the Sun… It is therefore necessary that the planets themselves rather like the skiffs have their own motive powers, as if they had riders [*vectores*] or ferrymen…

In modern jargon: the planet is equipped with a complete servo-mechanism incorporating a solar-wind sail; the functions of detecting the error relative to the Creator-intended path, computing the needed correction and applying the correcting force are separate. The specific job of the planetary "intelligence" is to detect and compute.

Animism provided Kepler with explanations; mysticism gave him at least analogies and guidelines. In his *Preface* to the *Mysterium*, Kepler reveals the starting point for his construction:

> That I dared so much was due to the splendid harmony of those things which are at rest: the Sun, the stars and the intermediate space with God the Father, the Son and the Holy Spirit. (*Mysterium,* 63).

We are reminded of Cusanus, and indeed Kepler is conscious of his debt to him for another concept:

> Nicholas of Cusa and others seem to me divine, that they attached so much importance to the relationship between a straight and a curved line, and dared to liken a curve to God and a straight line to his creatures. (*Mysterium,* 93).

However, Kepler is not remembered today for his animistic explanations, but for the mechanical ones that progressively took over in his mind. Remarkably, thanks to the meticulous descriptions of his thought as given by himself, it is possible to pinpoint the shift that turned out to be a pivotal one both for physics and astronomy: the “soul” replaced by a “force.” In the 1596 *Mysterium* chapter devoted to the *Ratios of the Motions to the Orbits*, we read that

> one of two conclusions must be reached: either the moving souls are weaker the further they are from the Sun; or there is a single moving soul in the center of all the spheres, that is in the Sun…

However, in the 1621 re-edition, a clarifying *Note* specifies that

> if for the word “soul” [*anima*] you substitute “force” [*vis*] you have the very same principle on which the Celestial Physics is established…For once I believed that the cause which moves the planets was precisely a soul… but when I pondered that this moving cause grows weaker with distance, and that the Sun’s light also grows thinner… I concluded that this force is something corporeal, that it is an emanation which a body emits, but an immaterial one. (*Mysterium,* 199 and 203, *Note* 3).

This novel approach became systematic. In a 1605 *Letter*, Kepler had written:

> I am much occupied with the investigation of the physical causes. My aim is to show that the celestial machine is to be likened not to a divine organism but to a clockwork… insofar as nearly all the manifold movements are carried out by means of a single, quite simple magnetic force, as in the case of a clockwork all motions are caused by a simple weight. Moreover I show how this physical conception is to be presented through calculation and geometry.

And in a second *Letter*, he had wanted “to provide a philosophy or physics of celestial phenomena in place of the theology or metaphysics of Aristotle.”[4] This Keplerian attitude is a new phenomenon which took him far beyond Copernicus. How difficult it was to admit for colleagues is well shown by the criticism in a letter received from Mästlin:

> Concerning the motion of the Moon, you write that you have traced all the inequalities to physical causes; I do not quite understand this. I think rather than here one should leave physical causes out, and one should explain astronomical matters only according to astronomical method with the aid of astronomical, not physical, causes and hypotheses. (Letter dated Oct. 1 1616, quoted by Holton 956, 345).

These objections are all the more illustrative because Mästlin was so well disposed toward Kepler: he had even helped in the printing of the *Mysterium*. For him, astronomy was a field allowed only to astronomers, i.e. mathematicians and, while long converted to Copernicus, he had not really progressed beyond Ptolemy’s way of thinking.

One last aspect of Kepler’s thought must be barely mentioned. His astrological activities were fairly extensive and not explainable from mere financial considerations. For instance, he computed carefully the heavenly set-up for several

[4] First Letter to Herwart von Hohenburg, Feb. 10 1605, and second Letter to Johann Bregger, Oct. 4 1607, both quoted by Holton (1956), 342, 345.

remarkable occurrences of his own career, starting with conception and birth. Nor did any wealthy patron pay him for a similar computation at the very instant of Creation; according to Kepler, this noteworthy event had taken place on April 27 4977 BC, and all on a Sunday (when else?) (*Mysterium,* final chapter XXIII; Koestler, *Sleepwalkers*, 230, 260). In a small treatise, the *Tertius Interveniens,* within a controversy between simple-minded devotees of astrology and die-hard opponents, he took the role of third party trying to separate the wheat from the chaff (see Beer, in *KFHY*, 399). Clearly, he hoped to make astrology progress; however, as one does not quote a single instance of his astrological beliefs distorting his own picture and mechanism of the World, no more need be said about them.

The Keplerian Solar Sytem

In the present Chapter, the main goal is to explain Kepler's beliefs about Moon and planets, and about stars with or without adjunct planetary systems; however, his view of our own system, including the way it held together, must be clarified first. Since a large amount of detailed historical research has been devoted to the subject, a mere summary is needed. The Keplerian edifice piles up two superimposed storeys: the early-youth *Mysterium* construct replete with Platonic solids, and the mature-age one (*Astronomia Nova* plus *Harmonies*), housing the three Laws. The first is seen today as a showroom of absurdity while the second one is a museum to inspired genius. Honest Kepler, who built the whole from an unvarying faith in geometrical order and physical harmony, rejoiced in a continuous progression and never saw any gap or flaw between lower and upper floors. Neither did a single visitor in his own time.

Even the two questions asked in the *Mysterium* no longer make sense: why six planets, and why are they spaced precisely so and not otherwise? Our number of planets has become greater than six, but this extension itself is unimportant: the actual integer is (for us) of zero interest. Kepler's starting point had been the Platonic discovery of five regular solids and five only; even non-mathematical minds have ever been struck by the beauty of the Greek proof. Six planets meant five intervals, hence the five solids nicely fitted in between; but Kepler failed to see that Plato had never demonstrated that figure of six from pure geometry, it was a mere contribution from fallible observers! Soon after, the telescope unveiled large number of new stars, and made clear at least the possibility of additional planets, but Kepler did not overhaul his construction, even when issuing a new unmodified edition of *Mysterium.* No revision was indeed possible, and the whole edifice would have crumbled from the removal of a single stone.

Only the beginning and conclusion of his own summary are given here:

> The Earth is the circle which is the measure of all. Construct a dodecahedron round it. The circle surrounding that will be Mars. Round Mars construct a tetrahedron. The circle surrounding that will be Jupiter. Round Jupiter construct a cube [etc…]. There you have the explanation of the number of planets.

All or most possible combinations for those five polyhedra had been tried, and the final agreement with actual orbits was only fair, but if there was much fiddling, no historian has fundamental found evidence for any fudging. Kepler never varied in his conviction of having hit on a fact of Nature, one built-in by the Creator at the very Beginning. He was (as often) deeply enthusiastic: "The delight I found in this discovery I shall never be able to express in words" (*Mysterium,* 69); soon he tried to have a model built, then gave it up as too expensive for his own purse and settled for an engraving. Which turned out a blessing in disguise: the silver or brass model would probably have been lost or melted down during the Thirty-Years War, like Tycho's admirable instruments, while we still enjoy that magnificent print (Figure 10.1). Note that the Titius-Bode law issued in 1772 after the discovery of

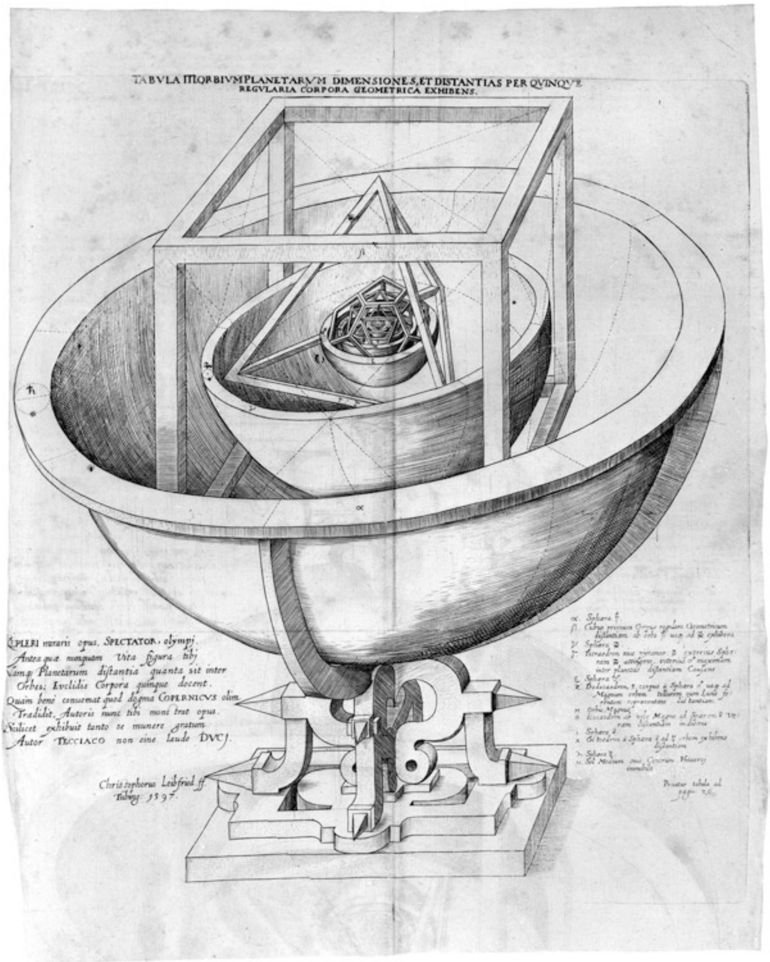


Figure 10.1 Kepler's polyhedra. Bibliothèque de l'Observatoire de Paris

Uranus, which consists in a mathematical formula supposed to give the respective sizes of the planetary orbits, is just as naive that Kepler's polyhedra: still it had been seriously considered for long, including by Le Verrier for his discovery of Neptune in 1846 (Lequeux 2013, 26).

An even more durable (but mostly forgotten) result within the *Mysterium* was a Kepler Law that should logically be called his first: all planetary orbit planes intersect at the Sun. This apparently simple result, which did not yet require Tychonic data, had escaped Copernicus who always considered the center of the Earth orbit instead. The Keplerian substitution of the physical and material Sun to a mere geometrical point was soon to have important consequences. After the *Mysterium*, but still before the telescope era, Kepler took another promising step by expanding the absolute size of the solar system by a factor of three. This was deduced from a re-analysis of Tycho's 1582 data on Mars, and of his own 1604 observations from Prague. Even so his solar system was still seven times too small, but the improvement is notable. As already seen, Galileo contributed nothing to that question.

The laborious generation of the three Laws, which constitute the major Kepler legacy, has been thoroughly analyzed by historians, last together with his underlying physics (see e.g. Dreyer 1905 and Koyré 1961). We are used to label them as *Law 1*: elliptical planetary orbits with Sun at one focus; *Law 2:* vector radii sweeping equal areas in equal times; *Law 3*: squares of revolution periods proportional to cubes of solar distances; this Law was soon found to fit also the Jupiter satellites. All three *Laws* were empirical, in the sense of being fitted by trial-and-error to the Tycho data, and Kepler never succeeding in a mathematical demonstration from any general hypothesis. Nevertheless he was convinced that the first two laws derived from his concept of a central (but not centripetal) force originating in the Sun, while the third was a consequence of his harmonic conception of the Universe. Along an ellipse, the motion could not be natural, hence a force was required; this came from the Sun through an *anima motrix*, but it was more or less tangential *"non est attractoria sed promotoria."* (*Letter to Mästlin*, March 1605, quoted by Dreyer 1905, 398). From the start, he saw this force as decreasing with distance, since the farther planets were slower; believing the Sun influence spread only within the orbital plane (unlike light), he decided on an inverse-distance law after many hesitations. The next natural assumption was a planetary velocity proportional to that *promotoria* force, hence varying inversely with solar distance; at which point, Kepler believed he had a complete demonstration. He was wrong: the true change of speed along the orbit (later correctly given by the equal-areas law) is close to an inverse solar distance law for low eccentricities, but still not identical to it; he never found out the small error, even for Mars. This false velocity law is so simple, so obvious, and looks so sensible that it will still be accepted by Leibniz! (Koyré 1961, 363). As to comets, for which the difference would have been large, Kepler (like Tycho) located them far beyond the Moon from their negligible parallax but believed they were moving along rectilinear paths; any apparent orbit curvature being solely due to Earth motion.

What was the nature of that solar force? It had to do both with solar rotation and magnetism, and Kepler had been fascinated by William Gilbert's *De Magnete* (1600). *Epitome* again:

> [Q] Does the Sun by the rotation of its body make the planets revolve? And how can this be, since the Sun is without hands with which it may lay hold of the planet, which at such a great distance away, and by rotating may make the planet revolve with itself?
>
> [A] Instead of hands, there is the virtue of the body which is emitted in straight lines throughout the whole amplitude of the World, and which… rotates with the solar body like a very rapid vortex… the Sun revolves in the narrowest space at the center… [Similarly we see] the attraction between the loadstone and the iron pointer… turn the loadstone in the neighborhood of the pointer; the pointer will turn at the same time. (*Epitome*, 897).

The magnetic analogy was pursued at great length, and Kepler held the Sun to be a magnet, just like Gilbert's Earth. As to solar rotation, he had long believed in the possibility because of his planetary vortex; it had to be much faster than the Mercury three-months period of revolution, thus he predicted a figure of three days. The telescopic discovery of sunspots by Galileo and Scheiner brought him disappointment: the Sun was indeed revolving, and even in the proper direction, but much too slowly (Koyré 1961, 207, 410)! A more or less similar force mechanism operated for the Moon, as it is "preferable to attribute to the Earth a force that retains the Moon, like a sort of chain, which would be there even if the Moon did not circle the Earth at all." (*Astronomia Nova*, 402). This is as far as Kepler progressed in his Solar system kinetics and dynamics.

The Newton contribution will be the full mathematical demonstration that all three Laws derive from a unique centripetal force coming from the Sun and varying as the inverse-square of distance; and further, that the orbits of the Moon and of the Jupiter satellites, the Galilean law for the fall of graves on the surface of the Earth, and the totally different phenomenon of the tides, are all explained from the single hypothesis of universal gravitation, a concept never reached by Kepler. For the flow of ideas (or sometimes, the lack of it) from Kepler to Newton, see Bernard Cohen's Kepler's Century: Prelude to Newton, *KFHY*, 3–36.

All Planets Are Equal but One Is more Equal Than the Others

Descriptions of solar-system bodies are found scattered through Kepler's works. His concepts about planetary physics are, as usual for him, a mixture of Platonic *a priori* arguments, and of empirical results; still, he does not seem to have derived notable new insights from his own telescopic observations, performed during the last twenty years of his life. Except for the Moon to which he devoted the more specific *Somnium*; the reason was in small part that the telescope had in this case revealed far more numerous features, but mostly that from early youth he had held the Moon to be a God-sent laboratory for demonstrating the Keplerian cosmological picture. We shall consider first his views of the planets.

Planetary sizes do not seem to have been predicted in the *Mysterium* through pure geometry; still, in *Epitome*, his so-called "archetypal reasons" provide him with a starting point:

> Nothing is more in concord with Nature than that the order of magnitudes should be the same as the order of the spheres, so that among the six primary planets, Mercury should have the least body… [etc, etc] and finally Saturn's globe the largest of the moving bodies, because it is the highest. (*Epitome*, 878).

But which is the true proportion? Should the diameter, the area or the volume of the planet be proportional to solar distance? Kepler tries all three, and only then calls in observations which gave (at opposition) 50″ for Jupiter, 30″ for Saturn, and made Mars "greater than Jupiter but not much greater", all at closest oppositions. These results are fair for the first two planets (the true ones being 48″ and 20″) but surprisingly wrong for Mars (24″) (*Epitome*, 879, and Van Helden 1985*,* 85). He is left with no conclusive agreement between Keplerian archetypes and observed planetary diameters.

Next, planetary densities: "What should we hold concerning the rarity and density of these six globes?" Here, observational data are still far in the future, and Kepler risks no contradiction from Nature. First, "it is not consonant that all the planets should have the same density of matter…whatever body is nearer to the Sun is also denser. For the Sun itself is the most dense of all the bodies in the World." (*Epitome,* 880, 881). Again, various proportions are tried and rejected, and Kepler finally manages to convince himself that "the ratio of the amount of matter should be set down as precisely the ratio of the square root of the bulks or amplitudes, and thus the ratio of the 3/2th powers of the diameters of the globes…" Here is a Fourth *Law* of Kepler (which the Creator had unfortunately failed to implement) and the delighted discoverer is able to construct a novel kind of Planetary Table, this one for densities, adding in the third column down-to-earth analogies, taken from "my book in the German language concerning weights and measures":

> Saturn 324 The hardest precious stones
>
> Jupiter 438 The loadstone
>
> Mars 810 Iron
>
> Venus 1175 Lead
>
> Earth 1000 Silver
>
> Mercury 1605 Quicksilver
>
> So that we may reserve gold – whose density in this proportion is 1800 or 1900 - for the Sun. (*Epitome*, 882).

A gold Sun, and a quicksilver Mercury; what else? Ever since Greek times, lead had been attributed to Saturn, because of their common dullness; on this count, Kepler brought no novelty to cosmology.

After densities, local and even not-so-local gravity; here, when compared with the still-prevalent Peripatetic outlook, the Keplerian concept seems modern, and to some extent even anticipates gravitation. He presents it in his *Introduction* to *Astronomia Nova*:

> Gravity is a mutual corporeal disposition among kindred bodies to unite or join together…the magnetic faculty is another example of this sort. Heavy bodies… are not drawn towards the center of the World, but toward the center of a kindred spherical body, namely, the Earth.

So far, this has just been our familiar gravity, as experienced on the surface of the Earth; but Kepler proceeds much farther, and introduces experiments valid anywhere in Space:

> If two stones were set near one another in some place in the World outside the sphere of influence of a third kindred body, these stones, like two magnetic bodies, would come together in an intermediate place, each approaching the other by an interval proportional to the bulk [*moles*] of the other.

Here, we remember Oresme.

The Earth-Moon pair offers an interesting special case:

> If the Moon and the Earth were not each held back in its own circuit by an animate force or something else equivalent to it, the Earth would ascend towards the Moon by one fifty-fourth part of the interval, and the Moon would descend towards the Earth about fifty-three parts of the interval, and there they would be joined together; provided, that is, that the substance of each is of the same density.

And on that puzzling question of the tides (where Galileo will soon go completely wrong) Kepler anticipates Newton:

> If the Earth should cease to attract its waters to itself, all the sea water would be lifted up, and would flow onto the body of the Moon… if the Moon' power of attraction extends to the Earth, the Earth's power of attraction will be much more likely to extend to the Moon and far beyond, and accordingly, that nothing that consists to any extent whatever of terrestrial material, carried up or high, ever escapes the grasp of this mighty power of attraction." (*Astronomia Nova*, 55-7).

Such gravity, while more than just local, is still far from universal as only kindred bodies attract each other; moreover, it does not explain orbits for which a different sort of force had been postulated. Even so, that gravity is adequate to support the local life that will appear in *Dissertatio*, and take center-stage in *Somnium*. Admittedly, Plutarch had anticipated some of it, but he had not seen the magnetic analogy (About the planets and the Sun as magnets, see e.g. *Epitome*, 897–8), nor been able to describe the Earth-to-Moon voyage, which Kepler will soon do.

Planets are also Earth-like in another sense: Kepler anticipated the Jupiter rotation, not to be discovered until later in the century, as it required improved telescopes. For him, this was an automatic consequence of revolving satellites, expected from his theory of planetary motion and formulated in *Dissertatio*, i.e. within a few days of receiving the news from Galileo:

> Like our Earth, Jupiter also rotates about its axis. That rotation is accompanied by the revolution of the four moons just as the rotation of the Earth is accompanied by the revolution of our Moon in the same direction.

Later he will guess the Jupiter rotation period to be less than one day (actually 9 h 50 m), and even the existence of a Red Spot! (*Dissertatio*, 41 and Rosen 1956, *Note* p. 380).

Early in his life, Kepler had supposed planets to be shining partly by their own light, and partly by light reflected from the Sun. Before the telescope, he devotes a section of *Paralipomena* to the "Light of the other heavenly bodies." Venus observed close to the Sun is "of such brightness that at the actual moment of conjunction it can be seen with the form of a great star…it is therefore necessary that it have this surpassing light as its own." (*Paralipomena,* 272). And he has a second argument: "Shining and twinkling are evidence for proper light, nebulosity and sluggishness for extrinsic light… by this rule to the Moon is ascribed borrowed light, to most stars proper light, least of all to Saturn." The explanation from air turbulence (as we would call it) is specifically rejected, and the effect results "…from a real twinkling of Venus, not indeed from the air passing in the wind, as I had believed. For it would also have applied to the Moon" (*Paralipomena*, 272–4). We have already noted the complexity of the correct explanation of twinkling. Next, the colors of the planets are also accounted for by this mixture of two lights, and Kepler makes laboratory tests giving some information about planetary physical nature:

> I showed that if a black surface be strongly illuminated, the color of Mars is returned; if bright red, that of Jupiter; if leaden or white, that of Saturn; if yellow, of Venus; if blue, of Mercury… the same thing must be believed of the proper light as if iron were put in the fire, or a coal, it becomes red…a shining similar to Jupiter is generated…

His overall conclusion; it is: "credible that these heavenly bodies are ignited by an inherent force, no less than the Sun." (*Paralipomena*, 273).

All these beliefs had been pre-telescopic. In *Dissertatio*, Kepler reacts immediately to Galileo's discovery of planets showing "their globes perfectly round." He answers:

> Your second highly welcome observation concerns the sparkling appearance of the fixed stars in contrast to the circular appearance of the planets. What other conclusion shall we draw from this difference, Galileo, than that the fixed stars generate their light from within, whereas the planets, being opaque, are illuminated from without, that is, to use Bruno's terms, the former are suns, the latter moons or Earths? (*Dissertatio,* 34).

In this interpretation, Kepler proceeds far beyond Galileo, for whom the "entirely dark" planets were not to be described before the *Dialogue.* He also uses the opportunity to stress his radical opposition to Bruno: "…let him not lead us on to his belief in infinite worlds, as numerous as the fixed stars and all similar to our own"; of which, more later. Kepler's *Narratio*[5] had been mostly devoted to the Jovian satellites. *Epitome* and *Harmonices* are not concerned with physical appearances of planets while *Somnium* deals only with the Moon. However, Kepler showed great

[5] *Narratio* is found in *KGW* XVI, 341; no full English translation exists. However Rosen translates a very interesting page describing Kepler's first observations of the Moon with a telescope, dated September 4, 1610 (*Somnium, Geographical Appendix*, 163–4, Kepler *Note* XXXIV); see also Koestler (1963), 378 and Caspar (1959), 197.

interest in the subsequent Galileo discoveries, and the picturesque history of how he learned about them is well known. In the second half of 1610, Galileo observed the phases of Venus, and also the bizarre shape of Saturn; he did not publish at once, as he had done in the *Nuncius,* but hid the news under two anagrams sent in private letters. The intent was probably to goad possible competitors into disclosing how much they had been able to discover so far, i.e. hopefully nothing at all. Kepler was intrigued, and tried rather desperately to unveil Galileo's meaning; in particular he managed to find confirmation of his own *a priori* conviction that Mars had two satellites (which are not the very faint Phobos and Deimos, only discovered in 1877). To him, the rule followed by the Creator had come from elementary arithmetic: Venus, nought; Earth, one; Mars, two; Jupiter, four. In November, Galileo at last condescended to unveil his meaning, and Kepler inserted (at the last minute) in the *Dioptrice* preface another characteristic outburst: "O you much knowing tube, more precious than any scepter. He who holds you in his right hand, is he not appointed king or master over the work of God." That *optick tube* more precious than any scepter? Perhaps, for once, Kepler's dithyramb is weak.

On the subject of extraterrestrial dwellers, Kepler in *Dissertatio* instantly proceeded far beyond Galileo, whose extreme prudence has been already noted. Even Lutherans had to show some care, and he agreed that "the planets are not mentioned in Moses, Job, or the Psalms" (*Dissertatio,* 40); still, he felt that some free speculation was allowed. He was to lump Moon and planets together, but the Moon case will be far more extensively treated in *Somnium*.

For Kepler, celestial inhabitants, while yet unseen, are far more than probable: they are necessary. They are bound to appear as an automatic consequence of the Creator's methods in the edification of His World. The assertion will be repeated several times:

> It becomes evident that these four new planets were ordained not primarily for us who live on Earth, but undoubtedly for the Jovian beings who dwell around Jupiter." (*Dissertatio,* 41).

Follows an elaborate technical discussion, involving angular distances and parallaxes, intended to prove that our Moon is just as invisible (to the naked eye) from Jupiter as the four new satellites are from Earth. Therefore "

> … Our Moon exists for us on the Earth, not for other globes. These four little moons exist for Jupiter, not for us. Each planet in turn, together with its occupants, is served by its own satellites. From this line of reasoning we deduce with the highest degree of probability that Jupiter is inhabited.

In passing, Kepler refers to "the inhabitants of Saturn" around which he does not doubt that satellites will also be found.

How did such novelties fit with the fundamental Keplerian anthropocentrism? Easily enough; whichever baubles the telescope had shown, Earth and Man still came first:

> If there are globes in the Heaven similar to our Earth, do we vie with them over who occupies the better portion of the Universe? For if their globes are nobler, we are not the noblest of rational creatures. Then how can all things be for mans' sake? How can we be the masters of God's handiwork?… This system of planets, on one of which we human dwell, is located

> in the very bosom of the World, around the heart of the Universe, that is, the Sun… We humans live on the globe which by right belongs to the primary rational creature, the noblest of the corporeal creatures. (*Dissertatio,* 43).

These thoughts seem to apply simultaneously to the Jupiter case, which Kepler has just been discussing, and to other stars and planetary systems he will presently consider; this line will be followed in the next section.

And all within a few days of receiving *Sidereus Nuncius*, months before having a telescope of his own, Kepler unveils a staggering anticipation:

> But as soon as somebody demonstrates the art of flying, settlers from our species of man will not be lacking…Given ships or sails adapted to the breezes of heaven, there will be those who will not shrink from even that vast expanse. Therefore, for the sake of those who… will presently be on hand to attempt this voyage, let us establish the astronomy, Galileo, you of Jupiter, and me of the Moon. (*Dissertatio,* 39).

Indeed, Kepler had long been having special thoughts about visits to the Moon, and seventeenth-century readers were not slow to catch the idea, far easier to follow than the three Laws.

The Moon and Somnium

Kepler notions about the Moon are mostly found in the 1604 *Paralipomena,* the 1610 *Dissertatio* and the 1630 *Somnium.* This last work, completed at the end of his life and published posthumously, had started as a student composition back in Tübingen. He worked on it intermittently, finally adding many *Notes* for clarification, and his own Latin translation of the *De Facie* Greek text: he had always been fascinated by Plutarch.[6] The student dissertation of Kepler has not survived, but the intent is clear: back in 1593, for a convinced Copernican, the best way to counter the standard argument that an observer on Earth did not feel any motion, had been to show that one on the surface of the Moon would not either. He was not even permitted to present these absurd notions by his Professor, but kept them in mind throughout his life. In *Dissertatio* he says that during that last summer before he heard of the telescope, he had been toying with the idea of writing "…a new astronomy for the inhabitants of the Moon…a sort of lunar geography. Among its basic propositions was this thesis that the spots are continents, while the bright areas are seas." (*Dissertatio,* 26).

His *Paralipomena* prove that he had not waited for the Galileo news before visualizing the Moon as another Earth. His first reported naked-eye observation, made in 1602, led to a drawing of the nearly-full Moon and the result is disappointing, probably due to his poor vision (*Dissertatio,* 13, *Note* 88 of Rosen 1956) and to the strange pinhole camera he used for the drawing: it shows merely one large dark spot

[6] A full history of the *Somnium* genesis is given by Rosen in the *Introduction* to his translation. The science-fiction aspect of the book is discussed by D.H. Menzel in *Kepler's Place in Science-Fiction*, *KFHY* 895.

looking like "the representation of the Hebrew samlech with its belly full", in which we cannot recognize any real feature. The next statement is even more bizarre:

> … the Moon, when it displays a bisected face, shows an uneven cutting and to some extend a twisted one. This is evidence that some of its parts are low, others more raised up, and these to such an extent that it can be perceived from sixty semi-diameters. (*Paralipomena,* 260).

Of course, the very best eyes have never been acute enough to discover in the terminator those irregularities due to the lunar mountains shadows, and Kepler often complained that his own were rather weak. The only explanation must be that he had seen in the Moon just what he wanted to see; probably, after an overdose of Plutarch-reading.

What he had hoped for was precisely what he was to read in *Sidereus Nuncius*; thus the enthusiasm shown in *Dissertatio*:

> For you have established most firmly by brilliant observations in full accord with the laws of optics that many peaks tower above the body of the Moon throughout the bright region, especially in the lower portion. Like the loftiest mountains on our Earth, they are the first to enjoy the light of the sun as it rises for the Moon… (Dissertatio, 25).

Of course, Kepler did not forget to point out what he himself had found long ago, and that Galileo only had to open the page of *Paralipomena* quoted above to read "…the half-moon [is] divided by a wavy line. From this fact I deduced peaks and depressions in the body of the Moon." Admitting that he had not thought about shadows, he conceded that "I made these suggestions only in a confused and superficial way, without distinguishing between the spots and the bright region. But under your skillful handling, how simple everything becomes!" (*Dissertatio,* 27). However, Kepler expressed puzzlement at one discovery he had not anticipated, those numerous round spots (the craters), which are not expected from Earth-like features:

> For among us on the Earth there are some curving valleys, but they are also extensive in length… Why then do you report no such long spots on the moon? Why are they for the most part bounded by a circle? May I indulge in the guess that the Moon is like pumice… (*Dissertatio,* 25).

Mere mineralogical explanations will not satisfy him for long. All within five days of getting the Message, still without a telescope in hand, Kepler, the mathematician, the rigorous geometer, our hallowed discoverer of exact empirical laws, has jumped to the ultimate conclusion, the one that has ever pleased Man's mind:

> It surely stands to reason that the inhabitants express the character of their dwelling place which has much bigger mountains and valleys than our Earth has. Consequently, being endowed with very massive bodies, they also construct gigantic projects. Their day is as long as fifteen of our days, and they feel insufferable heat. Perhaps, they lack stone for erecting shelters against the sun. On the other hand, may be they have a soil as sticky as clay. Their usual building plan, accordingly, is as follows. Digging up huge fields, they carry out the earth and heap it in a circle, perhaps for the purpose of drawing out the moisture down below. In this way, they may hide deep in the shade behind their excavated mounds, and in keeping with the sun's motion, shift about inside, clinging to the shadow. They have, as it were, a kind of underground city. They make their homes in numerous caves hewn out of that circular embankment. They place their fields and pastures in the middle to avoid being forced to go too far away from their farms in their flight from the sun. (*Dissertatio,* 28).

In which line he shows himself far closer to Bruno, the dreamer than to his correspondent Galileo, who was rejecting any such speculations. Closer also to H.G. Wells the skillful novelist, and to much twentieth-century thinking; however present selenologists speculating about lunar craters dismiss farmers and bring in meteorites.

Far more might be quoted from *Dissertatio,* every line of which shows the same exhilarating spontaneity from having been written within a few days. Let us now turn to *Somnium,* which makes use of the experience gathered by Kepler during his entire life. His voluminous added *Notes* are particularly helpful, being intended to clarify points of physics or astronomy, without interrupting the story. Even so, the mere narrative is not quite thrilling, and Bruno would have done distinctly better; but Bruno would never have provided the wealth of accurate information which, for the first time, unveils one of these Other Worlds as observed from inside. Kepler also appended his Latin translation of *De Facie*; but his own tale proceeded far beyond that of his beloved Plutarch.

The protagonist, Duracotus, son of an Icelandic witch, requires the help of a Dæmon (operating within a dream) to reach the Moon, no other suitable means being then readily available; even so, all that magic is mixed with serious astrophysics, and a *Note* makes clear that the "Dæmon stands for the science of astronomy." (*Somnium*, Kepler *Note* 55).

The operation is greatly helped by taking place during a lunar eclipse, and by tidal attraction from the Moon which "will aid their efforts by the magnetic pull from a kindred body." (*Somnium,* Kepler Note 62). The young Duracotus has received the very best astronaut training: he spent years as a student under Tycho Brahe at the Uranienborg Observatory, in this island of Hven Kepler must have dreamed about, but never visited. And throughout his lunar wanderings he behaves not as a tourist, but like a professional astronaut.

The initial voyage itself is performed according to the rules of Keplerian inertia and gravity; these are perfectly adequate for inventing the astronaut's couch later rediscovered by Jules Verne, then implemented by *NASA* in the *APOLLO* command modules. Poor traveller!

> …The take-off hits him as a severe shock for he is hurled just as though he had been shot aloft by gunpowder…he must be lulled to sleep with narcotics and opiates. His limbs must be arranged in such a way that his torso will not be torn away from his buttocks nor his head from his body, but the shock will be distributed among his individual limbs. (*Somnium,* 16).

And on the way, he is helped to keep his bearings by a suitable *Note*:

> I define "gravity" as a force of mutual attraction similar to magnetic attraction. But the power of this attraction in bodies near to each other is greater than it is in bodies far from each other. Hence they offer stronger resistance to being separated from each other when they are still close together.

Thus, "after the first stage of the trip is finished, the passage becomes easier."

Still the space traveller has to face other hurdles: "extreme cold and impeded breathing…relieved by applying damp sponges to the nostrils"; which seems simpler and cheaper than the corresponding *APOLLO* devices. Kepler is careful to point out that his solution had already been described by Aristotle for the use of "philosophers who strove to reach Mount Olympus for the sake of the view."

(*Somnium,* 71, 73, and Kepler *Note* 73). What a pity that *NASA* planners no longer seem to read much of the Stagyrite.

Once on the Moon (called *Levania*), Duracotus hastens to give an accurate description of the celestial show. First, the Earth (called *Volva*) is visible from one hemisphere only and "remains fixed in place as though it were attached to the Heavens with a nail." *Volva* presents phases, and as its spots are plainly visible, it serves to mark time by its rotation; it also shows seasons since "it clearly displays the North Pole of its rotation", which alternately appears and vanishes. *Volva* also provides convenient illumination (and even heat) when the Sun has set, and the correspondence with our so-called shadow-light is established; all celestial phenomena are followed with similar accuracy. On a single point does the modern reader disagree with Kepler: to lunar dwellers "the planet Mars sometimes appears almost twice as big as to us" (*Somnium*, 21, and Kepler *Notes* 121, 123), and the same happens to Venus. This is a consequence of the Keplerian solar-system size, which was still much too small; hence, while his Earth-Moon distance was correct, he believed Mars and Venus far closer than they really are. Kepler lovingly describes eclipses as seen from the Moon; in particular, the inhabitants

> never see a total eclipse of Volva. However for them the body of Volva is traversed by a certain small spot, which is reddish around the rim and black in the middle. Entering from the eastern side of Volva, it leaves by the western edge, following the same course as the natural spots of Volva, while surpassing them in speed. (*Somnium,* 25).

Only lately have Volvanians been enabled to enjoy that accurately-described sight of the lunar shadow, thanks to the striking pictures taken from Earth orbit by *LANDSAT* etc…

Compared to *Dissertatio*, Kepler adds relatively little about physical conditions on the lunar surface, and the reason is clear: *Somnium* is mostly a pedagogical tool for teaching Copernican astronomy to Earth-dwellers. The key point is well stressed:

> Everybody screams that the motion of the heavenly bodies around the Earth and the motionlessness of the Earth are manifest to the eyes. To the eyes of the lunarians, I reply it is manifest that our Earth, their Volva, rotates, but their Moon is motionless. If it be argued that the lunatic senses of my lunarian people are deceived, with equal right I answer that the terrestrial senses of the Earth-dwellers are devoid of reason. (*Somnium,* 106 and Kepler *Note* 146).

Truly, that learned Tübingen Professor who refused to listen should be celebrated on a par with the Galileo opponent who refused to look.

Levanians are kept stable by local gravity: "Since the Moon is a sphere, all heavy lunar objects will tend towards its center. Bodies will press on the surface of the sphere at right angles…" (*Somnium,* Kepler *Note* 100). Disappointingly, Kepler does not proceed beyond Plutarch by discovering that weights on the Moon surface will be smaller than on Earth. Still, he gets pretty close

> A body located between the two globes [Earth and Moon] at the point where its distance from each is in the same ratio as are the bodies to each other, will remain motionless since the pulls in opposite directions eliminate each other. This will happen if the body's distance from the Earth is 58 1/59 Earth-radii. But when the body moves a little closer to the Moon, it will be subject to the Moon attraction, since the Moon force is dominant on account of its nearness. (*Somnium*, Kepler Note 77).

Apparently, Kepler's concept of gravity was perfectly adequate to predict Levanians joyfully bounding around, just like Wells' Cavor and *NASA*'s Armstrong will do for our great delight, but he never did. However, his Moon experiences tides[7] and Kepler's language is almost our own; on Earth

> the causes of the ocean tides seem to be the bodies of the Sun and Moon attracting the ocean waters by a certain force similar to magnetism. Of course the body of the Earth likewise attracts its own waters, an attraction we call gravity. What therefore prevents us from saying that the Earth attracts the lunar waters too just as the Moon attracts the terrestrial waters? (*Somnium,* 124, Kepler *Note* 202).

The argument is carefully developed: the Moon has maximum tides when Earth and Sun are at syzygy etc.…; indeed, the tide phenomenon (which Kepler never watched for himself) played an important role in forming his gravity concept. One further speculation: the sea waters may be sometimes pulled by Earth-plus-Sun to the SubVolvan side, and "by contrast, the PriVolvan hemisphere is dry and cold because all the water may be drawn off." (*Somnium,* 27, Kepler *Note* 202).

After lunar seas, what about a lunar atmosphere? Mästlin had published in 1606 a small work on *Phenomena of the Planets* (*Dissertatio* 29, Rosen *Note* 256; the Mästlin booklet is lost.) in which he had presented "proofs of air in the Moon" and even reported having seen once on the body of the eclipsed Moon "a blackish spot, darker than the rest… [like] clouds laden with rain and stormy showers… [which] took up half of the diameter" (*Somnium*, 146); today, we do note color changes from eclipse to eclipse, but never such definite spots. Kepler considers other proofs: a fancied apparent excess of the full Moon diameter over that of the new Moon, and Tycho had agreed (*Somnium*, 137, Kepler *Note* 223); the young Moon showing excess width "the crescent bright light comes from the expanse of lunar air jutting out beyond the body"; and last, occultations of stars or Venus. However, Kepler remains skeptical:

> I connected the cause of the phenomenon with the process of vision. For at night, the pupil of the eye dilates in a natural movement. More abundant light enters from a point of the visible source and broadly affects the visual spirits of the retina…the bright parts expand.

In modern terms, he understood irradiation. Nevertheless, he had concluded in *Paralipomena* that "the whole Moon is surrounded by a certain airy essence, which transmits the rays on all sides." (*Paralipomena*, 263). His demonstration had come

[7] As early as 1616, Galileo had dropped all lunar waters in private letters (*Dissertatio*, 109, Rosen *Note* 276), but Kepler seems unaware of it when he writes his *Somnium Notes*. His own lunar observations were probably not conclusive on that point: he may never have held a sufficiently improved telescope. However, he was first to make the remarkable discovery of lunar radiant heat: "If you receive the rays of the full Moon on a concave parabolic, or even spherical, mirror, at the focal point, where the rays come together, you will feel a certain warm breath. This happened to me at Linz, when I was busy with other mirror experiments and not thinking about the warmth of light. For I began looking around to see whether anybody was blowing on my hand." (*Somnium,* 122, Kepler *Note* 200). Kepler's experiment was redone with success by Melloni in 1846 and quantitatively by Laurence Parsons in 1868–1873 (Lequeux 2009, 130–1). Given time, Kepler's successors were to understand that heat as coming (in part) from infrared radiation, and learn in that way a great deal about the temperature of Moon, planets and stars.

from a study of total solar eclipses during which he believed that "the rays, approaching from the edges of the Sun, go around the lunar body in a kind of bending through the refractions in the lunar air." (*Paralipomena*, 313). However, as already noted, Kepler never saw a total solar eclipse himself.

Now, the post-telescopic views. In *Sidereus Nuncius* he had read that

> around the body of the Moon, as around the Earth, there is a sphere of substance denser than the rest of the æther. The Sun's radiation can be received and reflected by this sphere even though it is not opaque;

and, as to the Moon bigger spots "the fact that they are not seen [near the edge] appears to be plausibly explained by their being hidden beneath a thicker and brighter volume of vapor." (*Sidereus Nuncius*, 39, and quoted by Rosen in *Dissertatio*, 110, *Note* 248). Hence the first and very imperfect telescope had not brought any great improvement on that count, and Galileo at first believed in a lunar atmosphere for roughly the same reasons. Kepler reacted instantly; he was delighted! "Pages 252 and 302 of [*Paralipomena*] could have told you about this air on the Moon. These passages of my book are splendidly confirmed by your pertinent observations." These findings fitted well within his own lunar scheme:

> I certainly do not understand how these inhabitants of the Moon can bear the Sun's terrific heat at full moon… unless the dense air covers the sun for them frequently, as happens among the Peruvians, and moderates the heat with its moisture. (*Dissertatio,* 29).

In the Keplerian teleological cosmology, inhabitants entailed an atmosphere, not the reverse.

The *Somnium* terminates with Kepler's speculations about those local Aliens. Actually, he did not proceed much beyond *Dissertatio*; still, twenty years of telescope use had provided him with some new arguments, reported with his own observations in the *Geographical or if you prefer Selenographical Appendix,* addressed *To the Very Reverend Father Paul Guldin, priest of the Society of Jesus, etc. (Somnium,* 149). Thus, right through the Thirty-Years War, shortly before the height of trouble for both Galileo and Kepler, some Jesuits were still conversing with some Protestants. Father Guldin and another Jesuit, Father Zucchi, even provided Kepler with the best telescope he ever handled.

On most of the pages in *Somnium* Kepler had just used inhabitants as tools for observing the Heavens from the Moon; only at the very end did he bother with local ethnology: "

> Whatever is born on the land … attains a monstrous size. Growth is very rapid. Everything has a short life, since it develops such an immensely massive body. In the course of one of their days they roam in crowds over their whole sphere… some use their legs which far surpass those of our camels; some resort to wings; and some follow the receding water in boats and then crawl into caves. Most of them are divers… whatever clings to the surface is boiled out by the sun at noon… The SubVolvan hemisphere is comparable to our cantons, towns and gardens; the PriVolvan to our open country, forests and deserts… [In the caves] they shut themselves up for the greater part of the day… In plants the rind, in animals the skin, takes up the major portion of the bodily mass; it is spongy and porous…. Generally they begin and end their lives on the same day… (*Somnium*, 27-8).

The extensive (and valuable) Kepler *Notes* stressed that such were rational speculations; for instance, that monstrous girth:

> This is demonstrated by the highly conspicuous size of their works…further proved by the persistence of extremes of heat and cold and by the scarcity of rebirths; on this subject see Plutarch's book… (*Somnium,* 129, Kepler *Note* 212).

The mere science-fiction fan, who just followed the rather-short text of *Somnium,* only read about these creatures with legs or wings; but any serious reader went to the explanatory *Note*, and learned that it had all come from adaptation:

> Nothing on Earth is so fierce that God did not instill resistance to it in a particular species of animals; in lions, to hunger and the African heat; in camels, to thirst and the vast deserts of Palmyrene Syria; in bears to the cold of the far north etc… (*Somnium,* 131, Kepler *Note* 214).

Thus, extra-terrestrial life operated from the same processes as the Earth-bound sample, but still according to God's Will.

And in an ultimate flight of fancy, lunar life even explains lunar morphology:

> Those lunar hollows, first noticed by Galileo …in them the moon-dwellers usually measure out the areas of their towns from the purpose of protecting themselves from the mossy wetness as well as from the heat of the sun, and perhaps even from their enemies. The design of the fortification is as follows. They drive a stake down in the center of the space to be fortified. To this stake they tie ropes which are either long or short depending on the size of the future town. The longest I have detected is five German miles. With this rope fastened in this way, they move out to the future rampart's circumference… Then the entire population assembles to do the digging for the rampart. The width of the ditch is not less than one German mile. They take all the excavated material inside some towns. In others they have built partly outside and partly inside; thus the rampart is constructed in two sections with a very deep ditch in between…. (*Somnium,* 151).

Obviously, Kepler had been deeply struck by the circular perfection of lunar craters, for which he knew of no match on Earth: "You ask who built those hills scattered through the fields of Bohemia… I shall name their creator. It is the river Elbe…" (*Somnium, Geographical Appendix*, 156 Note XVIII). Lunar craters seem to imply an altogether different mode of construction:

> …the perfectly round shape of the hollows and their arrangement…are artificial and produced by some architectural mind. (V *Somnium, Geographical Appendix,* 160 Note XXVIII).

Is the hypothesis absurd because of enormous size? Not in the least:

> …they must accomplish by their numbers what the size of their bodies cannot do. Let us take as various examples the tower of Babel, the pyramids of Egypt, the very long paved road in the province of Peru, and the wall protecting the Chinese from the Tartars. (*Somnium, Geographical Appendix*, 170, Kepler Note 17).

Which is fantasy, but still with a rational basis, and the following Keplerian principle might well be used for disentangling intelligent signals from noise within putative *ETI* messages:

> Axiom: when things are in order, if the cause of the orderliness cannot be deduced from the motion of the elements or from the composition of matter, it is quite probably a cause possessing a mind. (*Somnium, Geographical Appendix,* 159, Note XXVI).

When applying this perfectly sound principle to lunar morphology, Kepler had gone astray; so will Percival Lowell for Mars, and how many similar mistakes are lying in wait for all of us when we get radio signals that seem intelligent? However, Lowell and most of his fans were to prove dismally serious about their Martian-canals mania, while Kepler was not. *Somnium* concludes with a *Letter* ending with

> Let these comments be placed before you as a question to be settled piece by piece on the basis of phenomena discovered by the telescope, if those phenomena are brought into agreement with these conclusions by means of the axioms of optics, physics and metaphysics. But these are playful remarks, etc. (*Somnium,* 152, *Address to the Reverend Father Guldin*).

With this tongue-in-cheek ending, which sums up the *Somnium* spirit, we shall take leave of Kepler's Moon.

Keplerian Stars: No Room Left for Planets

As usual, Kepler operated on two different planes when he tried to describe the geometry and physics of stars. First, the edifice had been constructed by the Platonic Creator, later turned Christian; second, it had to fit observations. Copernicus himself had merely held stars to be immeasurably distant; instead of using similar prudence and admitting that he was unable to put numbers on those distances (and sizes), Kepler remained convinced that the data of Tycho (plus his own) just confirmed Plato. Thus, he regressed far beyond Bruno the incompetent geometer, whom he was convinced to have fully refuted.

If Kepler eliminated circles from astronomy, he ever remained in love with the sphere, which deserved frequent dithyrambs:

> The sphere, which is the image of God, the erector and archetype of the World… There are three regions, symbols of the persons of the Holy Trinity –the center, a symbol of the Father, the surface, of the Son, and the intermediate space, of the Holy Ghost. (*Epitome,* 853).

Here we remember Cusanus, and so did Kepler: before describing the great discovery that ever remained closest to his heart, that of the *Mysterium* construction, he explained that

> …Nicholas of Cusa and others seem to me divine, that they attached so much importance to the relationship between a straight line and a curved line, and dared to liken a curve to God, a straight line to his creatures… Nor can I be persuaded that any kind of curve is more noble than a spherical surface, or more perfect. For a globe is more than a spherical surface, and mingled with straightness by which alone its interior is filled… (*Mysterium,* 93).

Consequently, he made lavish use of spheres, and the entire *Mysterium* mechanism would have fallen apart without a set of nesting spheres between which the five Platonic solids solely acted as spacers.

Moreover, for Kepler, the stars themselves would not have kept to their places without a sphere behaving at least as an interior limit. Plato had failed to provide a sixth polyhedrum, suitable to define its diameter, thus it would have to be deduced through a different approach. The solution is already found in *De Stella Nova*: an extrapolation from the size of the solar system looks harmonious if the radius of the most distant planet orbit (i.e. Saturn) is the mean proportional between the radius of the Sun and that of the stellar sphere, and the *Epitome* will confirm (*Stella Nova*, *KGW* I, 234 and *Epitome,* 882). That unknown sphere radius is found equal to 34,177,066 2/3 times the Earth radius (*Stella Nova*, *KGW* I, 235: calculation summarized by Van Helden 1985, 62). Happily, this calculation from Kepler the Platonist fitted well with the data of Kepler the observer: from the maximum possible annual stellar parallax of 1 arc min (given by Tycho), he had previously deduced a minimum stellar sphere radius of 24,000,000 Earth radii. It all worked!

This use of proportions we perceive as wholly fanciful; however, Kepler also preserved the stellar sphere, with a central Sun, from a different line of arguments, more acceptable to the modern mind: this was the only model that fitted his observations of stellar apparent diameters. Unfortunately, here he made a considerable technical error. Ptolemy says nothing about the size of stars in the *Almagest*; however in his later *Planetary Hypotheses*, he transmits the figures he had been born and raised with, for both planets and stars*:*

> Hipparchus says that the apparent diameter of the Sun is 30 times as great as that of the smallest star [thus equal to 1’], and that… of Venus the largest star is about one tenth [3’]…the first magnitude stars 1/20th [1.5’]. (Goldstein 1967 and van Helden 1985, 24).

No method for measuring stellar diameter is described, nor any argument given for deriving these specific figures. The Hipparchus results were still used by Tycho Brahe: 3′ for Venus at mean distance, 3 1/2′ for his famous 1572 nova, 2′ for a first-magnitude star, and 1/3′ for the faintest (sixth magnitude) ones (van Helden 1985, 50). What is even more surprising than the gross error itself is the absence of justification, either by observation or by argument. In any case, all these apparent diameters are enormously overestimated, as they are completely determined by the observer’s vision and instrument.

Kepler did no better, which is passing strange, because he understood fairly well the process we call irradiation through which the size of a point source, as perceived by the eye, appears to grow when luminous intensity increases. In the *Paralipomena* chapter devoted to Vision, he writes:

> The retina enlarges the picture of luminous things…beyond the laws of optics…. As to white things at the burning point appearing wider… this seems to attest that what is widened is not the ray gathered upon the white object but the impression of the white object and of its picture on the retina, upon the visual spirit…” (*Paralipomena*, 235).

Thus Kepler seems to be well placed to discover that traditional star diameters had been pure nonsense, but he will never do so. The P*aralipomena* discuss star colors and twinkling, but not sizes. Neither does he anticipate that Galileo occulting-wire technique, while the very simple sights could have been easily fitted to his own “ecliptic instrument”, which had been used for his lunar drawing. The inference is that, like Tycho (and everybody else), he was convinced that the ancient star diameters were correct, thus saw no need for new observations.

After reading *Sidereus Nuncius*, he reacted immediately to the Galileo’s statement that

> the stars appear not to be enlarged by the telescope … the fixed stars are never seen bounded by a circular periphery, but have rather the aspect of blazes whose rays vibrate about them. (*Sidereus Nuncius,* 46).

His answer:

> Fixed stars generate their own light from within, whereas the planets, being opaque, are illuminated from without; that is, to use Bruno's term, the former are Suns and the latter, Moons or Earths. (*Dissertatio,* 34).

This conclusion is sensible and appropriate, and the ensuing criticism of Bruno will be followed later; but Kepler did not realize that the Galileo observation also meant a drastic reduction of all those stellar diameters handed down from Hipparchus and C°.

And he never will, which is a major puzzle. Still within *Dissertatio*, he makes the complaint (a frequent one) that his own eyes are very poor, but grants that

> persons with unimpaired vision, using astronomical instruments, not deceived by these wavy crowns as is the naked eye, [will] ascertain …star diameters in terms of minutes and fractions of minutes. (*Dissertatio,* 35).

Indeed, three centuries later, his successors will achieve the feat, even going down to fractions of seconds and reaching the true diameters thanks to interferometry; however, within his own time, the last word must be left to Galileo in his *Dialogue*:

> I am quite surprised at the number of astronomers, and quite famous ones too, who have been quite mistaken in their determinations of the sizes of the fixed as well as of the moving stars…Among these men are al-Fergani, al-Battani, Thabit ben Korah and more recently Tycho, Clavius…For they did not take care of the adventitious irradiation which deceptively makes the stars look a hundred or more times as large as they are without haloes…None of them, not even Tycho, accurate as he was in handling astronomical instruments…ever set himself to determine the apparent diameter of any star except the Sun and Moon. I think that arbitrarily, and so to speak by rule of thumb, someone among the most ancient astronomers stated that such-and-such was the case, and the later ones without any further experiment adhered to what the first one had declared. (*Dialogue*, 360-1).

Galileo might have added to his list Kepler, who had vanished from the scene before the *Dialogue* was printed; Kepler for whom the error had been catastrophic as it turned out to be the very foundation of his stellar geometry.

The estimate of stellar apparent diameters is not the only strictly optical problem where Kepler goes badly wrong. May stars be as bright as the Sun? In *Epitome,* he asks a sensible question, performs an appropriate optical experiment, and proceeds to a false conclusion. Question:

> Does it seem that anyone of the fixed stars is such a body as the Sun is, and the Sun in turn is seen from the fixed stars to be of so great and of such an appearance as any one of the fixed stars?

Laboratory test (never proposed before):

> If, for example, you pierce through a wall with only a pin, so that the sun can shine through the hole, a greater brightness is poured through from the beams that all the fixed stars shining together in a cloudless sky would give. (*Epitome*, 886)

It is hard to understand how an optician of Kepler's caliber fails to see that the pinhole diameter may be made (at least in principle) arbitrarily small, hence that a size will necessarily be found at which the appearance is bound to match that of any given star. Both Newton and Huygens will perform the actual test correctly, and, using no other conceptual tool than the Keplerian inverse-square photometric law, they will deduce reasonable orders of magnitude for stellar distances, which shall play an important role in astronomy and an essential one for Plurality. However, both had started from a belief that the Sun is just a common star, while Kepler wanted to prove that it was not.

There is little logic in actual History. From these two independent errors of observation on stars (apparent diameter and brightness), Kepler deduces a correct conclusion, and one endowed with a considerable future of its own. Here he is at his most brilliant, anticipating the ingenious and powerful *Olbers-de Chéseaux Paradox*, not to be formulated clearly before 1826.[8] For him, Cusanus and Bruno had failed to guess a spectacular consequence of their uniform stellar distribution: if they were right, the heavenly vault would look uniformly bright! Under Kepler's pen, the first appearance of the argument is found in *Stella Nova*; he computes the angular diameters of stars in the Orion belt as seen from each other, which he finds very large, thus: "if anyone were placed in Orion's Belt…he would see a solid ocean of huge stars apparently touching one another." (*Dissertatio,* Rosen *Note* 200 p. 128). Later, in *Dissertatio,* he wants to discuss the two main Galilean results about stars: "the sparkling appearance of the fixed stars, in contrast with the circular appearance of planets“, immediately followed by "that countless host of fixed stars [which] exceeds what was known in antiquity." His reaction is

> Suppose that we took only 1000 fixed stars, none of them larger than 1' (yet the majority in the catalogues are larger). If these were all merged in a single round surface, they would equal (and even surpass) the diameter of the Sun…If this is true, and if there are Suns having the same nature as our Sun, why do not these Suns outdistance our Sun in brilliance? Why do they all together transmit so dim a light?

Again, the actual remoteness of the stars is irrelevant "for the greater their distance, the more does every single one of them outstrip the Sun in diameter." An objection (also with a great future as often considered wrongly as an explanation for Olbers-de Chéseaux paradox) is made and dismissed:

> Maybe the intervening æther obscures them? Not in the least; for we see them with their sparkling, with their various shapes and colors. This could not happen if the density of the æther offered any obstacle. (*Dissertatio,* 34-5).

In 1823, when the paradox was given its modern form by Olbers, both stellar distances and apparent diameters had reached correct orders of magnitudes and a statistically uniform stellar distribution in the solar neighborhood was the norm; all Keplerian delusions had long vanished. Even so, the absurdity of a uniformly bright stellar vault could not be avoided if that local stellar distribution was extended to infinity, and that was Olbers' contribution; moreover, thermodynamics soon proscribed any easy escape from adding ad-hoc absorbing clouds… We shall not follow it further; but Kepler would have been delighted!

Admittedly, the Kepler picture of star sizes remains confused, but the important result is clear enough: the Sun cannot be a common star, and all stars are so crowded together that there is just no room left for planets. This lack of room proceeds from the Keplerian stellar distribution, for which the constraints are (as usual) in part

[8] An enthralling history of the case is given by Stanley Jaki (1969) in *The Paradox of Olbers' Paradox*, where Kepler's anticipation is treated on p. 30–36.

metaphysical, and in part observational. A sphere, "image of God," has to be fitted in at some prominent place, and stars must be located so as to fit the observed apparent diameters and parallaxes. The consequence is a strange construction, in which the Sun and attendant planetary system are given a central position within a huge spherical cavity. Impeccable logic is used throughout, and the model does fit all observations simultaneously; still, the result is far closer to the *Mysterium* edifice than to the Keplerian laws. Much like it, it will vanish without leaving any traces long before the end of the century.

Kepler's adoption of a minimum distance for stars is simply what could be expected from a Copernican who understands the stellar parallax problem, and possesses the Tycho data from which no stellar parallax could exceed 1′. For Tycho himself, this result had been a major reason for rejecting the Copernicus system and proposing his own, in which the difficulty vanished. By contrast, Kepler sees no impossibility in that immense emptiness between Saturn and the nearest stars; an attitude in which the modern mind easily follows him. However his belief in a sharply-defined, almost material, inner limit to the star region is properly stupefying:

> [Q] What do you think of the ratios of density of the solar body, the æther which permeates the whole Universe, and the sphere of the fixed stars which encloses all things from the outside?
>
> [A] Since these three bodies are analogous to the center, the surface of the sphere and the interval, three symbols of the three persons of the Holy Trinity… a third part of the matter of the whole Universe is packed together in the body of the Sun… a third part spread out thin throughout the immense space of the [sub-stellar] World… a third part rolled out in the form of a spherical surface and thrown around the World on the outside as a wall.

To make it more understandable, he resorts to analogies: "Let us imagine that the solar body is all gold, the sphere of the fixed stars of water, or glass, or crystal, and the inside space full of air." Which analogy comes dangerously close to an explanation, and one conforming to the Bible story:

> Whence we are able to understand, to a certain extent what divine Moses signified by the Firmament… and the super-celestial waters. For in this way boys have a game, which is an image of creation, when they make bubbles out of soap and water. (*Epitome*, 885).

Kepler takes his naïve picture so seriously that he is even able to determine the exact thickness of the star-layer, all from typically *a priori* arguments:

> [Q] How great do you set down the thickness to be, or the distance between the inner and the outer surface of the sphere of the fixed stars?
>
> [A] The matter of the sphere… [must have] a density which is a mean proportional between the density of the ether and the density of matter in the solar body.

From which assumptions he computes the wanted unknown:

> Therefore this skin, or tunic of the World, or crystalline super-celestial sphere is … not more thick than 6/1000 of the semi-diameter of the solar body, or a little more than 2 German miles. (*Epitome*, 886).

That is not all; Kepler even proceeds beyond mere geometry, and is able to say something about the physics of that layer: happily, it had been devised for the comfort not merely of Man, but of all Solar-system dwellers:

> The Sun is the fireplace of the World, the globes in the intermediate space warm themselves at this fireplace; and the sphere of the fixed stars keeps the heat from flowing out, like a wall of the World, or a skin or garment to use the metaphor of the psalm of David. The Sun is fire, as the Pythagorean said, or a red-hot stone or mass, as Democritus said, and the sphere of the stars is ice, or a crystalline sphere, comparatively speaking. (*Epitome,* 855).

Thus, Tycho had demolished the planetary crystal spheres, but his best disciple reintroduced one to hold the stars in their proper place.

The above quotations were all from the 1620 Book IV of *Epitome* “On the Position, Order and Movements of the Parts of the World”; but Book I “Concerning the Principles of Astronomy in General”, printed three years before, had given a rather different picture, and explained it by two actual prints, rather easier to follow. That thin shell does not yet appear, but the privileged position of the Sun, and its singular nature, is even better stressed. First, Kepler gives a fair summary of the system he rejects, i.e. the Bruno-Cusanus uniform distribution, in which our Sun

> would be nothing but one of the fixed stars, larger and brighter for us because it is closer than the other fixed stars; in such a way there might be around any fixed star a World similar to the one around us… our region with its Sun would be nothing but one region not differing from the others. (Extract from Koyré 1988, 104).

His corresponding plate (Figure 10.2 left) schematizes the Kepler view of stars filling three-dimensional space in regular rows: of course, had the Creator decided to construct His Universe in such a way, He could not possibly have tolerated any disorder. We are not too surprised to learn that He would have closely packed icosahedra, gifted with twelve apexes each; hence in the figure plane each star lies equidistant from six neighbors.

The rejection of the Cusanian principle by Kepler is unambiguous and definitive, all in the name of faultless geometry served by the best available astronomical data. For him, any uniform distribution is certainly false because

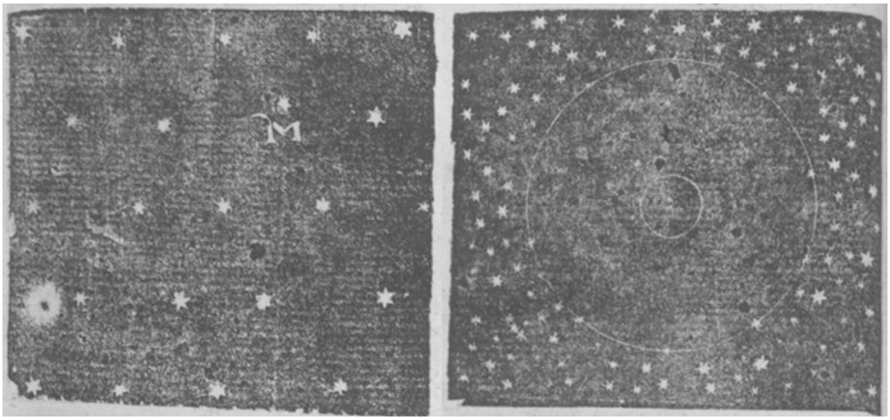


Figure 10.2 Two stellar distributions pictured by Kepler, from Book I of *Epitome*. Left: strictly hypothetical, with all stars occupying orderly rows. Right: actual, with the Sun at the center of a large empty bubble. Ten stars lie on an unexplained limiting circle; could it be for that “ice or crystalline sphere”? The smaller circle is probably intended for the Saturn orbit. www.e-rara.ch

> if the region of fixed stars was everywhere similarly filled with stars… then we would see only a small number of large fixed stars [because they are supposed to have a very large diameter], and the number of those which would be located at equal distance from us… would not exceed twelve…the next ones, hardly more numerous, would be twice as far… the third set would be three times as far, and so on…

Starting from this distribution, Kepler easily concludes that

> we would see very few stars, and they would present large differences. However, what we see is quite the opposite … Indeed we see fixed stars of the same apparent size and very close to each other… one must conclude their distances are roughly equal.

And his own solution is made clear by a second print (figure 10.2 right), in which the stellar region

> has in its center an immense vacuum, a large hollow surrounded and so to say closed by the dense army of fixed stars, as by a vault or partition, and within that vault is located our Earth, with the Sun and planets. (cited by Koyré 1988, 105-7).

All of which is not solely Platonic truth, and Kepler will stress that his model does fit the observations. For him, the main consequence is clear: that spherical cavity surrounding the Sun is unique, and none of the fixed stars is granted sufficient breathing space to house its own planetary system. This is one of those happy cases where observations just confirm expectations: he had expected that kind of stellar distribution all along, since the perfection exhibited by our solar system could not possibly be duplicated anywhere. In *Dissertatio*, he had gone rambling:

> Geometry is unique and eternal, and it shines in the mind of God… Now in geometry the most perfect class of figures after the sphere consists of the five Euclidean solids. They constitute the very pattern and model according to which the planetary world of ours was appointed. Suppose then that there is an unlimited number of other Worlds. They will be either unlike ours or like it. You would not say “like it”; for what is the use of an unlimited number of Worlds if every single one of them contains all of perfection within itself? …if you establish universes similar to one another in all respects you will also produce similar creatures, and as many Galileos, observing new stars in new Worlds, as there are Worlds. But what is the use of this? It is better to avoid the march to the infinite permitted by the philosophers…. Suppose these other Worlds are unlike ours. Then, they will be supplied by something different from the five solids. Hence they will be less noble than our World… (*Dissertatio,* 44).

Thus, the *Mysterium* edifice and its architect had been fated to remain unique.

One cannot discuss the Keplerian distribution of Figure 10.2 without also presenting the superficially similar one given by the early Copernican Thomas Digges about forty years earlier (Figure 8.1). Unlike Kepler, Digges does provide a caption:

> This orbe of starre fixed infinitely up extendeth it self in altitude spherivallye and therfore immovable the palace of foelicitye garnished with perpetuall shininge glorious lightes innumerable far excellinge our sonne both in quantitye and qualitye;

and it is precisely for daring to send stars up to infinity that he has been remembered. On the other hand, Digges gives no stellar parallax figure nor minimum stellar distance, merely stating

> the distance of the Earth fro the Sunne to be sutch as being compared with the other Planets maketh euidente alterations and diuersity of Aspects, but yf it be referred to the Orbe of starres fixed, then hath it no proportion sensible, but as a poinct or a Center to a circumference. (Johnson & Larkey 1934, 86).

The circle which limits his stellar region on the inside does not have a specified meaning, and his attitude, so far, appears more modern than the Keplerian one. However, the same caption proceeds to describe the star locus as pertaining more to the realm of theology than to physics or geometry: "the very court of coelestiall angelles devoyd of greefe and replenished with perfite endlesse joye the habitacle for the elect." Altogether, Digges preserves no more room around stars for other planetary systems than Kepler will later do; but his arguments are neither observational nor Platonic: they are theological.

All the elements necessary to understand Kepler's utter rejection of the Cusanus-Bruno Plurality have now been gathered. On this capital issue, no evolution of his thought is ever perceptible: the dual concepts of an homogeneous stellar distribution, Sun included, and of its extension to infinity, are equally horrible. When discussing the 1604 supernova, he had already written:

> Bruno makes the Universe infinite to the extent of admitting as many Worlds as fixed stars; and he makes our region, that of the planets, hardly different from that of the other Worlds surrounding it; thus an observer located on the Canis star (one of Lucian's Cynocephals) would see the Universe exactly as we do when we look at the fixed stars from our own World… Such a thought carries within itself some kind of secret horror; indeed, we find ourselves drifting within that immensity to which is denied any limit, any center and thus any determined place. (*De Stella Nova*, *KGW* I, 253; translation by Koyré 1988, 86).

And the Cusanian principle was specifically rejected:

> Contrary to a certain doctrine, it is false that our inferior World, with its Sun, should be no different in aspect from that of any fixed star, which is to say that some region or place is not in any way different from the others. (Koyré 1988, 88).

As far as Kepler is concerned, the telescope will bring no change at all; which is again a puzzle.

Just the same, the telescope had brought quite a shock to Kepler when the first news from Padua, in March 1609, came by word of mouth: a friend, Wacker of Wackenfels

> told me the story from his carriage in front of my house. Intense astonishment seized me as I weighed this very strange pronouncement… Men of the highest reputation were transmitting these messages about Galileo, while his book was still at the printer's… (*Dissertatio,* 10).

Since many mouths and ears must have been involved on the way, the report was not limpid: four new planets had been discovered, but where? Kepler's first reaction is given in a letter written a day later:

> Intense astonishment seized both of us. As we weighed this very strange pronouncement, our emotions were so strongly aroused that, overcome by joyful laughter, he did not manage to talk, nor I to listen. (*Letter* in *Le Opere di Galileo Galilei,* X, 320: 14-16; translation by E. Rosen, *Dissertatio, Note* 45 p. 61).

Kepler himself was not in the least inclined to laugh; the matter was far too serious for him, as made clear by his immense relief after getting a copy of *Sidereus Nuncius*; in the *Dissertatio,* he tells Galileo:

> I rejoice that I am to some extent restored to life by your work. If you had discovered any planets revolving around one of the fixed stars, there would be now waiting for me chains and a prison amid Bruno's innumerabilities, I should rather say, exile to his infinite space. Therefore, by reporting that these four planets revolve, not around one of the fixed stars but

> around the planet Jupiter, you have for the present freed me from the great fear which gripped me as soon as I had heard about your book from my opponents triumphal shout. Wacker of course had once more been seized by admiration for that dreadful [*horridae*] philosophy. (*Dissertatio,* 37).

Unlike Kepler, Wacker could well afford to laugh.

The relief brought by *Sidereus Nuncius* was so great that Kepler jumped to the other extreme, and deluded himself into believing that Galileo had definitively disproved the cosmos of Bruno's followers;

> These men thought that the other celestial bodies have their own moons revolving around them, like our Earth with its Moon… Bruno even expounded why this must be so… Now the weakness of his reasoning is exposed by your observations… Suppose that each and every fixed star is a Sun. No Moons have yet been seen revolving around them.

Kepler's knowledge of optics should have shown him that the enormous brightness difference between stars and planets would prevent any such proof, but only Huygens will make the point explicitly. However, his final conclusion on the detection problem is most sensible:

> Hence this will remain an open question until this phenomenon too is detected by someone equipped for marvelously refined observations. (*Dissertatio,* 38-9).

Here, Kepler's view extends over three centuries, and all without having yet looked through a telescope. Even so, that initial shock had been a nasty one…

Our concluding question about Kepler's contribution to the Plurality problem will remain unanswerable. That question is Why? Why is he able to show such overwhelming and instant enthusiasm for the Earth as a planet (even if it remains a privileged one) and simultaneously abominate the Sun as a star? What is Kepler's fundamental motivation? Doubtless, he is convinced to be holding definitive observational proofs: his crowded stellar distribution, based on (supposedly) large measured stellar diameters, prohibits extrasolar planetary systems from arguments of pure geometry. Which merely pushes the question back one step further; why does he never question nor revise his star diameter estimates? How can he fail to make use of the novel telescopic evidence? In the case of the Moon, he is not slow to take the hint, as shown in *Dissertatio* even before making any checks of his own; but as far as lunar mountains went, his long-cherished beliefs had merely been confirmed by Galileo. However, when planets around other stars are hinted at, his anxiety and next his relief are obvious: his entire System of the World has just come close to annihilation!

And the ultimate step in the inquest takes us back to the half-religious, half-mystical beliefs of the accused, best revealed in the *Mysterium* Preface by

> the splendid harmony of those things which are at rest, the Sun, the fixed stars, and the intermediate space with God the Father, and the Son and the Holy Spirit. (*Mysterium,* 63).

From such premises, crude human tools, even this delightful telescope toy, may no more display multiple Suns than create multiple Fathers. What mere Optics are allowed to contribute at such an exalted level will be shown by our final quotation:

> Imagine the sphere of the fixed stars as a concave mirror; you know that the eye placed at the center gazes upon itself everywhere…that can occur at no other point…since the Sun is the source of light and eye of the World, the center is due to it. (*Epitome,* 860).

Kepler the brilliant scientist, the inspired cosmologist, the most skillful and scrupulous analyst of observation data ever seen, not counting the devout Christian, is at heart a monotheist Sun-worshipper. Bruno, errant disciple of Copernicus, had apostatized to polytheism.

Appendix: Two Pre-Keplerian Moon Voyages

Here are two very-brief accounts of Moon-voyages that had long preceded Kepler. They are intended merely to show how modern and scientific *Somnium* looks by comparison; and so does *De Facie*.

Lucian of Samosata (125–180 AD): A True Story

Despite its title, no part of this little tale is intended to be taken seriously, which is not surprising, the author being a Skeptic; still, it has the distinction of being the first imaginary moon-voyage. The story is pure fancy, much closer to fairy tales or the Arabian Nights than to science-fiction; also, many passages are intended as parodies of now lost works, hence their point is equally lost. The astronomical information Lucian makes use of is scarce, and there would be no excuse for presenting even a brief discussion if Kepler had not been clearly interested: he even used that *True Story*, together with a German translation, in order to learn Greek at Tübingen. Later, when writing *Somnium*, he intended at first to add his own translation but gave it up. The tale had remained popular; many manuscripts are still extant, and the first printed edition is from Florence in 1496; such is the power of wit, even when supported by little substance.

The narration begins by a sea-voyage; all of a sudden the ship is caught up by a whirlwind, raised in the air and

> …for seven days and nights we sailed the air, and on the eighth day, we saw a great country in it, resembling an island, bright and round and shining with a great light. Running in there and anchoring we went ashore, and on investigating, found that the land was inhabited and cultivated. By day, nothing was in sight from the place, but as night came on we began to see many other islands hard by, some larger, some smaller, and they were like fire in color. We also saw another country below with cities in it and rivers and seas and forests and mountains. This we inferred to be our own world.

The key world is that "below" (*κατω*). Despite the land being inhabited, cultivated etc.… (otherwise, there would be no story at all), Lucian does not conceive of Moon as an Earth-like place, with a firm ground underneath and a sky above. The obvious inherent difficulties are elegantly solved: the inhabitants, many of them human-like, move (and fight) mounted on birds, or on giant creatures similar to fleas or ants, capable of creeping upside-down and caring little about gravity. Predictably, Endymion is found to be the local king. Soon the voyagers witness a great battle (no doubt, to make them feel thoroughly at home), and

> …so much blood dripped down to the Earth that I wonder if something of the sort did not take place in the sky long ago, when Homer supposed that Zeus had sent a rain of blood on account of the death of Sarpedon.

Both the great war and the peace treaty that follow are spoofs of the Athenian-Spartan wars as described by Thucydides. However, which way exactly is this "below"? Lucian appears a little confused since

> …I saw another marvel. A very large looking-glass [*κατοπτροσ μεγιστοσ*] is fixed above a well…and if a man looks into the looking-glass, he sees every city… we saw that the country was green and fertile and well watered… and every country [of the Earth] just as if he were standing over it. When I tried it, I saw my family and my whole native land…

Later on the travellers proceed to the Morning Star: "… we landed there and procured water", next to the Sun. Here, Phaeton, none the worse for his ancient mishaps, is the ruler; then

> sailing the next night, we reached Lamptown [Λυγνοπολισ] toward evening, already being on our downward way. This city lies in the air, midway between the Pleiades and the Hyades, though much lower than the Zodiac.

Such is all the astronomical substance of the tale. The voyage goes on and on, getting more and more like Arabian Nights, but turns again into a mere sea passage, as the author forgets that his ship is supposed to navigate the Heavens. Altogether, no great loss occurred when Kepler dropped his projected translation: *De Facie* was to prove far richer.

Ariosto (1474–1533): Orlando Furioso

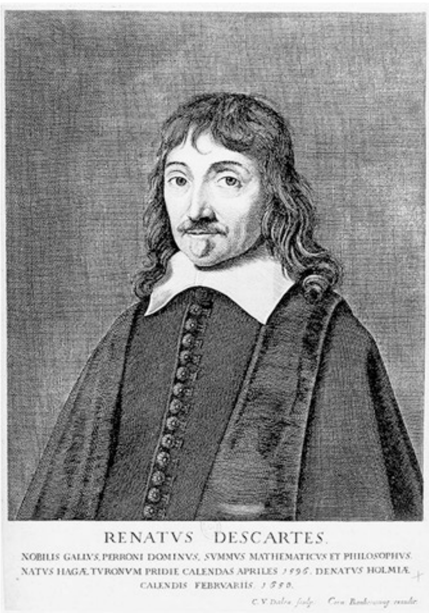
The theme of the moon-voyage had been taken up again by Ariosto and occupies a small part of his 1516 *Orlando Furioso*. By the time, it had become thoroughly christianized, and also given that most peculiar fairy-tale atmosphere of the chivalry novel. The hero, Astolpho, is a perfect knight and a most proper Englishman to boot; to perform his trip to the Moon, the one and essential commodity required is spiritual guidance, which soon becomes indistinguishable from actual piloting. This is sought for in highest and most orthodox circles: no less an authority than Saint John the Evangelist is induced to leave Patmos, and drive the knight to his goal. No one is greatly worried by technical details, and a pack of geese harnessed to a flying carriage proves adequate. A single piece of astronomical information seems to be given anywhere: the two travellers have to pass though the sphere of fire on their way, which means strictly orthodox Aristotelian surroundings. However, they do not meet the scriptural Waters Above (which would have greatly pleased John); even so, not a feather gets singed, and an easy lunar landing is accomplished. Nothing relevant to Plurality warrants a description; still, one notes that the Moon functions mostly as a convenient storage-place for everything lost on Earth, particularly the minds of madmen, a hill-sized pile of which is found. If ever the Moon is turned into a garbage-dump by humans, this should be code-named *ARIOSTO*, inventor of that dreadful proposal. Incidentally, these geese will be put to work again, at least within seventeenth-century fiction.

Chapter 11
Descartes, Fontenelle and Other Cartesians: Multiple Worlds from Vortex Power

We shall totally exclude from our Philosophy the search for final causes, since we should not presume so much about ourselves as to believe that God was bound to make us privy to His councils…

One should merely be concerned with objects of which our mind seems able to acquire certain and indubitable knowledge.”

René Descartes[1]



(Left) René Descartes, engraving from a portrait by Cornelis Banheining, Leiden, mid 17th century. Wikimedia Commons
(Right) Fontenelle, portrait by Nicolas de Largillière, beginning of 18th century. Chartres, Musée des Beaux-Arts. Wikimedia Commons

[1] First quotation from *Principia, OCRD*, IX, 37, and second from *Règles pour la direction de l'esprit*, in Descartes, *Œuvres et lettres*, Editions de la Pléiade (1937), p. 7.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-41448-1_11

Descartes and his Books

The two epigraphic quotations given above seem to have nothing to do with Plurality, and indeed Descartes never proposed in print other intelligent creatures anywhere in the Cosmos; but they are intended to clarify the reasons of that restraint. However, not only his immediate disciples Fontenelle and Huygens, but many distant ones were to develop the Plurality theme, sometimes according the Master's basic beliefs, but more often in hidden contradiction of them; still, Cartesian thought remained central.

Neither a life nor a full bibliography of René Descartes are required here; within his extensive philosophical and scientific output, only his view of our solar system, and his confident extrapolation to the rest of the Universe, have to be understood. Descartes had constructed a World-machine in which multiple fully equivalent planetary systems built on Copernican lines were not only possible: they were a necessary consequence of his mechanics, and nevertheless never fully spelled out by the Master himself. This strange outcome cannot be explained without some reference to the conditions under which his most relevant works, essentially *Le Monde* (The World) and *Les Principes* (the Principles), were written and published.[2]

When *Sidereus Nuncius* reached the *Collège de La Flèche* where Descartes was studying, he was a fourteen-years old student, thus the invention of the telescope and the subsequent astronomical discoveries did not act as a watershed in the development of his thought, as it did for Galileo and (to a lesser extent) for Kepler. As to the second major physical discovery that took place during his lifetime, that of vacuum, it should have proved far more than a mere watershed: it was a tidal wave, bound to wipe out all of Cartesian physics of which barely some shreds were to survive into the eighteenth century. However, the event happened too late in his life: all Cartesian devices were already assembled into a fully coherent and highly popular system. Descartes himself, while aware of the Torricelli and Pascal experiments (in which he was even deeply interested) remained convinced they fitted perfectly well within his universal vortices.

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[2] The Descartes complete works have been published as *Œuvres Complètes de Descartes* by Adam and Tannery (here referred to as *OCRD*); Volumes I to V give the *Correspondence*, Vol IX *Les Principes*, Volume XI *Le Monde*. For *Le Monde*, we will also use the edition by A. Bitpol-Hespériès and Jean-Pierre Verdet (1996) which gives a useful *Introduction* and *Notes* (referred to as *BHV*). There is a 1998 English translation: *The World and other writings*, by S. Gaukroger.

Descartes biographies used here are those of Charles Adam (1910), *Vie et Œuvres de Descartes*, and Stephen Gaukroger, *Descartes, an Intellectual Biography*. Other used works about Cartesian physics and cosmology are *The Vortex Theory of Planetary Motions* by E.J. Aiton (1972), and *Le Dévelopement de la Physique Cartésienne*, of Paul Mouy (2012).

Thus the Descartes speculations follow another blind alley in the development of the Plurality theme, which does not make them less interesting. Like the thirteenth century Scholastics, he made it a sensible proposition to his successors through arguments that have since vanished. Bishop Tempier had shown Plurality to be a permissible outcome of God's omnipotence; for Descartes, and with due reverence to God, who indeed is never far away in the background, it becomes deducible from the laws of physics, which are spelled out in mind-pleasing detail. The capital improvement is that God, when building these other Worlds, now operates through coherent and intelligible laws. Of actual Cartesian mechanics, very little is left today, while his beloved vortices have vanished into unsubstantial smoke; but this is no more than a technical point in the present story, as the main result survives. Like Bruno, Descartes became convinced that the Universe is filled *ad infinitum* by essentially similar Worlds; however, very much unlike Bruno, he was a scientist, and a mathematician to boot. Strangely enough, outside optics, his mathematics remained idle, and proved of hardly any use in depicting the Universe. Unlike Kepler, he was no astronomer, and his astronomical knowledge appears entirely acquired at second or third hand. There is no doubt that he could have followed those elliptical orbits in exquisite detail had he set his mind to the problem, but he never bothered about them, nor indeed about Copernican epicycles. Thus he remained unworried by technical niceties such as stellar apparent diameters, which had proved Kepler's downfall as far as other solar systems were concerned. Like Kepler, his contribution to the understanding, and even to the construction, of lenses and telescopes was considerable; but there is little evidence that he used to study celestial bodies himself with their help. He kept his primary interest for the living world; in which he remains very close to Aristotle.

If the Galilean discoveries did not come as a shock to Descartes, the Galileo trial certainly did. From 1629 to 1633, his main concern had been writing up *Le Monde*, his first treatise on the system of the World where are presented those specific Cartesian devices, the vortices, which similarly fill up space around the Sun and all stars. The Copernican system had been adopted as a matter of course, and no other model was even considered by Descartes; but, as a fully orthodox Catholic, he knew the matter to be a highly-sensitive one and used extreme caution, pretending to be writing a mere Fable. His descriptions were to be taken as those of an imaginary World: "For a little time, let your thought get out of this [real] World, in order to visualize another fully new one which I will make in imaginary spaces." (*Le Monde, OCRD* XI, 31; *BHV*, 22). Still, that Fable device was rather transparent, and he did not believe it would afford solid protection. He learned of the outcome of the Galileo trial in November 1633, just when he was ready to send the manuscript to his usual correspondent Marin Mersenne, and at once he gave up all thought of publication. The blow must have been severe: "This [Galilean affair] has astonished me so much that I almost decided to burn all my papers." No mitigation was possible; if the Earth motion was false, then "all the bases of my philosophy are also false, as it is obviously demonstrated from them. It is so much interconnected with all the parts of my Treatise that I could not detach it without making all the rest incorrect." (*Letter to Mersenne,* end of November 1633, *OCRD*, I, 270-271).

Nevertheless, the rather excessive caution shown by Descartes in the case is surprising, and has perhaps never been fully explained. He had settled in Holland in 1628, thus he could fear neither personal persecution nor difficulties of publication: indeed, the Elzeviers had just printed the Galileo *Dialogo* that triggered his condemnation, and French publishers were also available. Descartes seems to have sincerely wanted not to offend the Church; but he feared the probable interdiction by the Sorbonne, which would have reduced readership, and he also usually preferred to shy away from controversies. Even so, he did not lose "all hope that things would turn out as in the case of the antipodes, which had been similarly condemned long ago; thus my *Monde* might yet see daylight, given time." (*Letter to Mersenne,* April 1634, *OCRD*, I, 288). Which it ultimately did, being printed in Paris in 1664, fourteen years after the author's death, and (ironically enough), just after his complete works had been put on the *Index* for wholly different reasons.

Fortunately, Descartes did not give up writing about Nature, but at first merely shifted to less dangerous subjects, unconnected with Copernicanism. In the ensuing period, still from Holland, he produced not only the *Discours de la Méthode*, the *Méditations* and the *Géométrie* but also the *Dioptrique* and *Les Météores*, with which we are little concerned. Our main interest will be in the *Principia Philosophiae*, first published in Latin by Elzevier in 1644, then translated into French as Les *Principes de la Philosophie* three years later, and printed in Paris without any difficulty. As far as the natural world is concerned, the *Principes* is a Cartesian encyclopedia in which his system is fully detailed, covering mechanics, physics, astronomy, chemistry, and geology; and a much-needed one too, since the author's ultimate ambition was to explain just everything. We will consider mostly the Cartesian world system, somewhat more complete than in Le Monde, but not essentially different. Again, this is rather surprising: while only eleven years had passed since the time of Galileo's trial, Descartes felt that extreme caution was no longer needed, and did not pretend to be writing a Fable. In the interval, no abrupt change of the theological situation had taken place; still, outside Italy the consequences of the Inquisition's writ had been rather limited, and use of the Copernican system was obviously getting more widespread. Descartes may simply have felt his *Monde* was no longer comprehensive enough, and preferred publishing a wholly new account.

During his last years, no new publication nor any private Letters indicate any change of the Cartesian outlook; the vortex system went on with its multiple whirls and whorls irrespective of the major discovery in physics: Vacuum, and this lack of reaction by Descartes is in itself interesting enough to be briefly followed in these pages. Lastly, after a theological controversy with Dutch protestants, from which he had unfortunately not recoiled, he received a well-meant but ultimately disastrous invitation from the young Queen Christina of Sweden. Her hospitality he enjoyed for only a few months, as he caught pneumonia induced by the harsh Stockholm winter in early 1650: she made him rise at four in the morning three days a week for lengthy philosophy lessons. Descartes was only fifty-four, and as far as Plurality is concerned, he gives the impression of never having proceeded to the obvious consequences of his own world system. His disciples and successors will not prove equally prudent.

The Operation of Nature According to Descartes

The starting point in the study of Nature is presented with standard Cartesian clarity: God is at the origin of everything, and specifically of all human knowledge. And Nature is just a convenient word:

> Understand first that by nature I do not mean some kind of deity, nor any imaginary power, but I make use of that word to signify matter itself… under the condition that God goes on preserving it in the same way he had created it. (*Le Monde, OCRD* X1, 36; *BHV*, 24).

At the beginning, God had created not only matter, but all the laws which Descartes deems essential, namely those of motion; they are responsible for order in the Universe:

> …God has so wonderfully established these laws… that the parts of this chaos unravel themselves and they take such a good order that they have the shape of a very perfect world, within which we can see not only light but also all other things. (*Le Monde*, *OCRD* XI, 33; *BHV*, 23).

As to our own understanding of these laws, we should feel fully safe: "God does not lie to us because this is repugnant to his nature." (*Principes,* OCRD IX, 64).

The sole durable contributions of Descartes to mechanics are (using modern terms) the conservation of momentum and rectilinear inertia, both of which he attributes to the Creator, without any intermediary agent. To start with,

> God is the First Cause of motion [movement], of which He always preserves an equal quantity in the universe…When a part of matter moves twice as fast as another, and when this second part is twice as large as the first, we must think that there is as much motion in the smaller as in the larger… This is a perfection of God. (*Principes,* OCRD IX, 83).

Similarly, the law of inertia is:

> Any moving body tends to pursue its motion in a straight line…This rule, like the first depends on God being immutable. (*Principes,* OCRD IX, 85).

At which point Descartes comes to God's help (and ours) with a very sensible description of a stone leaving a sling plus a nice drawing. Even so, God had come first.

Which kind of God is He exactly? Definitely not Aristotle's:

> To say that these [mathematical] truths are independent of Him, is to speak of God like a Jupiter or a Saturn, and to submit him to Styx and Destinies. Do not fear to publish everywhere that it is God who established these laws within nature, as a king establishes laws within his kingdom. (*Letter to Mersenne*, April 151,630, OCRD I, 145).

But neither is He the God approved by the Catholic Church: within the *Principia*, references to theological matters are very rare. There is one brief paragraph pasted *in fine* to the *First Part*, devoted to the *Principles of Knowledge*: Revelation comes first and "We shall use as *infallible* rule that what God has revealed is *incomparably more certain* than the rest …" (*Principes*, *OCRD* IX, 62. All italics within Descartes quotations are by himself.) Next comes the Church: "…*because I do not want have too much faith in myself…* I submit all my opinions to the judgment of wiser people and to the authority of the Church." (*Principes,* OCRD IX, 325). Both additions look like the similar disclaimer inserted by Galileo at the end of his *Dialogo*, and they are equally skin-deep. Most surprisingly for a purported Encyclopedia, *Genesis* appears only once, and rather incidentally at that; the point under discussion is the primeval perfection of the World; Descartes does not doubt that "…Adam and Eve have not been created as children, but as perfect grown-ups. The Christian Religion wants us to believe it, and natural reason absolutely confirms…" However, the point is at once made that, even so, too much ink should not be spent on Revelation itself, as Science must be an independent enquiry:

> …We would know far better what has been the nature of *Adam* and that of the trees *of Paradise,* if we had studied *how children are slowly formed in their mothers wombs* and how plants grow out of their seeds. (*Principes,* OCRD IX, 124).

Nevertheless, we know that Descartes both feared and revered the Church, and some private letters show evidence of earnest attempts to make his world system compatible with *Genesis,* which never reached print. He is greatly helped by a willingness to take the sacred text as largely allegorical:

> As to *Genesis*, it might be that the story of Creation is metaphorical, thus best left to theologians…the six days [might be] a mere manner of speaking rendered necessary by our mode of understanding. (*Entretien avec Burman, OCRD* V, 169).

In 1641, eight years after the Galileo disaster, while the *Principes* were approaching completion, he feels safer, and writes to Mersenne "There should not be, I believe, any difficulty in conciliating theology with my philosophy." (*Letter to Mersenne*, January 281,641, *OCRD*, III, 295–6). (*Letter to Mersenne*, January 281,641, *OCRD*, III, 295–6). Ultimately, he proved wrong, as his entire work was to be put on the *Index*; moreover, the French Catholic Church was particularly hostile and Louis XIV renewed the ban on teaching Cartesianism in 1685 (Gaukroger 1995, 3). Unlike in the Galileo case, the system of the World was not explicitly involved; but the difficulty was even more fundamental as it dealt with the Descartes presentation of Space itself, which appeared (to critics) incompatible with transubstantiation. This grave problem is for instance expressed by a question of Antoine Arnauld "How may the body of Christ be present without its proper extension?" (Gaukroger 1995, 357). As we remember, Kepler had already come to grief on the same shore from the winds blowing within the Lutheran Church. Nowadays, Copernicus and Galileo have long vanished from the *Index,* but the works of *Descartes Renatus* still occupy seven lines in the final 1944 edition, all *donec corrigatur*; except for the *Meditationes* which are apparently beyond all feasible corrections.

The rejection of final causes by Descartes is explicit and marks the most radical change ever in scientific methodology:

> One should not examine what the aim of God has been when he created any thing, but solely through which means He has wanted it to be produced…We shall totally exclude from our Philosophy the search for final causes, since we should not presume so much about ourselves as to believe that God was bound to make us privy to His councils… (*Principes, OCRD,* IX, 37).

However, he was not the first to take that line of approach, and it is hard at this point not to quote Francis Bacon's famous one-liner "The Inquisition of Final Causes is barren, and like a virgin consecrated to God, produces nothing", nor his humorous elaboration; such Causes have been

> … a great misfortune to Philosophy. For the handling of final causes in physics has driven away and overthrown the diligent inquiry of physical causes… this I find done not only by Plato, who ever anchors upon that shore, but also by Aristotle, Galien and others who also very frequently strike upon these shallows… The natural philosophy of Democritus and others, who removed God and Mind from the structure of things… and assigned the causes of particular things to the necessity of matter without any intermixture of final causes, seems to me … much more solid and to have penetrated farther in Nature than that of Aristotle and Plato… These discoursing causes (like those fishes called remoras which are said to stick to the sides of ships) have in fact hindered the voyage and progress of the sciences… (*The Works of Francis Bacon,* edited by James Spedding, p. 471 and 473).

Descartes does not mention Bacon, as he very seldom refers to any predecessor; however, he had certainly read him (see *Letter to Mersenne, OCRD*, I, 109). In any case, he will proceed farther than Bacon or any one else in the banishment of teleology, and will even reverse hylozoïsm, from which Kepler had been far from free. For Descartes predecessors any sort of machinery was explainable as an animal, for him animals are machines themselves; and as he is more interested in the living world than in the cosmological one, les *animaux-machines* play an important role in his work. According to Burtt (1954, p. 119) "he does not even appeal to final causes to account for what goes on in the realm of the mind", which illustrates how thorough was his rejection of finality. Alas! neither Bacon nor Descartes managed to exterminate those hardy *remoras*: they will soon come back, livelier than ever, and play a major role in the elaboration of their own Pluralities by such deviant Cartesians as Fontenelle and Huygens.

Of great interest to any scientist is the Descartes-Fermat controversy about the law of refraction, or at least its essence. Proceeding farther than Kepler, who had believed the incidence angles of the incident and refracted rays to be proportional, Descartes (after Snellius, and probably independently) found the exact law: proportionality of their sines. His discovery was not the result of simple tests resembling those presented in schoolrooms or science museums today, but of a deductive treatment in which light involved projectiles; hence, optics reduced to mechanics, and only efficient causes were required. On the other hand, Fermat, while ready to accept the Descartes law as at least approximately true, disagreed with his demonstration, and tried to apply his own previously-discovered method for determining maxima and minima; which, so far, had only involved pure geometry, not mechanics. His approach was totally different: he searched for the shortest possible path of a light ray passing from the first medium to the second.[3] His final demonstration

[3] For the Fermat-Descartes controversy about the refraction law: see *Letter of Fermat to Mersenne*, April–May 1637, *OCRD* I, 354–361; *Letters of Descartes to Mersenne,* 5 October 1637, *OCRD*, I 448–9 and 450–4; *Letter of Fermat to Mersenne*, November 1637*, OCRD* I 463–474. For a thorough discussion of refraction as perceived by Descartes and Fermat, see Sabra (1995).

established that the Descartes path was indeed the shortest one, but it was not perfected before the death of his opponent; thus the discussion went on with Claude Clerselier, editor of *Le Monde* and of the Descartes *Letters*. Here we present Clerselier's reaction to the use of the Fermat minimum-time principle, an answer which could just as well have been formulated by his master Descartes:

> This principle you take as basis of your demonstration, namely that nature always operates through the shortest and simplest paths, is merely a moral and not a physical principle, which is not and cannot be the cause of any effect in nature… Otherwise we would be supposing knowledge within nature, by which word we mean this order and this law established in the world as it is, which acts without prescience, without choice, and through a necessary determination. (*Letter from Clerselier to Fermat*, 6 May 1662, quoted by Sabra 1981, 153).

Hence the rejection of teleology had been finally carried too far, and Cartesians were now battling the mere ghosts of final causes. However, Leibniz (see Mouy 2012, 301–2) was to reintroduce such causes throughout Nature, just as if Bacon and Descartes had never been born, and in his turn he will be most efficiently ridiculed by Voltaire's *Candide*. Does the battle go on? Today, an equilibrium appears to have been found at least within exact sciences: we are no longer bothered by the moral analogies of the Fermat least-time, and similar principles have gained permanent places in physics, all of which operate from *bona fide* causal mechanisms: the Maupertuis least action, Euler's extremum law, Maxwell's maximum magnetic flux.[4] Plus, as a final touch of irony, Darwinian evolution itself: another maximizing principle, Survival of the Fittest, has conquered a first-rank place in our view of Nature, not without immense and still extant opposition; paradoxically enough, because it looks so utterly amoral.

We follow more easily the thorough rejection of anthropocentrism by Descartes. While he held as true that

> nothing has been created out of which we cannot draw some use… nevertheless it is not at all likely that all things have been created for us in such a manner that God should have had no other aim when creating them. And it would be impertinent to make use of this opinion to shore up arguments within Physics, since we cannot doubt that there are infinite numbers of things in the World… no man has ever seen or known, and that have never been of any use to him. (*Principes, OCRD*, XI, 104).

Hence, for Descartes, filling the universe *ad infinitum* with vortices will not be a consequence of some Principle of Plenitude: the Creator had not been forced to act according to any maximum Good defined by His own creatures. Still, constrained He had been indeed, but not by any sort of moral law: God "will never make any miracle, and the intelligences, or reasonable souls…will perturb in no way the ordinary course of nature" (*Le Monde*, *OCRD* XI, 48; *BHV*, 29). That Necessity was coming solely from Cartesian logic. The best example is Vacuum, which was not merely non-existent, but unthinkable.

[4] For the progeny of Fermat within mechanics, see Dugas (1955) Chapter 5. Exactly like Clerselier, D'Alembert was to be much worried by the moral undertones of the Maupertuis principle. The underlying teleology is very-well followed in Barrow & Tipler (1986), p. 67, and 148 ff.

The rejection of vacuum plays a primordial role in the Cartesian world picture, and is found at the very beginning of the chapter devoted to the *Principes des choses matérielles*. The demonstration is typically Cartesian:

> Because God does not induce us in error, which would be repugnant to His nature… we are driven to conclude that there exists a certain *substance* extended in length, breadth and depth… It is neither the weight, nor the hardness nor the color etc.… that constitutes the nature of a body, but extension alone… Corporeal substance cannot be clearly conceived without its extension…. Space, or *internal place* [*lieu intérieur*] and the body that is contained in that space differ merely because of our [incorrect mode of] thought…

Descartes' own way to the true solution: consider a stone and

> …let us take out hardness, since if that stone was reduced to powder, it would have lost its hardness,… color …, weight…heat or cold and all other similar qualities… then we shall find that the only veritable idea that we are left with is that of a substance extended in length, breadth and depth; which is contained within the idea we form of space, not only that which is filled with a body, but also that which is called vacuum.

The conclusion is inescapable:

> There cannot be any vacuum in the sense that Philosophers take that word… There is no such space *in the universe.* (*Principes, OCRD* XI, 64–71).

This capital result has been deduced from logical premises without appeal to experience nor to available literature. Again, Descartes never quotes his precursors or the sources of his thought; he obviously knew his Aristotle fairly well, but was he unaware that the late Middle Ages discussions about vacuum had proceeded much farther?

So far, experimentation has played no role in his rejection of vacuum. At last, he is willing to consider a suitable thought-experiment, in which God, after being (most respectfully) summoned to the laboratory, is actually used as a vacuum pump. Descartes considers a vase, filled with any substance:

> Almost all of us have been *preoccupied* with this error, from the beginning of our lives because, seeing no necessary connection between the vase and the body inside, it has appeared to us that God might take out the body…and *preserve the vase in the same state*, without any need for any other body succeeding in the place of the one He had taken out. However, in order to correct such a thoroughly false opinion, we must remark that [the connection] is so absolutely necessary between the concave shape of the vase and the extension that must be included within its concavity, that it is no more repugnant to conceive mountain without valley than concavity without the inside extension… If God were to take out the entire body that is in the vase without letting in any other… the sides of that vase would find themselves so close together that they would immediately touch… since distance is a property of extension, that could not subsist without something extended. (*Principes, OCRD* XI, 73).

In modern (and mischievous) terms, the experiment ends disastrously, with an ill-designed vacuum-tank collapsing under atmospheric pressure. Altogether, we are left wondering: despite his Platonic-type demonstration that "there cannot be any vacuum", Descartes world-picture cannot be wholly free of sensory inputs; he must have watched that commonplace experiment of sucking out the air from a pig-bladder, of which he unconsciously remembers something.

Which is as far as the logic of our great Descartes, apostle of rational thinking, self-proclaimed expert on clear deductions, definitive slayer of the School, took him on the subject of vacuum. One longs for the plain common sense exhibited three centuries before by Oresme and Richard of Middleton: "God might destroy the whole created substance that lies between Earth and Heaven… God might accordingly create a vacuum, and it does not follow that He would produce two contradictories." A pity we do not have a Cartesian refutation of those Scholastic lines. The capital irony is that the crucial tests will finally be made in Descartes lifetime; not by God in person, but by very much human colleagues; nor through the agency of pure thought, but using commonplace laboratory tools he was familiar with. And the container will not collapse! And a vividly interested Descartes will not only reproduce the set-up many times, but also draw out several conclusions (some quite sensible) and suggest additional tests, all without an inkling of the disastrous consequences for his cherished vortices.

Even before the Torricelli experiment, Descartes had been aware of the technical fact, discovered by gardeners in Florence, that pumps were unable to pull water above a certain height, but missed its fundamental character: for him, that failure was just due to trivial leaks. In a 1639 letter to Mersenne, he provided the diagram of a suction pump, and explained that.

> the force through which that water in the pipe tends to descend is so large that the air… makes its way in between the piston and the pipe, however small the intervening space is; thus, instead of water, one draws merely scum, that is air mixed with water. (*Letter to Mersenne, OCRD*, I, 589; see also Mouy 2012, 33–45).

Torricelli, who had dispensed with both water and pump, and used a thoroughly leak-proof container, could not be dismissed so easily. Thereafter, Descartes fully adopted quicksilver and glass tubes, but neither caused him any mental anguish:

> All your experiments with quicksilver do not surprise me, and there are none which I cannot easily make to agree with my principles, insofar as these experiments are true." (*Letter to Mersenne*, April 41,648, *OCRD*, V, 141).

He even wrote that it was himself who had suggested to Pascal the famous experiment later carried out on the *Puy-de-Dôme* mountain, that demonstrated decrease of atmospheric pressure with altitude. He also proposed some well-conceived tests, such as: try burning sulphur or camphor in "your vacuum." (*Letter to Mersenne*, December 14, 1647, *OCRD*, V, 98). And in Stockholm, during his very last days, Descartes was still busy constructing a new device, involving both mercury and water in specially designed tubes, for improved sensitivity. Alas, all those tubes broke because local glassblowers did not have the necessary skill (*Letter from Chanut to Périer,* September 24, 1650, *OCRD*, V, 476).

All to no avail; by the time Descartes learned about the Torricelli experiment, he had so long been filling the universe with pervasive subtle matter, and he was so much pleased with so many well-explained phenomena, that the mere demonstration of Space emptied of Air could not compel him to make a new start. Not for a minute did he suspect that the ground had been pulled out from under Cartesian physics, and that his entire world system was left dangling in vacuum.

The attitude of Descartes concerning the use of mathematics in the study of Nature has been much studied, but remains difficult to grasp just the same. He was not only a gifted mathematician but also an innovative one, inventor of analytical geometry, a tool that has since proved essential in all scientific disciplines. Clearly, he is in no doubt about the prime role of mathematics: in his *Règles pour la Direction de l'Esprit*, Rule Number Two is "One should merely be concerned with objects of which our mind seems able to acquire certain and indubitable knowledge," and when discussing this Rule he is led to stress that "among already known sciences, only arithmetic and geometry are exempt from falsity and uncertainty." (*Œuvres et lettres*, Editions de la Pléiade (1937), p. 7-9). His goal is a complete system of deductive science, and he wants to reach total certainty in all fields. The immensity of his ambition is illustrated by a letter to poor Mersenne, who was suffering from erysipelas: "Please try to keep well at least until I discover whether there is a way to find a Medicine based on infallible demonstrations, which is what I am presently looking for." (*Letter to Mersenne*, January 1630, *OCRD*, I, 105-6). Which is only half of a joke, as he proceeds to treat in the same breath optics, music, acoustics and cosmology. Fortunately, he is willing to concentrate upon those aspects of Nature most easily amenable to mathematicians; as already quoted "… it is neither the weight, nor the hardness nor the color etc… that constitutes the nature of a body, but extension alone." Altogether, he seems better equipped than anyone else to grasp all available mathematical tools and apply them to the construction of his physics and of his System of the World; in particular, far better than Galileo. However, within his physics, he will neither make an attempt nor even hint that his qualitative treatments are merely first approximations, and that future disciples might develop his Vortices using mathematics. Alexandre Koyré: "Cartesian physics, as presented in the *Principia*, no longer contain any explicit mathematical laws; they actually are as fully un-mathematical as those of Aristotle." (Koyré 1966, 128).

Admittedly, within optics, he is a different man. For instance, from his exact law of refraction he demonstrates that perfect lenses must embody an hyperboloid surface; in modern terms, such lenses will be free of spherical aberration. Despite the exceedingly small difference between circle and hyperbola in such cases, his *Dioptrique* and many of his *Letters* show him not merely studying the point in minute details, but taking considerable trouble to design a polishing machine for generating hyperboloids; and rather indignant when correspondents fail to see that the point is vital. Hence, in such cases, he is not only aware that Nature requires the most precise mathematical description but he is ready to carry it out himself to the full. But when planetary orbits are concerned, he is uninterested by the difference between a circle and an ellipse: he never even mentions the three Kepler laws. Of Kepler the optician, he is very much aware, writing that "I confess that Kepler has been my first master in optics, and I believe that so far he has been the one who knew the field best." (*Letter to Mersenne*, March 31, 1638, *OCRD*, II, 86). He also has read the minor Kepler work on snow crystals *De Nive Sexangula* (*Letter to Mersenne*, March 4, 1630, *OCRD*, I, 127), but never hints that any contributions of the same Kepler to astronomical motions might be worth considering. While optics and astronomy are the twin fields where the need of mathematics had been undisputed since antiquity, the guiding principles of Descartes in the two cases proved opposite, and that opposition remains puzzling.

His reaction to the work of Galileo is characteristic; in an often-quoted *Letter*, he writes to Mersenne on October 11, 1638 (*OCRD*, II, 379):

> I find that in general [Galileo] philosophizes much better than common people, insofar as he gets away from the errors of the School, and attempts to examine physical questions with mathematical arguments. Here I entirely agree with him, and I hold that there is no other way to reach truth… However, he largely fails by continually digressing and not attempting to give full explanation of any matter… without having considered the first causes in nature, he has only searched for the reasons of some particular effects, and thus has built without a base.

From this beginning, Descartes proceeds to a rather thorough demolition of the just published *Discorso*, invariably missing or rejecting that contribution of Galileo we find most pregnant, even more so than all his telescope wielding: the technique for injecting mathematics within the study of Nature. A typical example, from the same *Letter*:

> Everything he says about the velocity of bodies descending in a vacuum etc., is built without foundations; because he should have first determined what gravity is; and if he had known the truth about it, he would realize it is naught in a vacuum.

The point stressed here is not the standard Cartesian rejection of any vacuum, but that he remains blind to that Galilean application of mathematics to mechanics that was to prove definitive.

Doubtless, in the Kepler case, separation of the three *Laws* from the enormous volume of chaff proved most laborious (it still does), and Descartes possibly did not even see *Astronomia Nova*; but about the Galilean fall of graves, he has no such excuse. Soon after, in another *Letter*, he finds striking terms for contrasting the two lines of approach: “As to what Galileo wrote about levers and scales, he explains fairly well *quod ita sit*, but not *cur ita sit*, as I do from my Principle” (what things are, but not why they are so; *Letter to Mersenne*, November 15, 1638, *OCRD* II, 433). That *cur* (why), or lack of it, is the *crux*; it is precisely because Galileo, and later Newton, largely gave up worrying about the *cur* that they are at the source of modern mechanics, while both Cartesian *quod* and *cur* have vanished into so much smoke; except for linear inertia and conservation of momentum, which he never attempted to put in mathematical form at all. Had he remained equally vague about light ray paths, there would be no Descartes law of refraction today.

In the words of Koyré (1966, p. 135): “Within [Cartesian] physics, there is a plenum, everything depends on everything, everything acts instantaneously on everything. No phenomenon may be isolated, thus it is impossible to propose simple mathematical laws.” Our own proposed summary: for Descartes, mathematics always provides an archetype, never a tool. Invariably, he hopes to build with the clarity and the certainty of mathematical argumentation, but for any mathematical formula or theorem he has no actual use outside optics. When constructing his System of the World, he follows the tradition of ancient philosophers (i.e. physicists), and thoroughly disdains mathematicians: merely saving the appearances, accurately or not, is pure waste of time for one who, like himself, has unveiled the true Causes. As a consequence, his vaunted astronomical vortices will be found non-geometrical, and even fuzzily described, to a stupefying degree.

Then, why bother with the obsolete cosmological views of a seventeenth century philosopher who never looked through a telescope (or at least never reported on what he saw), thus did not even qualify as an amateur astronomer? One for whom neither Ptolemy nor Copernicus the geometer, not to speak of Kepler, seem to have been born? Because he was first to introduce a Plurality of identical Worlds from rational and causal developments based on universal and homogeneous mechanics. His multiple and analogous Vortices do not fill up the Universe *ad infinitum* just to suit God's unlimited power, but they are a direct consequence of physical and mechanical laws. For these laws God had been originally responsible, but He had, ever since Creation, elected to follow them himself, enabling Man to do the same in the bargain. As Thomas Kuhn (1959, p. 242) writes, "All that remains of the Cartesian system is that the Universe is indeed a machine built with corpuscles and moving according to specific laws;" but that lonely residual is capital, and all too-easily forgotten. Today, we are ready to orbit Earth-like planets around Sun-like stars anywhere in the Cosmos from one central argument: over there, corpuscles of all feather cannot move differently from the home variety, thus they are bound to follow the same Laws. That essential conviction we take from Descartes; even if Democritus had shown the way.

We might proceed further and enthusiastically furnish these planets with vegetables, animals and intelligent creatures, an extension Descartes most carefully shunned (except in rare private letters) but he had created the right conditions for their growth, and followers soon took that tempting step.

Cartesian Mechanics and Matter

From the viewpoint of the history of Plurality, the essential improvement of Cartesian mechanics, compared the still-prevalent Peripatetic varieties, is that they are homogeneous: there is no longer any difference between explanations used for Heavens or Earth. Descartes even introduces in the *Principia* the modern procedure of first establishing the laws of mechanics in his Earth-bound laboratory by experiments, either actual or merely conceived by thought, and later applying the results to celestial bodies. However, it is disappointing to see that the lasting Cartesian contributions (rectilinear inertia, momentum conservation and a single one of his collision rules) are so little used in the rest of the text. These basic Laws are compatible with the vortices, but they never intervene explicitly. The most that can be said is that everything works by collisions of particles.

Descartes presents his first two Laws quasi-simultaneously, and both are at once attributed to the Creator:

> God is the first cause of motion [movement], and he always preserves an equal quantity in the universe… if a body has once begun to move, we must conclude that henceforward it keeps moving and never stops by itself.

In his discussion, Descartes introduces *quantité de mouvement* (quantity of motion), which has remained the standard French term for *momentum*. He explains in the clearest terms that the common-experience apparent contradictions are due to friction, in particular, that of air:

> It is obvious that air and the other liquid bodies between which we see things moving, reduce the speed of their motion little by little…; we can even feel by hand the resistance of air if we agitate fast enough an extended fan. (*Principes*, *OCRD*, IX, 84–5).

The improvement is radical: for Peripatetics, air had ever remained the motor responsible for the violent motion of projectiles after they had left the hand. Descartes at once proceeds to his.

> Second law of nature: That any body that moves tends to proceed with its motion in a straight line…

The explanation is more subtle, but again proceeds directly from the immutability of God who "does not preserve [momentum] as it had been some time before, but as it is precisely at the instant of preservation." (*Principes*, *OCRD*, IX, 85-6). Descartes contributes the perfectly apt analogy of a sling, with the freed stone proceeding along a straight line, complete with an often-reproduced drawing (Figure 11.1). Here, he clearly overtakes Galileo, for whom circular motion had still been the only natural one, without need of any explanatory force. Galileo had also remained blind to the difference between the terrestrial and heavenly cases: planets may appear to prefer circular orbits, but no stone ever behaved so in the laboratory from its own devices.

The next mechanical problem is that of collisions, but it will be the last one to be tackled with Cartesian clarity: "How one may determine to what extent bodies that meet change the motions of one another through the following rules." (*Principes*, *OCRD*, IX, 89–93). Then, seven rules are provided for the two-body case, according

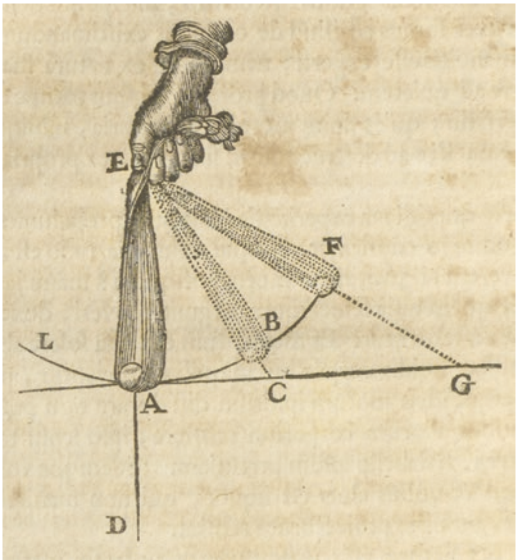

Figure 11.1 The Cartesian sling. The illustrated point is that the stone, once freed, proceeds along a straight path. There is also some anticipation of centrifugal force. www.e-rara.ch

to the bodies initial velocities and *grandeurs* (sizes); which last quantity is never fully discussed. The bodies are supposed “hard”, which means non-elastic in the modern sense; the clumsy discussion is at best semi-quantitative, and not a word would be changed if geometry and algebra had never been invented.[5] Alas, only Rule 1 will be found to hold in the long run, and it is the late Cartesian Huygens who will provide our correct collision laws.

Which sums up the durable Descartes contribution to mechanics; all the rest is Vortices which, while immensely popular in his own century (despite King and Church), have left no lasting traces. To the modern mind, the elaborate vortex edifice, described with loving care and used to explain all of mechanics and much of physics, appears not merely artificial but arbitrary. Still, the starting point had been a straightforward consequence of the Vacuum rejection. Ionians and Epicureans had made a different, but equally logical choice, that of a void suitable for moving atoms through. However, Descartes does not endorse atoms but corpuscles, of which a single feature is made clear: they totally fill up Space. Hence, corpuscles may only proceed along closed circuits, to which Descartes remains as completely committed as ancient philosophers had been to circular motion: “All places are full of bodies… we must necessarily conclude that there always must be a circle or ring of bodies that move together simultaneously…” (*Principes*, *OCRD*, IX, 81). Even within optics, he takes most of his analogies from commonplace experience: light-ray paths from the palm-ball game, light velocity from the stick of a blind man feeling his way around. Animals sometimes come in to help, but merely through analogies:

> Look at fishes within the water of a pond; if they do not come too close to the surface, they will not agitate it at all, even when passing under with great velocity… they do not push all the water from the pond, but merely the part which may best complete the circle of their motion, and take the place they have made vacant. (*Le Monde*, *OCRD* XI, 18-20; *BHV* 16).

Such is the way through which Descartes is led to take vortices as universal model; the Ionians had done it long before, but he never says so. However, his description remains qualitative; he proves unlucky in having selected a commonplace phenomenon, which turned out fiendishly difficult to describe mathematically. The feat was to remain unachievable before the contributions of Daniel Bernoulli, d’Alembert and Euler, and the tools of Laplace; by then, cosmological vortices were wholly forgotten about**.** The one explicit feature required by Descartes of his vortices is that they should be able to function while preserving the obligatory plenum.

One last Cartesian mechanical concept that requires clarification is his peculiar view of the relativity of motion. He starts again from commonplace experience: “a fluid body that moves wholesale in some direction necessarily carries with itself all the solid bodies it contains.” So far, so good; but his conclusion is appalling:

> One cannot properly say that a solid body moves when it is carried along by a fluid body… the true nature of motion is properly the transportation of the body being moved, away from

[5] Aiton (1972), p. 36, explains and illustrates the seven Cartesian collision rules with helpful diagrams and modern algebra.

> the vicinity of some other bodies that touch it, and that such transportation is reciprocal in bodies touching each other. (*Principes*, *OCRD*, IX, 100).

In other words, the motion concept is strictly local, and motion relative to a distant point of reference has no more meaning than force at a distance, since forces act solely through collisions. And a consequence (for Descartes, a highly welcome one) will be: I have succeeded in making Copernicus acceptable to the Church, because the Earth does not move, it is just carried along by its own Vortex. Hence his famous statement:

> I deny the motion of the Earth with more care than Copernicus, and more truth than Tycho…. through [the hypothesis] of Tycho one actually grants to the Earth more motion than through that of Copernicus, while granting it less in words. (*Principes*, *OCRD*, IX, 109).

This fancied success must have been partly responsible for Descartes daring to publish *Les Principes* without hiding his world system under the guise of a fable, as he had prudently done in *Le Monde*. Koyré (1966, p. 318–9) even argues that Descartes adopted this idiosyncratic form of Relativity in order to make his system acceptable to the Church!

After the laws of motion, the structure of matter. Altogether, Descartes requires three elements:

> I conceive the first, which may called the element of fire, as the most subtle and penetrating liquor existing in the world… its parts are much smaller and moving far more rapidly than any of those from the other bodies… The second might be taken as the element of air… its parts must be imagined approximately round, and connected together like dust or sand grains. Consequently, they cannot dispose themselves nor press against each other well enough to avoid small intervals in between, within which it is easy for the first element to insinuate itself… The third I conceive to be that of the earth, in which I judge the parts are much larger and move much slower, in the same proportion as those of the second to the first… I am even ready to believe they have little or no motion at all. (*Principes*, *OCRD*, IX, 22-5; *BHV* 18-9).

So far, at least the names sound familiar. Does it mean that the sole improvement brought by Descartes is the reduction of five elements to three, like Copernicus doing away with a few epicycles? No; there is a far deeper conceptual change: unlike for Peripatetic elements, all properties of the Cartesian ones reduce to those handled by geometry and mechanics:

> To explain these elements, I do not use the qualities called heat, cold, humidity and dryness, as done by the Philosophers… these four qualities themselves require explanations, and even all the others may be explained without supposing anything within their matter except motion, size, shape and disposition of the parts. (*Le Monde*, *OCRD*, XI, 25; *BHV*, 19).

Another change, and a capital one, is the demise of quintessence:

> It is not difficult to infer from all of this that Earth and Heavens are made from the same matter,

together with that of the venerable fancy we have called External Plurality:

> Even if there were an infinity of worlds, they would only be made of the same matter; from which follows that there cannot be several, because… we cannot discover in ourselves the notion of any other matter. (*Principes, OCRD*, IX, 75).

Weak argument? Descartes' trust in every clear notion that God has implanted in his own mind is boundless. He will similarly dispose of atoms, once for all:

> It is also very easy to know that there cannot be atoms, or any indivisible parts of bodies, *as some Philosophers have fancied*…From that we know clearly and distinctly that some thing may be divided, we must also *judge* that it is dividable.

And the infinite power of the Creator is brought in to help; if God had reduced some part of matter to such an extreme smallness that "it could not be within the power of any creature to divide it, still He could not have deprived himself of that power." (*Principes*, *OCRD*, IX, 74). Here we may remember Tempier's *Article 63*: "God could not produce the effect of a secondary cause without the help of this secondary cause." We may agree in principle: those atoms which came back into fashion two centuries after *Les Principes,* have turned out to be not so in the etymological sense. Just the same, they have remained excellent tools, never obsoleted by our ceaseless quest for elementary particles. Contrary to Descartes beliefs, most of science was to be built on such insecure foundations while all that Cartesian matter, subtle or not, has remained a physically useless masterpiece of logic. Here, just as in his banishment of vacuum, Descartes remained a member of that School he was convinced to have destroyed.

In the fourth part of *Les Principes*, devoted to *La Terre* (the Earth), the structure of Cartesian matter is used to explain a large number of physical or chemical phenomena. Here are a few, in the (most revealing) order of the text: light, heat, transparency or opacity of bodies, structure of the Earth, air, water and ice, quicksilver and vitriol, salt or metal mines, sulphur, bitumen, mineral oil and clay, earthquakes and volcanoes, fire and thunder, luminescence of rotting wood and shooting stars; why firewater burns while water does not; gunpowder and glass; and magnets, the amazing properties of which deserve a thorough study, together with that "strange attraction of amber, jet, wax and glass." (*Principes*, *OCRD*, IX, 201–325). These pages will not be followed here: our interest lies in the Cartesian vortices, a purely cosmological device which is not required to understand any mechanical phenomenon or experiment on the surface of the Earth, except for gravity and the tides. Thus Descartes, while firmly believing in homogeneous physics throughout the Universe, did not actually try to demonstrate his own brand in the laboratory.

Vortices Operate the Entire System of the World

In Descartes' own words:

> What are the assumptions?… All bodies that constitute the universe are made of the same matter… divided in several parts that are differently moved, their motions are in some sort circular; and there always is an equal quantity of these motions in the world.
>
> He is unable to determine the size of these parts:
>
> These things may have been organized by God in an infinity of diverse ways; only from experience and not through reasoning may we know which one He has chosen.
>
> Still, he feels himself entitled to select as the most likely hypothesis
>
> parts as equal between themselves as they might have been, with sizes intermediate between those which today constitute the heavens [*cieux*] and the celestial bodies [*astres*]… all have

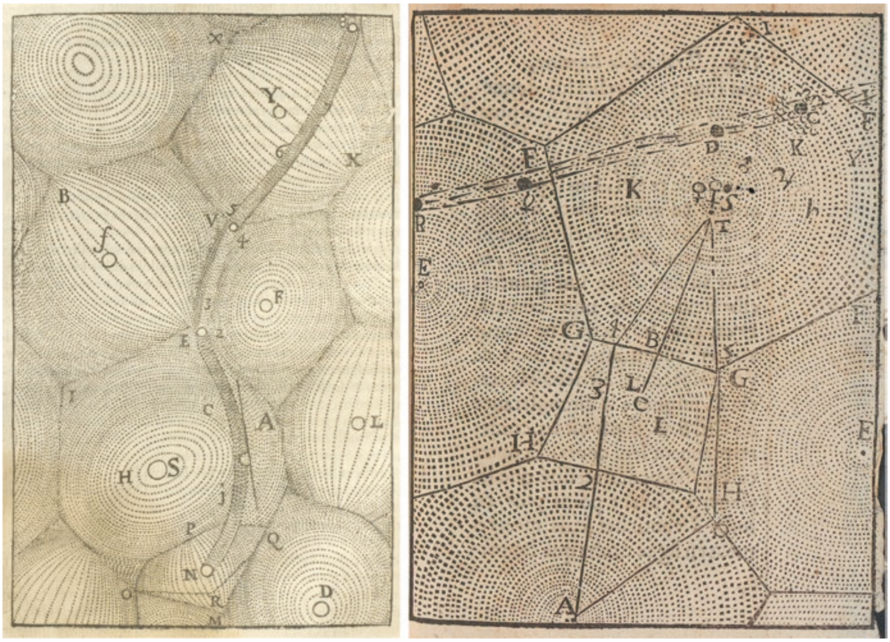

Figure 11.2 Left: Vortices from *Principia*. Right: Vortices from *Le Monde*, emphasizing the planets of our own solar system. Straight lines to T (the Earth) are rays of light from other stars. The cluttering dots represent subtle matter, not orbits, and the two wavy bands show the path of a comet. www.e-rara.ch

> started by moving with equal force in two different manners, namely each around its own center… then several together around some centers… disposed as we see presently the fixed stars…in such a way they have produced as many different vortices [tourbillons] (*from now on I will use that word to mean all the matter that revolves in circles around each of these centers*) as there are celestial bodies [*astres*] in the world. (*Principes*, *OCRD,* IX, 524-5).

Hence, the essential similarity between all these vortices is stressed from the start.

Let us consider figure 11.2 left, and use modern language. Descartes adopts a three-dimensional, random and homogeneous distribution of stars, of which the Sun is merely one; here, he overtakes Kepler. He partitions Space in cells roughly centered on stars; their sizes are unequal but of comparable magnitudes. Their shapes are polyhedral, since no vacuum is permitted anywhere, but the exact shapes of the frontier surfaces are not specified; on two plates they are represented by straight lines, on another by curved lines. The system looks much like a conglomerate of soap bubbles, but Descartes is not interested by such an analogy, since within any bubble agglomeration no whirling motion is observed. Each star lies close to the center of its own vortex; the solar vortex fills up its own cell, and carries along all planets; the Earth vortex carries the Moon, and the Jupiter vortex its four satellites, but these secondary vortices are not shown in this plate. Next, the three elements, already described in *Le Monde*, are recalled, together with their main properties as far as visual appearance is concerned. The first element emits light and is used for the Sun and the fixed stars; the second is transparent and constitutes the matter of the vortices themselves; the third reflects light, and makes up Earth, planets and comets. The only remarkable feature of the vortex centerd on S (the Sun) is that "this is the one where the Earth, our home is found, thus we are able to notice far more things inside than within all others" (*Principes*, *OCRD*, IX, 130); it will be stressed later in the second half of Figure 12.2.

The vortices of different stars appear to be more-or-less randomly oriented: "The poles of some of these vortices touch the parts farthest from the poles of some others." The plate attempts to present a plane cut of the 3-D system; even so, the description remains confusing. The first vortex, centered at S, revolves from A to E and I; the F-centered one from A to E and V. Another, centered at f, has its axis EB in the figure plane. The small dots, which clutter all vortices, symbolize particles of subtle matter; when they form an oval, the vortex axis of rotation is roughly perpendicular to the figure plane, and roughly within it for open curves. Descartes attempts, not very successfully, to have all motions agreeing along borders, and has to confess that no exact solution exists: three *Eclyptiques* (we would rather speak of equators) cannot just meet at E where the pole of the fourth EfB vortex is located, and "the motions of these vortices have to be distorted a little in order not to oppose each other." Even so, two vortices are not allowed to meet by their poles: if they were of the same polarity, both would fuse; if not, they would "hinder each other extremely." They cannot be of the same size, because of "that incomprehensible variety which appears in the positions of the fixed stars." Altogether, Descartes is delighted by the cleverness of his own construction: **"**I do not believe anything better might be invented to make the motions of several vortices fit together." (*Principes,* OCRD, 136–8).

Descartes has a qualitative understanding of centrifugal force; hence, first-element matter leaks out of the equator of each vortex, and conversely leaks in through its poles; there is a continuous inter-vortex flux, reaching down the centers, while the less-subtle second element does not penetrate quite as far. The motions of all three types of matter are able to explain many cosmological features; for instance, the Sun is like a red-hot glass bottle in which air is blown through an iron tube, and "the first element which enters the Sun through its poles must push equally on all sides the parts of the second…", thus the round shape of the Sun is explained. There is a relationship between first-element motion and light emission, none too clear to Descartes himself: "the matter of the first element contributes to the action, which I believe to be taken as light." Which implies a puzzle because "the Sun does not send light only to the Ecliptic [of the Vortex], but also to the poles." (*Principes*, *OCRD*, IX, 144–5). The resolution of the difficulty is laborious (as in many of the other cases) and will not be followed here. We will concentrate on two problems, which Descartes is convinced to have conclusively solved: gravity, and planetary motions.

First, what about gravity? While preparing the *Principes*, Descartes writes to Mersenne: "It is certain that if the subtle matter that revolves around the Earth was not revolving, no body would have weight." (*Letter to Mersenne*, Dec 251,639, *OCRD* II, 635). Why this unprovoked statement? Because the Earth-centered vortex of subtle matter provided that fundamental explanation of gravity Galileo had never bothered about, and the lack of which made nonsense of his fall of graves study. For Descartes, weight is unthinkable as an intrinsic property of the falling body, as it would be a mere Peripatetic occult quality; and equally so as a force exerted by the Earth, any force at a distance being no less occult. No cause of any kind may deviate a moving body from uniform straight-line motion except collisions; happily, subtle matter is available to provide as many as needed. Before studying gravity, the rather unexpected starting point is an explanation of what we call capillarity: "This celestial matter… makes the drops of all liquors round when wholly surrounded by air or another liquor… as already explained in my Meteors." (*Principes*, *OCRD*, IX, 211). The mechanism appears to be a sort of pressure exerted by subtle matter, leading to a spherical surface of equilibrium as the one which least hinders particle motions. Only then does he feel free to tackle gravity itself, for which the proposed mechanism is comparable. The reader of today is not convinced: the Earth centered gravity appears a consequence of the Earth vortex, but no mini-vortex is described as active around any drop of water.

If the Earth was not surrounded by some suitably resisting medium and nevertheless kept revolving, then "all its parts not intimately joined would fly away to the heavens just like the dust one throws upon a top… all terrestrial bodies might be called light rather than heavy." (*Principes, OCRD* IX, 211). Actually, celestial matter revolves much faster than the Earth itself, thus tends to fly away; but as it cannot leave any place empty, earthly matter falls down to replace it; the situation is not unlike that of a solid body sinking within a less-dense fluid, and "it is the lightness of that celestial matter which makes terrestrial bodies weighty." Thus, the centripetal gravity of heavies is an automatic consequence of the centrifugal force acting on celestial matter because of the vortex rotation. However, this explanation entails a serious difficulty: weight generated in this way should not be directed towards the center of the Earth, but perpendicular to the polar axis, thus increasingly oblique at high latitudes. Distant disciples like Claude Perrault and Huygens will be very conscious of that oblique-gravity difficult problem and propose solutions (Aiton 1972, 76).

Criticism of Cartesian gravity is easy today, but the redeeming points should not be forgotten. First, it is universal: since all celestial bodies are endowed with vortices of their own, they also have their own local gravities, which proves a great improvement compared to the Peripatetic view. Admittedly, Kepler had also reached that picture; but even Kepler did not anticipate a reduction of weight with increasing altitude, while Descartes does, asking in a *Letter* whether "…a body weighs more or less when near the center of the Earth or far away." (*Letter to Mersenne* July 131,638, *OCRD*, II, 222). Furthermore, he proposes a test with a great future: go to the top of a tower and measure the weight of a lead block, first on one dish of a pair of scales in a normal way, then hanging the block with a long wire. Unknown to Descartes, Francis Bacon had already considered a possible decrease of gravity with altitude, and proposed a different, well conceived experiment but non feasible at his time (Bacon, *Novum Organum*, II, 36, p. 166 in *GBWW*, vol. 30). Hooke tried Descartes' experiment, also without success (see Chapman 2005, p. 200).

Two-hundred years later, Von Jolly succeeded in the Munich University tower; with 5 kg masses and a 21 m height he measured a 31 mg change in weight (see Poynting 1894).

A further sensible argument is that

> planets…being as is most probable, bodies of the same matter as the Earth…they should have weight and fall to the Earth except for their large distance, which removes from them the tendency.

However, he has no feeling for the orders of magnitude involved, and we are less impressed to learn that

> large birds like cranes, storks etc… find it much easier when flying high rather than low…this is also confirmed by these paper dragons flown by children, and all that snow in the clouds… If that experiment you wrote me about is true, that cannonballs shot straight to the Zenith do not fall down, one must conclude that …they have entirely lost their weight. (*Letter to Mersenne* July 13 1638, *OCRD*, II, 222).

This Descartes' belief that birds lose weight when flying higher may have been common at the time: it was at least shared by Hooke and Wilkins. Indeed, they do; but more than gunpowder was to be involved, and Isaac Newton, Jules Verne and *NASA* had to play their bits before that cannonball reached weightlessness. The kindest possible presentation of the Cartesian vortex today is to treat it as a primitive and wholly-qualitative precursor of our field of forces.

Planetary motions are not explained by solar gravity, but both motions and gravity have the solar vortex for a common cause; likewise, the Moon is carried along by the Earth-vortex. The motions themselves, never described in any detail, are Copernican but of the crudest kind: Descartes is not interested in eccentricities nor inequalities of any kinds, as he concentrates on the hidden causes which he does not doubt to have found out.

How are these vortices constructed? Today's reader longs for some plain description of their main properties, like velocity and/or density, with analytic geometry providing some simple graphs in (why not?) Cartesian coordinates… Alas, such is not the Descartes way, and meager information has to be gleaned from many scattered passages. The least-unsatisfactory exposition is found in *le Monde*, from which figure 11.2 (right) presents much the same vortices as *Les Principes*, but stresses our own solar system. The near-circular dotted lines are meant to represent circulating particles of subtle matter, but the planetary orbits are not shown. Dotted straight lines between vortices, boundaries; they represent "surfaces without thickness" and are called *firmaments*; A, E, ε are the nearest stars. Planets are identified by their old astrological symbols, except for the Earth T *(Terre)*, which had never received one, not being a celestial body. KK marks the sphere of Saturn, most distant planet. However, the drawing is not a true map with a definite scale: the boundary is actually "two thousand or three thousand times more distant" than KK, which is "but a point relative to the firmament;" this means that Descartes was aware of the absent stellar parallax difficulty.

Descartes' goal is a simultaneous explanation of the motions of planets and comets; his main trouble is that the fastest planets are closest to the Sun, while he locates

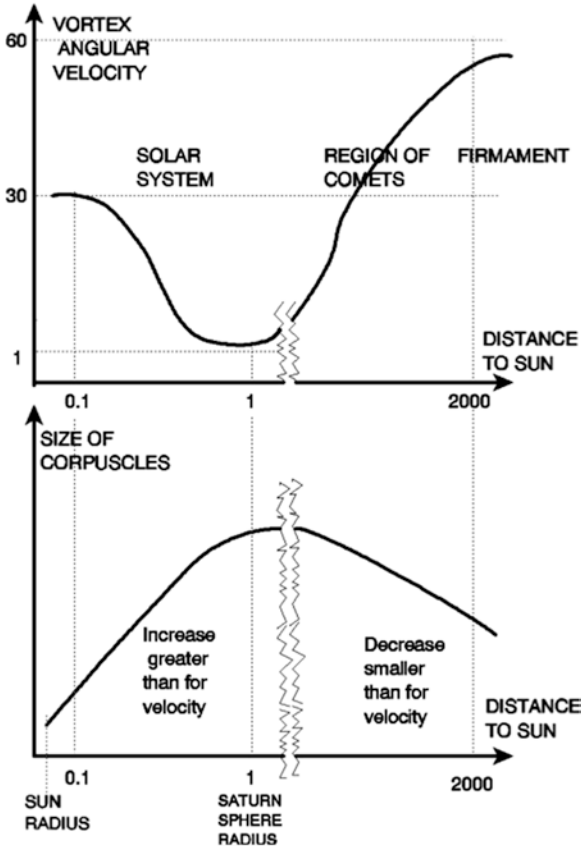

Figure 11.3 The Cartesian solar vortex properties presented in Cartesian coordinates, i.e. a somewhat-risky attempt at quantifying the Master's thought

comets beyond Saturn despite their even-faster apparent motions. Clearly, the vortex distribution he fancies is an *ad hoc* one intended to solve that difficulty, and he does not harp on the obvious fact that such a vortex is quite unlike any other seen in Nature. Linear velocities are not considered, as they seldom appear in Cartesian mechanics anyway. Only numbers of revolutions during a given (but unspecified) time are discussed; the time taken as reference is that for sphere KK that seems to be the Saturn orbiting period. Our figure 11.3 attempts to describe the solutions adopted by Descartes in terms of particle sizes and of number of revolutions, all from semi-quantitative statements: at a distance of the Sun equal to that of the Earth, the number of revolutions is "maybe more than thirty times as large", and at the firmament "maybe more than sixty"; thus, it is minimum for Saturn. As to the particle sizes, in the outer part, between firmament and sphere KK, they are either constant, or (maybe) slightly decreasing away from center; in the inner part, from the Sun to KK, they increase either in inverse proportion to the velocities or faster; no choice is made between the two possibilities, and no reference size is given. No law of variation with solar distance is hinted at in either case; the sole numerical quantities taken from professional astronomy are the ratios of the Saturn/Earth orbit radii, which is equaled to 10 (modern figure 9.54), and that of 30 for orbit periods (modern 29.4). The figure of "maybe more than sixty" for the firmament seems arbitrary, and no use is made of the well-known solar rotation period.

Descartes wastes no time in any specific description: precise geometry is no more needed for the vortex than for the planetary orbits themselves. Next he shows that his system also explains transient cosmic phenomena: novae and comets, subjects that had made no marked progress since Kepler's time. "How does it happen that a new star suddenly appears in the Heaven?" Here, explanations are so detailed that it would be hard to do them full justice; it is all a question of vortices pressing against each other, expanding and contracting, and obscure matter getting in the way; sunspots are generated through similar mechanisms. Furthermore,

> fixed stars may become comets or planets… when a celestial body [*astre*] begins to be moved by the influence of some nearby vortex… [either] it ascends to the circumference [of its own Vortex] and enters another one, and is thus changed into a comet,… [or] it descends lower than the place where the parts of the vortex move slowest [i.e. sphere KK, roughly that of Saturn]…and thus it will be transmuted into a Planet. (*Principes*, *OCRD,* IX, 172-3).

The actual motion (hence the ultimate fate) of the star is largely a matter of its original density, called solidity: "…I mean by solidity of that celestial body the amount of third matter, including spots and surrounding air, of which it is built." (*Principes*, *OCRD*, IX, 174). And from such hypotheses, Descartes is able to explain the origin of the solar system: "How all the planets might have been formed?" (*Principes*, *OCRD*, IX, 194). Simple enough: all planets and satellites derive from ancient vortices, while they became obscure through an accumulation of dark matter essentially similar to sunspots.

Comets are studied in depth. On Figure 11.2 left, N marks the birthplace of a comet; the comet body is "more solid than the parts of the second element" (Principes, *OCRD*, IX, 177) which surround it. Apparently this mini-vortex OPQR is in the process of collapsing; vortices are maintained by the emission of light (an anticipation of light pressure) from their central star, and if that star is obscured by too many spots, the vortex is destroyed (*Principes*, *OCRD*, IX, 170). From this origin, the comet describes a curved orbit within our solar system (centered at S), but finally escapes at E, beyond which point it is allowed to proceed through the next vortex, escaping again at V, etc.….. Descartes calls attention to two specific points:

> The first is that when this body passes from one vortex to another, it always pushes in front some of the matter from the one it is leaving… the other is that the path of the body is variously curved according to the various motions of the vortices… (*Principes*, *OCRD,* IX, 178-9).

Indeed, the orbit always turns its concavity towards the local vortex center; of course not from any attraction of the star, but solely because of collisions with orbiting subtle matter.

Why do comets seem to vanish as soon as they get out of our vortex while we do see neighboring stars? Mostly because "the light of the stars, proceeding from themselves, is far stronger and more vivid than that of comets, borrowed from the Sun"; and Descartes uses the opportunity to remind the reader that these are *"…stars in the number of which I also place the Sun."* (*Principes*, *OCRD*, IX, 181).

Why waste here paper by following such bizarre interpretations, never taken seriously by any astronomer (nor optician) of note? Because the Cartesian view of comets strengthened his concept of universal homogeneity. By wandering freely from vortex to vortex with similar orbits within each, comets helped to demonstrate the essential similarity between neighboring stellar systems.

Not merely comets are involved. Seen today, the entire vortex edifice is arbitrary, ill fitting, and unable to provide a single quantitative explanation. Nevertheless, Descartes started from, and ended with, an essentially correct distribution of stars; Kepler, the thorough professional (and using the best available data) had reached completely wrong conclusions because he was misled by false notions about stellar apparent diameters. Descartes, wholly innocent of technical astronomy, did not even guess that such parameters might be relevant to his problem and thus escaped the difficulty, mentioning (as usual) neither observations nor sources from the literature. In essence, the Keplerian enclosed bubble did not please him, because it would have required an unthinkable vacuum outside; also, he adopted the homogeneous Universe, hence Sun-like stars (which soon gathered their own planetary retinues) because he was so pleased with his model of our own Solar system that he wanted similar vortex mechanics operating throughout the Universe. Just like Bruno, he chose the solution best suited to his *a priori* beliefs.

Did he proceed further, and envision his vortices as possible Other Worlds? Never in any printed text, but he wrote in a private *Letter*:

> I remember that Cardinal Cusanus and several other Doctors have supposed the World to be infinite without being reprimanded by the Church on the subject… I fail to see why the Incarnation mystery & all the advantages given to Man by God prevent Him from granting an infinity of very-large other [Worlds] to an infinity of other creatures. While I do not conclude that this point leads to other intelligent creatures on stars or anywhere else, I do not either see any reason to prove that they do not exist. (*Letter to Chanut*, June 6 1647, *OCRD* V, 51).

Thus, he did reject the theological objections for attributing to Man a privileged central place, and refused that old Incarnation argument through which Augustine had made the antipodes barren; but he did not proceed to people Vortices with the help of his own scientific tools. Nor did Descartes ever print that our Moon or solar-system planets might harbor life. The closest he ever gets to such a speculation seems to be within a *Letter* to the lens-maker Ferrier in which, after a detailed description of an elaborate machine for fabricating hyperboloidal lenses, he adds "if you spend a year or two getting all that is necessary, I hope we shall see, with your help, whether there are animals in the Moon." (*Letter to Ferrier*, Nov 131,629, *OCRD* I, 53). Which is a mere joke; similar notions had been rampant ever since *Sidereus Nuncius*, and we shall soon find Molière illustrating them on the stage.

The Cartesian Extrapolation by Fontenelle

The engravings from *Le Monde* and *Les Principes* never show planets except around the Sun; but stars are all sun-like, comets pass from one vortex to the next, and the mechanism of planetary formation from subtle matter is universal. Had Descartes lived longer, might the comparative indolence of the Holy Office (which seemed to lose interest in such matters) have induced him to take the risk of being more specific? That speculation is idle: Cartesianism was flourishing and merely had to be followed by disciples to display the logical consequences. This will be done presently for Fontenelle, while Huygens will deserve a full chapter of his own.

The most thorough account of the subsequent vagaries of the Vortex theory is that of E.J. Aiton (1972) who follows it up to the middle of the eighteenth century, when a few attempts were still being made to derive cosmological results from vortices. This appears strange, but Newton had patently failed to provide a much needed physical explanation for his attraction: *Hypotheses non fingo*! Action at a distance remained incomprehensible, while collisions still provided an easily pictured machinery. However, the power of mathematical tools within mechanics could no longer be denied, and the limitations of *Les Principes* on that count were glaringly obvious. Hence many features were added to vortices, the most notable being those of Leibniz, who had unrestrictedly adopted the Keplerian Laws, but still rejected Newtonian gravitation. They will not be followed here, our interest in Vortices being that, as constructed by Descartes, they did provide both room and reason for multiple planetary systems no farther out than the nearest stars. Technical refinements of the said Vortices are of little concern, and the question now turns to: planetary dwellers or none? The Master had remained mute on the subject, but disciples will be eloquent. The most famous was Bernard le Bovier de Fontenelle whose *Entretiens sur la Pluralité des Mondes*[6] have remained a minor classic studied in all French *lycées,* although more for the elegance of its seventeenth-century prose (sometimes announcing Voltairian irony) than for scientific content or relevance.

Fontenelle indeed was more writer than scientist, but "played a leading role as interpreter of science not only to the lay public but to the scientists themselves… His role was not that of an amateur, but of a professional participant in the life of

[6]The complete works of Fontenelle have been published as *Œuvres Complètes* (referred to as *OCBBF*); the *Théorie des Tourbillons Cartésiens* (hereafter referred to as *Théorie*) occupies Volume VII. However, most of our quotations of the *Entretiens* will be translations from the modern critical edition by Alexandre Calame, which differentiates the many successive Parisian re-editions from 1686 up to 1742; this is important because the Huygens *Cosmotheoros* appeared in 1697. Fontenelle's success was such that three English versions of *Entretiens* appeared within two years of the original; a *fac-simile* reprint of the 1688 one by a "Mr Glanvill" is available in *The Achievement of Bernard le Bovier de Fontenelle,* with a comprehensive *Introduction* by L.M. Marsak (1970), much used here in our brief account of Fontenelle's role and thought. Glanvill himself is not identified by Marsak, but is perhaps the Joseph Glanvill discussed by Mac Colley (1936, p. 423). The most recent English version is *Conversations on the Plurality of Worlds*, translated by H.A. Hargreaves, which also gives a useful *Introduction*, plus a full Fontenelle bibliography. Surprisingly, Mac Colley (1936) does not mention Fontenelle at all.

science." (Marsak 1970, p. cvii). The *Entretiens* are still considered a model of intelligent science popularisation, with no hint of science fiction; the author's extensive writings show he was also a good historian of science in his own time, and a non-negligible philosopher. His attitude to Descartes he described himself when criticising some "philosophy teachers who were Cartesians as committed to Descartes as the scholastics had been to Aristotle… we must always admire Descartes but follow him only occasionally." (*Théorie, OCBBF,* VII, 213; quoted by Marsak 1970, lxvii). Much unlike Descartes, and as far as had become possible in his time, he showed himself to be a freethinker and almost a Christian deist. His philosophical outlook is essentially nominalist and empiricist: ideas start from experience, and he is ever asking for more scientific observations; metaphysics and even pure logic are useless. He was to praise Newton as an experimenter while utterly rejecting universal gravitation as based on incomprehensible premises, thus he remained bound to Cartesian physics. Such is the ground upon which he erected his own Plurality, fated to become better remembered (at least, within France!) than all variants so far visited.[7]

Fontenelle, born a few years after Descartes' Stockholm demise, wrote his *Entretiens* in 1686, that is one generation later, and they made him immediately famous. The device used is that of an elegant dialogue between an imaginary Marquise, devoid of any scientific knowledge but quick-witted and brimming with interest, and the author posing as a man of the world well aware of all latest astronomical results and theories. Which, however, solely means the Cartesian ones: unlike for Galileo's *Dialogo*, no hint of controversy is found in the *Entretiens*, and the Marquise's role never rises above that of literary tool. As already stressed, Fontenelle himself is not a first-class scientist; still he was to make a serious attempt at bringing Descartes up to date in his *Théorie des Tourbillons Cartésiens*, which (unlike the *Entretiens*) was not written for the general public. According to our invariable plan, we have to start from the author's views on physics and cosmology before presenting his concept of Plurality. However, this approach carries in the present case a clear difficulty: the above *Théorie* was printed in 1752, sixty six years after the *Entretiens*. Still, some allowance should be made for the fact that Fontenelle published the said *Théorie* at the mature age of 95 (he died almost a centenarian), and the text repeatedly shows that his concepts had become frozen long before reaching print. Hence, even if a severe anachronism is committed when using the *Théorie* before the *Entretiens*, there is no involved absurdity.

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[7] The *Entretiens* were at once put on the Catholic Church *Index Librorum Prohibitorum*, and the subsequent history of the case is picturesque. According to A. Calame in his *Introduction*, they were taken off in the 1825 and 1878 versions, and even reprinted within a Catholic publication with the apostolical benediction of Pius IX in 1859. However Leo XIII put them back on the *Index* in 1900, which is frankly puzzling. Might the reason be that his main philosophical concern was a return to Thomism, and that (as seen in our *Scholastics* chapter), Aquinas had been distinctly hostile to Plurality, and condemned by pro-Plurality Tempier? Whatever the true explanation is, good old Fontenelle still figures in the last *Index* edition, that of 1944, which leaves us wondering. Had that *Index* not been suppressed in 1966, would the pioneering papers of *SETI*, those of Cocconi & Morrison, Sagan, Drake etc.… have been included?

Thus, we discuss the *Théorie* first. Fontenelle's full title is *Theory of Cartesian Vortices with thoughts on Attraction,* since (more than half a century after Newton) attraction could not be altogether ignored. Hence he presents a somewhat modernised vortex system, incorporating modest attempts at introducing mathematical formulas, plus the latest astronomical discoveries, tirelessly repeating all the way that attraction cannot provide a true cosmological explanation. The starting point is fully Cartesian, since his very first article of faith is "I suppose an absolute *plenum*" (*Théorie*, *OCBBF*, VII, 383): neither Torricelli nor Pascal nor Otto von Guericke had made the slightest impression on true disciples of Descartes. And the rationale for introducing vortices remains as pioneered by the Master: matter extends to infinity and fills all space, hence no motion is possible except along closed-circuit courses; moreover, these logically-deducted vortices are still the only tools required for driving planets and satellites along their orbits.

God's Will remains the Universal Cause: "All motion is an action of God on matter", but God acts only through intelligible means, and matter endowed with attraction is just as unthinkable as matter possessing thought:

> Newtonians may say that, just as bodies move only because of God's Will, it would be possible that, through this very same Will, they would mutually attract, but the difference is extreme: in the first case, God's Will solely makes use of an essential property of matter, mobility, and inclines to motion the natural indifference [of matter] to rest or motion. In the second, one fails to see that bodies should have by themselves any tendency to attract each other; God's Will would have no connection to their nature, and would be purely arbitrary, which is most opposed to everything that the order of the Universe offers on all sides. Admitting such arbitrariness would ruin the whole philosophical proof of the spirituality of the soul: God might as well have given thought than attraction to matter.

Moreover, calling-in attraction is a poorly-disguised return to Aristotle & C:

> If one says that mutual attraction is an essential property of bodies even if we do not see it, one might say as much of sympathies, horrors and of all that constitutes the opprobrium of ancient scholastic Philosophy.

Even worse, that inverse-square-law attraction involves a technical absurdity:

> It will also follow that this force becomes infinite when the distance is nought, or when the bodies touch, which is not conceivable: there would then arise between the bodies a cohesion that no finite force might be able to break… this will easily be seen provided one is a Geometer. (*Théorie*, *OCBBF*, VII, 454-6).

Hence, Newton's calculation of a finite Earth-surface gravity, which fully solves that problem, is simply ignored. However, it must be granted that gravitational attraction at very short distances still poses delicate theoretical and experimental problems today.

While the Descartes physics are never openly criticised for remaining strictly qualitative, Fontenelle does see the need to introduce at least some mathematical formulas. For instance (and unlike his Master) he adopts the Galilean law of the fall of graves, but he explains it in Cartesian terms:

> The Galileo system of gravity is very easily deduced from our principles…the initial velocity of any body falling from any height is the true measure of the general centrifugal or

> expansive force of the vortex, that is of the reigning gravity. One knows by experience that in the solar [rather terrestrial?] vortex this velocity is 13 feet 8 lines and a little more per second. (*Théorie, OCBBF,* VII, 408-9; the velocity is that after the first second of fall).

And he proceeds to revisit that venerable hole-in-the-Earth thought experiment, which Descartes had missed; he has some understanding of friction, and concludes that the dropped body will finally stop at the Earth centre; however his main interest lies in the demonstration that at this point "it will be absolutely without gravity, since gravity is not an inherent nor essential quality of the body."

Fontenelle is enthusiastic about Kepler's Laws:

> …if two planets are in two different layers, their velocities around the sun will be in inverted ratios of the square roots of their distances to the Sun. Such is the famous Kepler rule, adopted by all astronomers, which has become the fundamental law of the heavens. (*Théorie*, *OCBBF,* VII, 397).

Moreover, and very much unlike Descartes, in many instances he is willing to consider times and velocities; also, the term *masse* at long last appears in a French text, though it does not yet mean anything more specific than quantity of matter. Another considerable tool available for building these modernised vortices is the mathematical expression for a quantity Descartes had qualitatively introduced: centrifugal force. The correct formula had been given by Huygens in his *Horologium Oscillatorum*, for which he is lauded by Fontenelle almost as much as Kepler and right after him:

> On another side, M. Huguens [sic] has very ingeniously discovered the expression of the law for centrifugal force, adopted by everybody, but because it had been well-proven by geometry.

And that geometrical proof gives him an opportunity for praising Huygens, and also for downgrading Newton!:

> One has proved not merely that centrifugal force contains the square of velocity, but why it does so in a necessary manner. Here, I am asking why does attraction follow the squares of distances rather than any other power? I do not think this would be easy to say. (*Théorie*, *OCBBF,* VII, 457-9).

An apt question, and indeed an immensely difficult answer, to be discussed in our Huygens chapter. Fontenelle will manage to pursue his feud with attraction in his *Elogium of Sir Isaac Newton,* London, 1728 (*facsimile* copy in *Isaac Newton's Papers…*, edited by Bernard Cohen, 1978): "It is not known in what Gravity consists. Sir Isaac Newton himself was ignorant of it…".

Fontenelle, unlike his Master, is aware of such basic astronomical features as orbital ellipticities and Earth-axis precession. Both are explained by "jets of foreign matter" (Théorie, OCBBF, VII, 436), expelled by neighbouring vortices; in both cases, he does not mention the definitive explanations provided by Newton, and his own are again hopelessly qualitative. Next, we are rather amused to see a Cartesian rediscovering classical Newtonian phenomena without saying so, and presenting them in his own light. One of the most famous Newton predictions (or should we say inventions?) has been that of the low-orbit artificial satellite: a cannon ball, shot up horizontally from the top of a high mountain with the right velocity would circle the Earth in 90 minutes, all under the influence of universal gravitation. Fontenelle distinguishes between the "solid rotation" of the Earth atmosphere taking place in 24 hours, and the "fluid rotation of ethereal matter" which constitutes the Earth vortex. To these subtle particles he is willing to apply Kepler's third Law, and concludes correctly that "…they should have made their circuit in 1 ½ hour, judging from the circulation that the Moon, satellite of the Earth, makes in 30 days." And when next considering the Earth vortex action at different altitudes, he even comes close to inventing the geo-stationary satellite! He simply tries to find the altitude at which "both velocities [i.e. solid and fluid] pass through equality; this must take place between the circles which have 6 or 7 for radii" (*Théorie*, OCBBF, VII 446–7), a perfectly correct result. The idea had probably been taken from Jean-Dominique Cassini, the Paris Observatory astronomer who was another Cartesian (Aiton 1972, 244–245).

Fontenelle also knows all the latest astronomical discoveries, which means that his view of the solar system is far more complete and accurate than that of Descartes. First, thanks to the 1672 estimate of the parallax of Mars by Cassini and Jean Richer, planetary distances had at long last become approximately correct: the Ptolemy figure, still used by Galileo, had been about 20 times too small. In Fontenelle's words "… the Earth is 30 million leagues from the Sun… Mercury 13 million and Saturn 300 million." (*Théorie, OCBBF*, VII 423). The important consequence is that the diameters of all planets had ever been underestimated, and Earth had so far appeared exceptionally large; from now on, it is understood to be an intermediate-size planet. Moreover, thanks to Keplerian eyepieces plus screw micrometers (invented independently in England by William Gascoigne and in France by Adrien Auzout), the apparent diameters of all planets had now taken values very close to the modern ones. As to the telescope objectives, they still remained single lenses plagued by chromatic aberration; but, compared to those of Galileo, they had become far larger, better polished and made of more homogeneous glass. Hence Fontenelle is able to list five satellites of Saturn; he knows about the spots and various surface markings of Jupiter and Mars, together with their correct rotation periods, plus that amazing Saturn ring discovered by Huygens and already split in two sections by Cassini.

From these revamped Cartesian mechanics and a very limited use of mathematical formulas, plus improved telescopic observations, Fontenelle was able to give a more specific picture of vortices than Descartes. They are built-up of concentric *couches* (layers), sliding upon each other, each with its own rotational velocity. The obvious difficulty of inter-layer friction is airily dismissed: "…the fluid may be composed of such subtle parts and so little interconnected, that the friction trouble will disappear; moreover, the velocity difference may be very small." (*Théorie*, *OCBBF*, VII 395). However, no demonstration we would consider adequate is ever presented; Fontenelle calls in centrifugal force "according to the formula m x u^2 / r" but fails to make any intelligible use of it. A mathematical description of the vortex phenomenon was far beyond his ability, and d'Alembert who attempted it at roughly the same time, had wholly given up Cartesian vortices. The obsolescent character of Fontenelle's *Théorie* at the time of publication in 1752 is clear: the Paris Observatory library treasures a copy of the *Entretiens* in their original 1686 edition, but never bothered to acquire one of the *Théorie*.

Unfortunately, Fontenelle does not provide a single drawing of his own vortices; still, he uses some analogies, which at least make the scene clearer than the one rather confusedly described in the *Principes*. He comes close to the soap-bubble picture:

> One may imagine that the Universe, as far as known to us, is a cluster of large balloons, of large springs pressing against each other, inflating and deflating, and having a kind of alternate inspirations and expirations, similar to those of animals; which will be the life of that immense body. (*Théorie, OCBBF*, VII 434).

The Master would have hated that zoological analogy, dangerously close to an explanation; and worse sins against the Cartesian spirit will soon be committed by the disciple, as teleological arguments will be back in droves under his pen.

Such are the physics, and the astronomical data, on which was to be based the best-remembered attempt to introduce a Plurality of Worlds that we have met so far; again with the restriction that no one knows how much of the 1752 *Théorie* Fontenelle had yet evolved when he gave his *Entretiens* in 1686. Still, there is no doubt that Kepler and Galileo laws, Huygens centrifugal force and correct planetary sizes had been available to him at the time. As to the Newtonian *Principia*, they were published a year later and he cannot yet have seen the text; which matters not at all since he never made any use of it later. What does matter is that his own book became so popular that, even in today's France, the words *la Pluralité des Mondes* instantly evoke Fontenelle's name to the layman.

We are now ready to tackle the *Entretiens* themselves, using at first the translation by a "Mr. Glanvill", which appeared barely two years later, with the Marquise promoted to Countess. The very *First Evening* gives the tone by presenting the Cartesian and rationalist view of the Universe with a fair dose of wit:

> Suppose then the Sages at an Opera, the Pithagoras's, the Plato's, the Aristotle's, and all the Wise men who have made such a noise in the World for these many Ages: We will suppose 'em at the Representation of Phaeton, where they see the aspiring Youth lifted up by the Winds, but do not discover the Wires by which he mounts, nor do they know any thing of what is done behind the Scenes…. One tells you Phaeton is drawn up by a hidden Magnetick Vertue, no matter where it lies… another says Phaeton is compos'd of certain Numbers that make him mount… a third tells you Phaeton has a secret love for the top of the Theatre, and like a true Lover cannot be at rest out of his Mistresses Company, with a hundred such extravagant fancies…. But now comes Monsieur Descartes with some of the moderns, and they tell you Phaeton ascends because a greater weight than he descends… I perceive, said the Countess, Philosophy is now become very Mechanical. So mechanical, said I,… that they will have the World to be in great what a Watch is in little; which is very regular, and depends only upon the just disposing of the several parts of the movement. ("Mr Glanvill" translation in Marsak 1970, 9-10).

Erected upon such a ground-base, the Plurality of Fontenelle compared to that of Bruno stands like modern atomic theory compared to ancient atomism: in between, the whole seventeenth-century scientific revolution has taken place.

The rest of the conversation acquaints the Marquise-Countess with the outline of Copernican astronomy, and the reader with the interesting fact she is a blond beauty; as we already know the Fontenelle cosmological picture from his *Théorie*, we may pass to the *Second Evening*, which proceeds far beyond Descartes by introducing lunar inhabitants. To a large extent, also beyond Kepler, for whom both *Subvolvans* and *Privolvans* had remained tools within a pedagogical novel, intended to make Earth rotation manifest to humans by presenting an outsider's viewpoint. Fontenelle, even if discoursing for men of the world, is not writing a novel and shows himself strongly tempted to believe in lunar life, but still uses suitable caution. For him, the absence of direct telescopic evidence is not compelling: the situation is much like that of a Paris burgher looking at Saint-Denis from the Notre-Dame towers, and claiming it is empty of life since he sees none whatsoever; at which point the Countess retorts "We are not all sure so silly as your Cockney" (Glanvill, 37), since in the act of crossing the Channel, Paris and Saint-Denis have become London and Greenwich, and the Parisian burger a solid Cockney. Then Fontenelle calls in the authority of *"L'illustre Monsieur Cassini, l'homme du monde à qui le ciel est le mieux connu"* which Glanvill transmutes to "Mr Flamsted [Flamsteed], one of the most Learned Astronomers of our Age."[8] He would certainly have translated chauvinism by jingoism, had both words been invented; after this anti-Gallic outrage, we shall give him up and provide our own translations from the original.

Selenography had progressed since the days of Galileo and Kepler, but some interpretations remained rather fanciful: "Mr. Cassini… has discovered on the Moon something that splits in two parts, next reunites and then gets lost in a sort of Well. We may confidently trust this is a River." (*Entretiens,* 60*).* No clouds are ever seen, but "vapours on the Moon will not gather as clouds nor fall back as rain: they will merely produce dews." (*Entretiens,* 79–80*).* Altogether, lunar appearances are compatible with a very subtle atmosphere: "we find that our own is mixed with much thicker and more consistent vapours than the one of the Moon. Thus, a lunar Inhabitant reaching the edge of our World, would drown as soon as entering our Air, and we would see him dropping dead to Earth." (*Entretiens,* 81). And, conversely, "our Air is not breathable for us throughout its whole extent: some say that it is already no longer so on top of some Mountains." (*Entretiens,* 82). All of which bodes ill for communication; still, the author is optimistic, People from the Moon perhaps already know how to make small trips in the Air, while in our own case "the art of flying is only being born now [sic]; it will be perfected, and some day, we will go to the Moon." (*Entretiens,* 72). Which we did, and merely three Fontenelle life-spans later.

The next two *Evenings* enthusiastically put inhabitants aboard all solar-system planets, and here the *Entretiens* proceed far beyond *Somnium*. Some particulars of planets are first given, most of them correct and relevant to the subject: Mercury very hot, Mars smaller than Earth and "with days longer than ours by half an hour," (*Entretiens,* 113) Jupiter of immense size and illuminated by four satellites, Saturn with five plus

> a singular resource, unique within the entire known Universe… a large Circle and wide surrounding Ring, high enough to be almost entirely outside the shadow from the Body of the Planet, which reflects the light of the Sun to places which do not see it, and reflects it with more strength that all five Moons, being lower than the lowest one." (*Entretiens,* 126).

[8] Glanvill, 50, and *Entretiens,* 60 (M. Cassini, the man in the whole world to whom the Heavens are best known). Cassini and Flamsteed were Heads of the Paris and Greenwich Observatories respectively; between them, one finds a healthy mixture of competition and collaboration.

Whenever satellites are discussed, either by the author speaking in his own name or by the Marquise, their usefulness as illuminators is stressed: Mercury and Venus do not require any, because of their proximity to the Sun; the need is greatest for Jupiter and Saturn; Mars stands as a puzzling exception, thus

> …it must be provided for its nights with resources unknown to us… maybe Mars has very-high large boulders which are natural phosphors and store during the day provisions of light later given up at night." (*Entretiens,* 127).

Which shows that one chief tenet of Cartesianism was already being shelved, as Descartes himself would never have wielded such teleological argumentation.

There is worse to come: in Fontenelle's time, Life could not be injected to our sister planets without calling-in final causes. Basically

> …all Planets are of the same nature, all opaque Bodies receiving light from the Sun only… and having only the same motions; up to this point everything stands equal. Nevertheless, one would have to conceive that such large Bodies had been made in order not to be inhabited, that such would be their natural condition, and that an exception had been made for the sole Earth. Whoever wants to believe it, may do so; as to myself, I cannot. (*Entretiens,* 91-92).

The Creator, never explicitly mentioned in the *Entretiens*, is not called in; nevertheless, He is the one who must have been faced with this dilemma at the time of Creation, and whose subsequent choice Fontenelle confidently makes for Him without ever asking for Church permission. The eighteenth century is getting close, and those theological constraints that had been partly responsible for Descartes stopping short of extraterrestrial life, are clearly on the wane.

At the same time, efficient causes are also at work to make the resources of life boundless:

> Do not believe that we see all creatures peopling the Earth; there are as many kinds of invisible Animals as visible ones. We see from the Elephant to the Mite [*Ciron* in French], where our sight terminates; but from the Mite starts an infinite multitude of Animals to which he is the Elephant… One has seen with microscopes very small drops of Rain Water, or Vinegar or other Liquors, brimming with small Fishes or small Serpents…Expose these Liquors to the Sun, or abandon them to corruption, at once new species of Animals are generated. (*Entretiens,* 92-4).

The belief in spontaneous life generation, not to be shelved for two hundred years, makes planetary life quite easy to conceive. Inter-planetary transport is unnecessary: within any leaf, countless tiny worms are found, and

> from one side of the leaf to the other, they have no more communication with the other worms than we do with our own antipodes. Even more easily, it seems to me, a large planet will be an inhabited world…. Will you believe that [Nature], after proving fertile to the excess down here, will remain on all other Planets sterile to the point of excluding any form of life? (*Entretiens,* 95).

Planets are next reviewed and their differences stressed as likely to induce widely different forms of life. The author and his blond listener alternate serious physical arguments with literary fancies, and the Marquise might well be une *Précieuse* playing the lead in a Molière comedy; such is the winning style which made, and still makes, the *Entretiens* so palatable. Venus inhabitants "look like the Moors of Granada, a small dark People roasted by the Sun, full of wit and fire, always in love, making Verses, enjoying Music, everyday inventing Feasts, Dances and Tournaments." This was the Marquise; the author fully agrees, but still manages to slip in some hard facts of astronomy:

> Common Venus People are only Céladons and Silvandres, their most commonplace conversations are equal to the most beautiful by Clélie. Climate is most favourable to love: Venus …receives from the Sun a more vivid light and more heat than we do. Her distance from the Sun is about two-thirds of our own.[9]

As to those of Mercury, "our Iron, our Silver, our Gold would melt with them," (Entretiens, 106) while in the Sun

> there is no way to put inhabitants… the Sun is not a Body of the same kind as the Earth or the other Planets…. What kind of body? One used to believe it was made of highly pure fire; but the illusion vanished at the beginning of our Century, when Spots were discovered on the surface… not planets but clouds, smokes or scum rising above the Sun." (*Entretiens,* 108-110).

The scum interpretation of sunspots is strictly orthodox Cartesianism.

Mars "is not truly worth a stop. But what a pretty thing Jupiter is, with its four Moons or satellites!" Jupiter, being the centre of an obvious vortex, is immediately put to good use as a prop for explaining at some length "the *Tourbillons* of Descartes, these *Tourbillons* of which the name is so terrible, and the notion so pleasant." (*Entretiens,* 114). Here, let us stick to inhabitants: some are to be found on the central planet, and some on the satellites since "these Planets are not less worthy of habitation from the misfortune of being constrained to revolve around a more important one." Which of these locals are superior? Absurd question, and immediate answer: "the low superiority we hold over the People of our Moon makes me doubt that Jupiter might have any over the Inhabitants of his own." (*Entretiens,* 120–121). A far more serious problem deserves a full discussion: are these intelligent planetary denizens at all aware of the Earth and its human cargo? Of the first, there is no doubt: "On Jupiter, there will be Astronomers who, after taking great care to construct excellent Telescopes… will at last discover in the Heavens a very small Planet never seen before." (*Entretiens,* 123). The second should remain a great puzzle to the Jupiterians, and is presented by the Marquise: "What is this World? What kind of inhabitants lives there?" Her listener's answer is both prudent and witty but unimaginative:

> Our Earth is not us; they have no inkling that it might be inhabited. Should anybody propose that it is, God knows how much all Jupiter will laugh. Perhaps we are even the cause of some Lawsuit against Philosophers who have asserted that we exist. I would rather believe that the Jupiter Inhabitants are sufficiently busy making discoveries on their own planet and not thinking about us. It is so large that their Columbuses should not lack employment." (*Entretiens,* 124).

[9] *Entretiens,* 104–5. Fontenelle's speculations about Life taking different forms as a function of solar distance will prove popular and long-lasting. Kant asserts that for planetary dwellers "the excellence of their thinking natures…. becomes higher in proportion to the remoteness of their dwelling places from the Sun." (quoted by Lovejoy 1976, 193).

Twentieth century Earthlings would love to see those Jupiterians finally allowed to discover life on Earth after radical improvements of their own telescopes; Fontenelle, who has just speculated on the future of Earth-to-Moon flights, does not consider the possibility: he is no telescope builder, nor even an astronomical observer himself. Huygens, despite explicitly presenting his *Cosmotheoros* as a second *Entretiens*, will hold very different views.

No surprise awaits us on Saturn "which is the most distant Planet:" even with their ring and five satellites, inhabitants suffer from cold and darkness as

> even the Sun, which they see one hundred times smaller [in area] than we do, is merely a small and pale white Star…if you were to put them in our coldest Countries, Greenland or Lapland, you would see them perspiring profusely, and expiring from the heat. The Spirit of Wine, which never freezes here, would be hard as our Diamonds.

Which concludes Fontenelle's Grand Tour of the solar system; and after stressing that "…it is necessary that the two Worlds at the extremes of this huge Vortex should be opposed in all ways," he bows out and leaves his Marquise free to present the whimsical conclusion "Thus, people must be very wise on Saturn, since, as you said, everybody was mad on Mercury." (*Entretiens,* 129–130).

The subtitle of the *Fifth Evening* is a program in itself: "That the fixed stars are as many Suns, each of which illuminates a World." Descartes had provided them only with vortices, while Fontenelle will be far less timid. He understands that the subject cannot be treated without providing a rough stellar distance, and attempts to provide at least a minimum figure:

> The Fixed Stars cannot be less distant from the Earth than twenty seven thousand six hundred times the distance from here to the Sun… and if you angered an astronomer, he would put them still farther. (*Entretiens,* 133, 1708 edition only; no figure in previous editions).

The nineteenth century was to show the figure as still too small by one order of magnitude, but that failing matters relatively little as it leaves the author with plenty of room to house the neighbouring planetary systems. Fontenelle is not aware of Cusanus; even so, the celestial scenery he describes, whether witnessed from Earth or from any of these extrasolar planets, fully conforms to the Cusanian principle:

> Our own Sun is so close to us, compared to the Suns of other vortices, that its light must exert far more strength upon our eyes than upon theirs… but within another large vortex another Sun dominates… ours appears only at night with all the other foreign Suns, that is the fixed stars. [The inhabitants] nail it to that vast sky vault, and it forms a part of some Bear or some Bull. As to the Planets revolving around it, for instance our Earth, as they remain invisible from such a distance, they are not even thought about. (*Entretiens,* 138-9, 1708 edition only; derives from Huygens' *Cosmostheoros*).

Fontenelle is able to proceed far beyond Cusanus and Bruno: neighbouring planetary systems are real, but extremely hard to detect for optical reasons, soon to be followed in our Huygens chapter. One should not expect mathematical demonstrations within the *Entretiens*, particularly from the Marquise, but she manages to make the capital point all right:

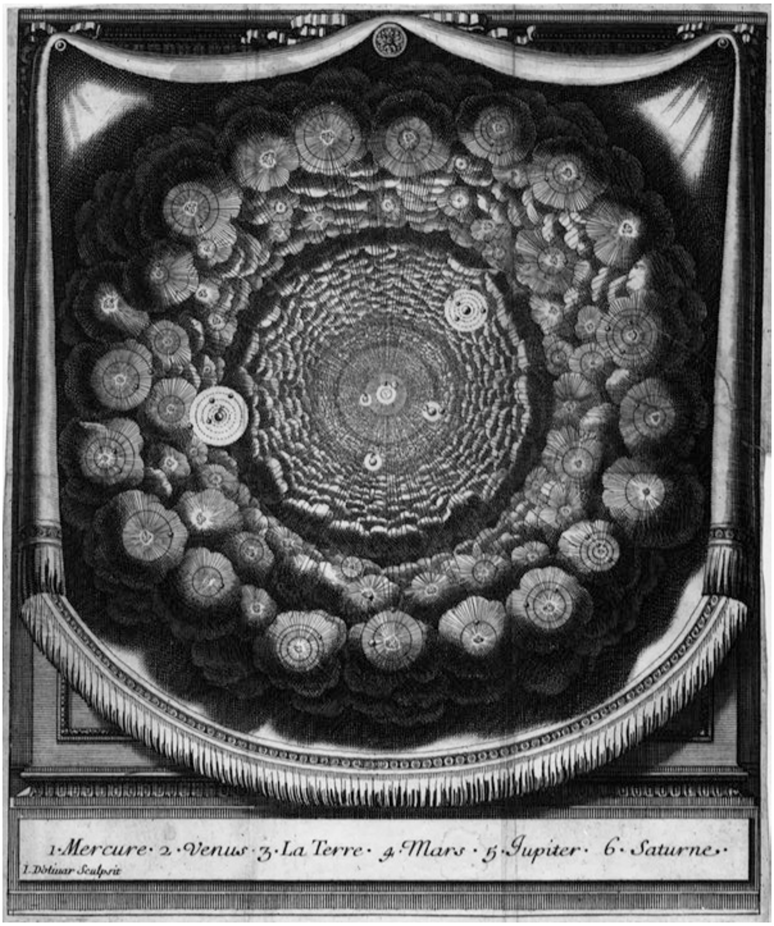

Figure 11.4 The grand Cosmic Theatre, frontispiece of the 1686 Fontenelle *Entretiens.* Mars has two satellites, Jupiter four and Saturn five. Most stars are generously supplied with planets of their own. Cumulus-like clouds seem merely an engraver's attempt at prettifying the picture, and so is the irregular shape of those stars. Bibliothèque de l'Observatoire de Paris

> Nothing is so beautiful to behold as this prodigious number of vortices, the centre of which is taken by a Sun which keeps planets revolving around it. Inhabitants of one planet within one of these infinite vortices see on all sides the Suns of the surrounding vortices; but they have no way of perceiving planets which, as they emit only a feeble light, borrowed from their own Sun, cannot project it beyond their world. (*Entretiens,* 135).

Prodigious indeed, and illustrated by a magnificent print (figure 11.4), which might receive as caption: *The Theatre of the Universe*.

However, Fontenelle still has misgivings about the Milky Way which

> somehow resembles the Maldives Islands, these twelve thousand small islands or sand-banks merely separated by sea channels which can be jumped over almost like ditches… from one world to the next one might speak, or stretch hands. At least, I believe that birds easily pass between worlds, and that pigeons may be trained to carry letters…Within one of these mini-vortices of the Milky Way, your Sun is not appreciably closer and has no more strength on your eyes than a hundred thousand Suns of the next vortices. (*Entretiens*, 141).

This naïve view of the Milky Way is wrong, but the notion of stars closely packed together in such a way is not physically absurd: a recent hypothesis is that (just as Fontenelle had predicted) planets cannot form under such crowded conditions. Under such conditions, planets, if any, have no satellites, for which the argument is characteristically half-causal and half-final:

> … they would be of no use to the main planets, which have no nights, and which anyway proceed through too-narrow spaces for the encumbrance of subordinate planets. (*Entretiens,* 142).

To start with, the Fontenelle comets had been strictly Cartesian, but soon found themselves endowed with a purpose:

> Comets are only planets from a neighbouring vortex… but maybe this vortex was pressed by the others around it in a different way, rounder on top and flatter below… They proceed above Saturn…Our enemies have blamed us about the uselessness of that vast space [above Saturn]; they should no longer worry, we have found its use: it is the dwelling of foreign planets entering our world. (*Entretiens,* 146-7).

Another and greater purpose follows; despite its tumultuous course, the comet carries a population of its own, and (says the Marquise) "it brings to us all its inhabitants in perfect health. Nothing can be more pleasant than changing vortices in this way" (*Entretiens,* 149); alas, the subject is not developed, and we are told nothing specific about cometary dwellers. To learn more about Cartesian comets, we should take leave of the Marquise and turn to other *Précieuses*, those of the *Femmes Sçavantes*, of which a few extracts are given within a *Note*: clearly, Molière rather liked Descartes. However, a novel theme with a far greater future is introduced in the *Entretiens* at this point: the concept of changes in Nature over long periods of time. The minor but remarkably early contribution of Fontenelle deserves to be treated presently.

The theme of any cosmological change not mentioned within Scripture was to remain rather *risqué* for a long time; here, it is prudently introduced as a mere fable:

> If roses, which last merely one day, were writing histories…the first would have portrayed their gardener in some specific way, as endowed with more than fifteen thousand rose lives… They would say: We have forever seen the same gardener; in the memory of all roses, he alone has been seen; he has forever been the same; assuredly he does not die like ourselves; he does not even change.

Of course Fontenelle soon reverts to safer topics, merely stressing the real-world application of his parable: "A thing should have lasted over many lives of men before giving signs of immortality." He has very high opinion "…of the power of Nature; might she be able to have planets and animals getting born or dying through a continuous revolution?" He is even led to a truly prescient understanding of stellar formation:

> … I believe that the Universe may have been made in such a way that new Suns will now and then be formed. Matter suitable to compose a Sun, after being dispersed to several different places, might perhaps be able to gather slowly in some definite location and form the beginning of a new World? (*Entretiens,* 153-4).

Modern cosmogonists will complete the picture with supernova explosions, but Fontenelle seems to lack only nucleosynthesis.

A full century after Tycho had removed both comets and novas beyond the Moon, far more subtle cases of heavenly change were being unveiled:

> Over the nearly one hundred years during which wholly novel Heavens have been observed through telescopes, there have been few constellations without sensible changes…" (*Entretiens,* 155: the proper motion of stars has only been announced by Halley in 1718).

On the Earth itself, evidence for geological change is common:

> Several high mountains, far from the sea, have extensive shell beds which necessarily have been covered by water. Often, and again far from the sea, one finds stones with petrified fish. Who may have placed them, if the sea has not been there?

The ancient story of the Herakles Pillars is recalled as an incredible fable, but

> … that the Ocean should have overwhelmed two weak mountains, perhaps with the help of some earthquake, and should have surged between Europe and Africa, I am ready to believe it without much difficulty. This must have been a beautiful Spot that the Moon Inhabitants have suddenly perceived on our Earth… (*Entretiens*, 171).

As to the other planets, they fare no better or even worse:

> This is nothing compared to what happens in Jupiter. On his surface appear bands… these are continents or seas, or possibly large parts of the Jupiter surface with just as much difference between them. Alternately these bands widen or narrow; sometimes they suffer interruptions and next reunite… such changes, perceptible only to our best telescopes, are far more considerable than if our own Ocean was to inundate all dry earth and create new continents…. About twenty years ago, a long light has been seen on Jupiter, brighter than the rest of the planet. (*Entretiens,* 1722 edition, 173). … Maybe they have not only these commonplace floods but also great fires…. Large changes are also seen on Mars, even from one month to the next. Within such a short time, seas cover large continents then ebb away with far more violence than ours, or at least something equivalent happens. (*Entretiens*, 172-3; these were perhaps the dust storms that can cover a large part of the disc).

Even the Moon is far from safe:

> …there is even a maiden lady, observed on the Moon with telescopes some forty years ago, who has aged considerably. She had a rather beautiful face; her cheeks have fallen in, her nose lengthened, her brow and chin have protruded so that her charms have all vanished… (*Entretiens,* 167-8; this is imaginary, this time!);

at which disturbing news the Marquise is understandably distressed. Modern interpretations of telescopic scenery tend to be less naïve, but these are trifles compared to the incorporation of Change in the cosmic picture, as observed through telescopes and interpreted from sensible terrestrial analogies. Which remarkable novelty had proceeded far beyond Descartes, and will terminate our Fontenelle account.

Conclusion

Descartes had built his cosmic system from rational and mechanical premises, but only his followers, Fontenelle and Huygens the most notable among them, provided it with both planets and inhabitants. What are the essential reasons? Those of the Master for escaping the Kepler delusion of a central and spherical solar bubble, empty of stars, are clear enough: the Keplerian picture of the Heavens could not be twisted to accommodate his own rejection of vacuum, and Kepler's technical arguments from stellar apparent diameters escaped Descartes entirely. Next, the Vortex model seemed to work so well within the solar system that temptation to fill space *ad infinitum* with replica copies must have been irresistible. But Descartes stopped at this point: his multiple vortices did not explicitly orbit planets, and the question of extraterrestrial life, either within our solar system or outside it, was never asked by himself, not even under the shield of a fable. The fear of getting involved in theologically dangerous matters must have been quite real for him. His own life span was brief, and he might perhaps have proceeded further without the misguided enthusiasm of Queen Christina; even so, all such explanations seem incomplete at best.

A more fundamental one may be found in Descartes utter rejection of final causes: for him, Vortices were causal tools required to fill up space and explain motion, but Life had no such obvious role. Animals, conceived as elaborate machines, might have operated equally well on other planets, solar or not, from the same efficient causes and the same physico-chemical mechanisms demonstrated on Earth, but any urge to postulate their apparition was absent. By contrast, for his successors and quite explicitly in the case of both Fontenelle and Huygens, planets had to be of some comprehensible use within a grand cosmic scheme: supporting life was the most obvious and appealing one. The Creator had constructed other Earth-like planets, which He could not possibly have intended for Man; that much was within the Descartes legacy: "there are infinite numbers of things in the World no man has ever seen and that have never been of any use to him." However, the next step involved quite different arguments: if these spheres have to support living creatures, intelligent or not, one of the most basic of Cartesian teachings is being not merely shelved but openly contradicted. When the narrator explains to his trusting Marquise that it is impossible to maintain planets "made in order not to be inhabited…whoever wants to believe this may do so; as to myself, I cannot," he is no longer a disciple of the Master who had written "We shall totally exclude from our Philosophy the search for final causes, since we should not presume so much about ourselves as to believe God was bound to make us privy to His councils." Simultaneously, Fontenelle understands well that the immense numbers of life forms on Earth also involve efficient causes, and "will you believe that Nature after proving fertile to the excess down here will remain sterile on all other planets?" He lies at the transition point where the thinking about our modern and scientific Plurality originates. With Huygens, that transition will be complete.

Appendix 1: Non-Cartesians

Descartes and his followers had not been the only thinkers to introduce and develop Plurality through the seventeenth century, since universal speculation had started right after the landing of *Sidereus Nuncius*. However, from now on, the theme becomes literary more than scientific, thus it will be but briefly mentioned here; admittedly, Fontenelle's case was on the borderline. Still, it proves fascinating and has been very well followed in the writings of Marjorie Hope Nicolson; to mention just a few of her studies: *The Telescope and Imagination* (Nicolson 1935)*, Kepler's Somnium and John Donne, Cosmic Voyages, Early Space Travellers,* and *Voyages to the Moon.* There is also a very-readable account in Mac Colley (1936). Here we merely quote the "New Discourse proving the Plurality" from these two historians and stick to just a few titles.

In France, thirty years before Fontenelle, Pierre Borel, *Conseiller et Médecin ordinaire du Roy*, had already presented his *Discours Nouveau*

> of Worlds, that Celestial Bodies are inhabited Earths, that the Earth is a Star, that it is out of the centre of the world in the third Heaven and revolves in front of the fixed Sun, & other most-curious things." (Borel 1657).

While referring to the latest astronomical discoveries, the small book also presents in favour of Plurality many proofs rather unexpectedly taken from Scripture or ancient writers and philosophers: "an argument taken from the location of Hell… from the celestial and Earthly paradises…from the answers of demons." Altogether, only the title anticipates Fontenelle, not the spirit nor substance, and the text does not have much literary merit either. The same cannot be said of the Cyrano de Bergerac 1650 novel *L'autre Monde ou Les États et Empires de la Lune et du Soleil* (*The other world or States and Empires of the Moon and Sun*), still read in French schools, although less commonly than the *Entretiens*. Cyrano's travels to the Moon are pure fancy, closer to Lucian's *True Story* than to Plutarch's *De Facie* or to Kepler's *Somnium*; they do illustrate themes made fashionable by the telescope, but their cosmological content is negligible. In England, Robert Burton in his rambling *Anatomy of Melancholy* (Burton 1624), written in 1621, had opposed Plurality; so did Bishop John Wilkins, founder of the Royal Society, nevertheless admitting the Moon to be an Earth, and even writing of a *Discovery of a World in the Moone* (Wilkins 1638). Henry More, in the poem *Democritus Platonissans* (More 1646)*,* adopted multiple Copernican solar systems; Henry Power in his *Experimental Philosophy* (Power 1664), did the same and referred to "the Noble and Elastic Soul of Descartes" as originator of the concept. And Joseph Addison (Addison 1837), in 1712 lauded Descartes who "scorned to be longer bounded within the straights and crystalline walls of an Aristotelian world; no, his delight is to search the regions above, to discover new suns, and new worlds, which lay hid among the stars…" (Quotations by Mac Colley 1936, 425).

During the eighteenth century, extra-terrestrial life is taken for granted, and the theme becomes a mere tool for introducing whatever fancy the author has in mind. The best remembered essays are those of the two great humorists, Jonathan Swift and Voltaire. Swift (1724) in his *Voyage to Laputa…* takes Captain Lemuel Gulliver to an "island in the air" which is not quite the Moon, even if some astronomical references are given in the story; all the interest lies in local beliefs and customs. As to Voltaire, his giant comet-hopping *Micromégas* (Voltaire 1752) humbled men in size, but not human astronomers in wisdom; the scientific content of the tale is far more precise than the one displayed by Swift. On the way, the author manages to mock poor Fontenelle, obvious model for the Saturnian Academy Secretary, who "had truly never invented anything, but gave good accounts of the inventions of others, and made passable little verses and great computations." Some time before, Voltaire and his intimate friend the Marquise du Châtelet had been responsible for introducing Newton to the French readers, still largely Cartesian at the time.

Even theatre goers were not spared. In 1697, one Elkanah Settle gave in London *The World in the Moon, an Opera*, for which the stage machinery must have been not far second to *NASA*'s:

> three great Arches of Clouds…with a prospect of Cloud-Work… a circular part of the black Clouds rolls softly away, and gradually discovers a Silver Moon, near Fourteen Foot Diameter; After which the Silver Moon wanes off by degrees and discovers the World within… a large Landscape of Woods, Waters, Towns etc… (Quoted by Nicolson 1948, p. 47).

Somewhat less forgotten is Joseph Haydn's opera *Il Mondo della Luna* from a century later; happily, winds no more than strings were in the least bothered by the lack of lunar atmosphere.

Appendix 2: Molière on Cartesian Astronomy

Here are some extracts of Molière's *Les Femmes Sçavantes* (1672) Act IV, Scene 3:

> Trissotin: Je viens vous annoncer une grande nouvelle.
> Nous l'avons en dormant, Madame, échappé belle
> Un Monde près de nous est passé tout du long,
> Et chu tout au travers de notre tourbillon;
> Et, s'il eût en chemin rencontré notre terre,
> Elle eut été brisée en morceaux comme verre.

Translation by R.Wilbur, Harcourt Brace Jovanovitch, NY, London, 1978:

> I bring you, Madam, some startling news I've heard:
> Last night a near catastrophe occurred:
> While we were all asleep, a comet crossed
> Our vortex, and the Earth was all but lost;
> Had it collided with the world, alas,
> We'd have been shattered into bits like glass.

The play contains other verses attesting Descartes' drawing-room popularity, not unlike Einstein's in the nineteen-twenties. Act III, Scene 2:

Bélise: Je m'accommode assez, pour moi des petits corps;
Mais le vide à souffrir me semble difficile
Et je goûte bien mieux la matière subtile.
Trissotin: Descartes, pour l'aimant, donne fort dans mon sens.
Armande: J'aime ses tourbillons.
Philaminte: Moi, ses mondes tombants.

Translation:

B. I rather like his atoms, but as between
A vacuum and a field of subtle matter
I find it easier to accept the latter.
Tr. On magnetism, Descartes supports my notions.
A. I love his whirling motions.
Ph. And me, his falling worlds.

Next, the conversation proceeds to the topical subject of the recent telescopic discoveries:

Philaminte: Pour moi, sans me flatter, j'en ai déjà fait une
Et j'ai vu clairement des hommes dans la lune.
Bélise: Je n'ai point encor vu d'hommes, comme je crois;
Mais j'ai vu des clochers tout comme je vous vois.

Translation:

Ph. I can already offer one such rarity:
I have seen men in the moon, with perfect clarity.
B. I'm not sure I have seen men, but I can say
That I've seen steeples there, as plain as day.

The first representation of the play took place at the *Palais Royal* on March 11 1672, and among the early spectators was Christiaan Huygens who wrote to his brother Lodewijk that *"on l'a trouvée fort plaisante, mais un peu trop sçavante."* (*It was found much pleasing, but somewhat too learned*; *OCCH*, VIII, 161).

Chapter 12
Christiaan Huygens: Humans Give its Present-Day Form to Extraterrestrial Intelligence

Should we allow the Planets nothing but vast Deserts, lifeless and inanimate Stocks and Stones, and deprive them of all those Creatures that more plainly speak of their Divine Architect, we should sink them below the Earth in Beauty and Dignity; a thing that no Reason will permit… What a wonderful and amazing Scheme have we here of the magnificent Vastness of the Universe! So many Suns, so many Earths, and everyone of them stock'd with so many Herbs, Trees and Animals…

Christiaan Huygens[1]

Huygens discovers the rings of Saturn, anonymous painting (ca 1820). Bibliothèque de l'Observatoire de Paris

[1] *Cosmotheoros,* 150.

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
https://doi.org/10.1007/978-3-030-41448-1_12

I have felt considerable misgivings about this lengthy chapter title, and the choice of *present day* was most laborious. *Definitive* was tempting, but obviously preposterous. The said title is also meant to make understandable my choice, which was to make this chapter the last one in the story. (A final chapter was however added by the editor, using elements left by the author.)[2]

When Christiaan Huygens was born in 1629, Kepler was still alive and Galileo had not yet faced his trial, while the greater part of the Descartes opus remained unwritten. The Dutch physicist was to acknowledge his debt to all three, and more explicitly to the French philosopher; however, the greatest and most durable Hugenian contributions to science had little to do with his Cartesian convictions, which anyway soon drifted far from the orthodox path. But when he died, five years short of the new century, the structure of Plurality developed in his *Cosmotheoros* had almost reached the modern form, largely from his own contributions. His Universe is filled with stars that he was first to locate correctly, through an astute method for determining their distances. Those stars are equipped with planets orbiting according to Keplerian laws, and enjoying quasi-Newtonian mechanics; and their invisibility is accounted for by optical explanations. Thus, when Huygens describes his planets as lavishly furnished with life forms progressing from vegetal to animal and from intelligent to civilized, *Cosmotheoros* stands in respect to the Fontenelle *Entretiens* like the *Proceedings* of a twenty-first century Extraterrestrial Life meeting compared to Jules Verne.

Except for two severe limitations. First, Huygens' understanding of the Sun and neighbouring stars in relation to each other is indeed spatially correct; today we consider that sampling such a small fraction of the Universe is adequate for asking, and maybe later answering, all relevant questions about extraterrestrial life. But the Huygens outlook is still static, as it was bound to be in the waning seventeenth century: the time element is lacking. The origin, the age and any possible evolution of these planetary dwellers are not discussed, as for Huygens they do not even pose a problem worth considering. Along this line Fontenelle had proceeded farther by wondering about possible changes in Nature over long periods of time. While the Creator makes remarkably few explicit apparitions through most Huygens works, he is still very much required in *Cosmotheoros*, behind which he lurks as the

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[2] The complete works of Huygens have been published in the 22 volumes of *Œuvres Complètes de Christiaan Huygens*, by H. Nijhoff, 1888–1950 (here referred to as *OCCH*). They contain mostly French and Latin texts, and provide French translations of the latter. Of particular interest here are Vol. I to X (*Letters* plus many fragments and even observing or laboratory notes), Vol. XV (*Systema Saturnium*), Vol. XVI (*De Motu* and *De vi centrifuga*), Vol. XVIII (*Horologium Oscillatorium*), and Vol. XXI (*Cosmotheoros*). However, all quotations of *Cosmotheoros* will be from the 1698 English translation *The Celestial Worlds Discover'd*.

Two interesting conference proceedings are: *Studies on Christian Huygens* edited by Bos & al. (*STCH*); and *Huygens et la France*, introduced by René Taton (*HFR*). For biographical information, we have mostly used *Christian Huygens and the development of science in the seventeenth century* by A.E. Bell (Bell 1947); *Christiaan Huygens, a biographical sketch,* by H.J.M. Bos in *STCH*; *Huygens, the Man behind the Principle* by C.D. Andriesse (Andriesse 2005, translated from the Dutch), valuable because written by a physicist.

ultimate explanatory device; the author does not think he has to account for the rise of his fancied planetarians any more than for very real fellow humans. More than three hundred years later, after having groped our way through the time-scale of the Universe and at least some of the main rules for geological, cosmological and biological evolution, we have far more questions to ask than either Fontenelle or Huygens. And since we have given up all recourse to final causes, the answers are far more difficult to unveil.

The second clear limit of the Huygens anticipation is that he fails to consider any possible travel or contact between planets or planetary systems. Here, it is not Huygens but Kepler who had shown the way; admittedly, his Duracotus had required some help from witchcraft to reach the Moon, but the physical conditions of the trip had been sensibly described. For interplanetary communication, Huygens at least held the suitable tools: light beams and waves, which he wielded expertly throughout his life. Still, his prescient wave theory is less relevant to our subject than his awareness of the finite velocity of light, the discovery of which he learned with the greatest delight from his Paris Observatory colleague Ole Rømer. Even so, he never formulated the basic rule limiting contact between alien civilisations scattered through the Universe: that of the unavoidable and catastrophic time delay involved. Had he merely asked the relevant question, he might today be presented as the discoverer of both Space and Time Pluralities in their modern forms; truly, he anticipated the first, never the second.

After a brief account of his life and works, we will present enough of his method, and of his views on matter, mechanics and the Cosmos, to prove that *Cosmotheoros* is built over the same hopefully firm soil upon which are grounded similar grand extrapolations today. Huygens marks the transition of Plurality from the metaphysical to the scientific age, and thus nearly ends the present historical account.

Christiaan Huygens' Life and Works

The Huygens family has been a most remarkable one: his father Constantjin, distinguished diplomat and fair poet, also showed concern for such technical problems as lens grinding and longitude determination, an interest which he transmitted to his two first sons. The collaboration between the eldest, Constantjin junior and the second, Christiaan, is one of the best remembered in the annals of science. Their joint efforts were responsible for the polishing of some of the most excellent objective lenses of the period, which were to be used in the sensational astronomical discoveries of Christiaan. Their father had been a friend of Descartes and corresponded also with Mersenne, to whom he underlined the accomplishments of his two sons while still in their teens: see Bachrach, *"The role of the Huygens family in seventeenth–century Dutch culture"*, *STCH*, 27. He was to call Christiaan *Mon Archimède*; no doubt this was a piece of paternal boasting but a singularly apt one, and Mersenne was to concur: "If your Archimedes comes with us, we shall show him one of the most beautiful treatises on geometry ever seen, just written by the young Pascal." (*Letter to Constantjin Huygens*, 17 March 1648, *OCCH* I, 83). The resemblance between Huygens and Archimedes was to be often stressed later, as both brought to mechanics and physics a happy mixture of fundamental intuition and experimental skill. At the age of sixteen, in 1645, Christiaan entered the University of Leiden where he was to spend two years with two subjects: law and mathematics, the latter under a convinced Cartesian teacher, Frans Van Schooten; but the boy had already read the Descartes *Principia* just off the press. The University climate must have proved exciting; merely a few years before, all teaching had remained strictly Peripatetic, and considerable opposition to all novelties, Cartesian or Baconian, was still extant.

Huygens began to work on mathematical problems, followed by others in optics and physics. Two remarkable results soon made him famous all over Europe: the invention of the pendulum clock, and the discovery of the Saturn ring in 1655-56. At about the same time, he made his first visit to Paris, to be followed by many others; he settled there in 1663 as founding member (and a very active one) of the new Académie des Sciences, largely thanks to the patronage of Colbert, the intelligent Louis XIV minister. The fact that he was a Calvinist proved at the time no hindrance; unlike for Galileo, Kepler and Descartes, theological constraints played little role in his career, and he also kept largely aloof from politics. Moreover, he had been born in a wealthy family, always lived in a favourable atmosphere and received adequate support. Still, in the climate that arose in Paris around the 1685 Révocation de l'Edit de Nantes, and also because of the death of Colbert, he was to prefer return to his own country, where he was soon followed by a crowd of Protestant intellectuals and artisans; altogether, a disastrous loss to France.

The most important Huygens books were the 1659 *Systema Saturnium*, in which a full account of his telescopic observations and ring hypothesis is given; the 1673 *Horologium Oscillatorium* where, starting from the technical problem of improving clocks he proceeded to some of the basic theorems of classical mechanics; and the 1690 *Traîté de la Lumière*, in which he gave the outline of his wave theory: he was able to explain the novel and puzzling phenomenon of double refraction in Iceland spar, which defied the Snell-Descartes laws. The first two books were well received and abundantly discussed; but to the prescient achievements of the third, relatively little attention was paid at the time, as the Newton emission theory seemed so much more obvious for explaining the major known fact about light: rectilinear propagation.

Huygens entertained fair and lasting relations with the major English scientists of the period, and went twice to Britain (see Hall, *Huygens scientific contacts with England, STCH*, 66). The first time was in 1661, and his travel journal is preserved. After Paris, he was not exactly impressed by the pre-Great Fire London "the reek of the smoke is unbearable and very unhealthy, the city poorly built, the streets narrow and badly cobbled…" Much worse, "women have very poor conversation, and show far less wit and animation than they do France." (*Letter to Lodewijk*, June 9 1661, *OCCH* III, 275). On the other hand, scientific contacts were at once pleasant and fruitful. At Gresham College he discussed clocks and the longitude problem, and attended vacuum experiments with Boyle's pump; as soon as he was back home, he was to build an improved version of his own (see Bell 1947, 162). He was elected F.R.S., and ever after remained in close touch with the Royal Society.

Just before his second visit to London, in early 1689, there had been a notable upheaval in royal circles. Brother Constantjin and Christiaan came over for a three-month summer visit. "I would like to be in Oxford, merely to get acquainted with Mr. Newton, whose beautiful inventions I greatly admire in the work he has sent me." (Andriesse 1993). Actually, he did speak at some length with Newton, and even rode with him from London to Hampton Court. No close relationship nor correspondence developed between the pair, as the two views of Nature were thoroughly incompatible. Still, the meeting may have goaded Huygens to publish the *Traîté de la Lumière* soon after his return (Hall, *STCH*, 78, 79), while he was usually rather slow to print.

Thus Huygens, who had rather narrowly missed meeting Descartes in person[3], only managed a rather superficial encounter with Newton, but with Leibniz the case is quite different. Leibniz first visited Paris in 1672, at the age of twenty-six when he was still unknown within science (see Heinekamp, *Christiaan Huygens vu par Leibniz*, *HFR*, 99). Huygens, seventeen years older and a famous scientist, helped him to make a start with mathematical problems; a friendly correspondence developed, which was to last until his death and be well preserved. However, the pupil was soon to surpass the master: Huygens always had difficulty in grasping the point and handling the tools of differential calculus, either in the Leibniz or Newton forms. He used it rather little himself, preferring the traditional-style geometrical or algebraic demonstrations, in which he excelled (see Bos, *Huygens and mathematics, STCH,* 126-146).

After leaving Paris, Huygens settled in the Hague, or in his nearby manor of Hofwijck, perfecting solutions to his old problems in optics and mechanics; no more astronomical discoveries were made. Still, during the last year of his life, he attacked a novel subject by writing *Cosmotheoros*, which remained a mere manuscript at the time of his death in 1695. Brother Constantjin was entrusted with the publication of the Latin text, three years later, and popular success was immediate, much like that of the Fontenelle *Entretiens*; English, Dutch, French and German translations appeared within a few years. Immediate, but not lasting: Huygens, who

[3]Andriesse (p. 46) speculates that Huygens may have met Descartes in 1632 at the age of three. Surprisingly, when attending the University of Leiden, he did not attempt to see his father's old friend who was staying at Egmond-Binnen, sixty km to the North. In late 1650 Huygens went to Copenhagen and definitely planned to visit Descartes, who had just arrived in Stockholm; but the philosopher died in February 1651, and the young Huygens was reduced to writing an excellent epitaph (quoted by Andriesse, 96): *"Cette âme qui toujours en sagesse féconde / Faisait voir aux esprits ce qui se cache aux yeux, / Après avoir produit le modèle du monde, / S'informe désormais du mystère des cieux"* (This soul, that with fertile wisdom / showed to the minds what was hidden to eyes / after having produced the model of the world / is now learning the Heavens mysteries). Which proves that, among many other accomplishments, boy Huygens expertly manipulated French versification.

had never constructed a system nor led a school of his own, was to lay largely forgotten during the eighteenth century, to be rediscovered after the revolution in optics due to Young and Fresnel, but merely as an optician.

Thus, his brief venture into Plurality did not exert any real influence over the next three centuries. The reasons why it should be recalled and treasured today will hopefully be made clear.

Physics Without Metaphysics

"*Il n'avoit point de goust pour la Metaphysique*" (He lacked all taste for metaphysics), (quoted by Heinekamp, *Christiaan Huygens vu par Leibniz*, *HFR*, 106), was to complain friend and disciple Leibniz, who himself never suffered from any like deficiency. This judgement was one written merely a few years after Huygens demise, but the modern view is exactly the same: "Of all the major figures in seventeenth century physical science, Galileo, Gassendi, Pascal, Descartes, Huygens, Leibniz, Newton, the Netherlander is the only one who is not markedly a philosopher…" (Hall, *Summary*, *STCH,* 304). This limitation is in no small part responsible for the thoroughly modern view of Plurality the said Netherlander was to develop; and, incidentally, makes him far easier to deal with for some poor scientists lacking all metaphysical training. Moreover, Huygens was never caught up in any theological controversy, even if his brand of religion was too liberal, and his approach too rationalistic to make it palatable for many fellow Calvinists; he may be understood as precursor to the Encyclopaedists. Still, he never suffered from persecution, and he has been seen moving easily from Holland to France and England; Italy might have proved different, but merely one generation after Galileo's demise, it no longer held a major scientific appeal.

Thus, unlike in the case of our previous heroes, we can pass directly to Huygens' picture of the material world; with the usual caveat that the frontier line between physics and metaphysics is often hazy. On the key issue of God's role in Nature, it is however clear; Burtt (1954, p. 101, 292): "It is in Huygens and Leibniz that we first meet spirits adventurous enough openly to confine the divine activity to the first creation alone… The conception of the world as a perfect machine is thus rendered inevitable." Then, how did this machine work? Here, the question of Descartes' influence is central: was Huygens a true Cartesian or not? His initial debt had been openly acknowledged: "I am one of those who have profited from the wisdom of that great man" (quoted by Bell 1947, p. 80, without reference); however, nearly at the end of his life, he scribbled voluminous and highly critical *Notes* on his copy of the Baillet biography *De la vie de M. Des Cartes* that he had just received. From these comments, the progression from student enthusiasm to mature disenchantment is easily followed, and they deserve extensive quotations (Ensuing quotations found in *OCCH,* X, 399–406):

> M. des Cartes had found the way to have his fictions and conjectures taken for realities… When I read his book of Principles for the first time, it seemed to me that all was for the

> best, and whenever I found any difficulty, I believed this was my own fault from not understanding his thought. I was only fifteen or sixteen. However, having since discovered visibly false things now and then, and others very unlikely, I have felt much estranged from that belief, and presently I find almost nothing that I can approve as true within all his physics, metaphysics and meteors.

This Huygens frustration with Descartes is essentially our own, and he finds the exact words to convey both the magnitude of the Cartesian achievement in his pioneering rational description of the World, and the ultimate failure of his physics. He makes us feel the excitement of intelligent students, who had so far been fed by routine Peripatetic stuff, when discovering the *Principia*:

> What has been most pleasing at first when this philosophy began to be published, was that one understood what Mr des Cartes was saying, while the other philosophers merely gave us incomprehensible words like these qualities, substantial forms, intentional species, etc…More universally than anybody else, he has rejected that impertinent hotchpotch… he has dared to substitute understandable causes…

Alas! that demolition of the Scholastics had been most enjoyable, but the Cartesian construct built on the ruins did not hold together: those hopefully understandable causes proved seldom so in practice. With one notable exception:

> The finest thing he has found within physics, and maybe the only one in which he was right, has been the reason of the double rainbow as far as angles and apparent diameters go, but as for his causes of the colours, nothing is less likely…

The great French champion of rationality, who had proclaimed that pure arguments starting from clear and distinct visions would be enough to reconstruct the World, had failed to demonstrate most of his cases or even sometimes to achieve clarity himself:

> … he went on blathering about the things he had once asserted, often quite false ones… He gave his conjectures for truths, as appears from his grooved particles which he uses for explaining the magnet… and a hundred others without ever stopping to consider the mass of absurdities these hypotheses implied. He certified some things without any demonstration, for example…

And the example selected at this point is not just any trifle about magnets or meteors, but a tool lying at very core of the Cartesian physics: the collision laws themselves:

> …for example those laws of motion for colliding bodies; which he believed to have made acceptable as true by implying that his entire physics would be false if these laws were so. Which is about the same as if he wanted to prove them by taking an oath. Nevertheless only one of these laws is true, as I shall easily prove.

Indeed, Huygens was the expert in the case, having corrected Descartes in his own *De motu*, and provided our theoretical mechanics with their definitive collision laws.

What Huygens cannot stand from Descartes is that intolerable assertion of utter certainty in all his deductions:

> He should have proposed his system of physics as an attempt to speak plausibly within that science from admitting only the principles of mechanics, and invited other fair minds to

> search in the same way…. However, when making believe that he has found the truth, as he does in all occasions, and glorifying in the smooth flow of his own arguments, he has done great harm to philosophical [scientific] progress… his sectarians believe they know the causes of everything, waste their time upholding their master's doctrine, and do not attempt to penetrate the true reasons of these many natural phenomena about which des Cartes has merely spouted chimeras.

No more devastating (or apter) criticism of Descartes can be found than under the pen of the ex-disciple. Moreover, still in the same *Notes*, he admitted other influences:

> Verulamius [Francis Bacon] also has seen the inadequacy of that Peripatetic philosophy, and moreover has given very good methods for building a better one through making experiments and using them correctly… However he did not understand mathematics… and was unable to conceive the motion of the Earth which he mocks as an absurdity.

And Bacon had not been the sole renovator of natural philosophy:

> Galileo possessed in the way of mind, and of knowledge of mathematics, all that was required for progress in physics, and one has to grant that he was first to make beautiful discoveries about the nature of motion, even if leaving room for other considerable ones… To me, it appears that M. des Cartes has been highly jealous of Galileo's fame…

All these thoughts were those of an ageing man; but when still fresh from the University Huygens had already been dreaming about a necessary reform of Cartesianism; this was shortly after the Master's demise, and at a time when prevalent attitudes were either total rejection or slavish acceptance. Here, we must understand the resulting Hugenian concepts, on which he will much later base *Cosmotheoros*; how much of the Descartes cosmos did he throw out, and which tools did he preserve? His limitations and guiding lines are simple: he was not himself a system builder, thus to the end of his life he used the main principles at the base of the Cartesian system. However, he became a highly skilled problem solver, which led him to reject all the specific mechanisms developed by Descartes.

What kind of matter does Huygens require to build this cosmos? Unlike Descartes, he sees no logical impossibility in the existence of a vacuum; furthermore, he requires matter to possess at least one additional property beyond extension:

> As to a vacuum, I accept it without difficulty, and I believe it is even necessary for the mutual motion of the small corpuscles, not sharing the opinion of Monsieur des Cartes who wants extension alone to constitute the essence of the body; but adding perfect hardness which makes it impenetrable, and impossible to break or damage. (*Discours de la Cause de la Pesanteur*, *OCCH*, XXI, 473).

Which is unsurprising: at long last, the consequences of the Torricelli discovery had become difficult to escape. Moreover, Huygens' view of matter is also influenced by that of Parisian philosopher-scientist Pierre Gassendi, who had opposed both Aristotle and Descartes by modernising Epicurean atomism. The Gassendi atoms are thoroughly Christianised, since God had been responsible for their creation, but ever after they

> cannot be created or destroyed, are primordial, impenetrable, simple, unchangeable and cannot be subdivided into smaller parts; degrees of hardness were due to varying amounts

of empty spaces between the solid atoms (see Snelders, *Christiaan Huygens and the concept of matter, STCH*, 104);

moreover, they also are endowed with weight, unlike the strictly-geometrical Descartes particles. Still, no attractive forces are postulated, and cohesion is due to shape, acting through a handy assortment of made-to-order hooks and eyes.

For Descartes any motion had been explained by some other motion, thus cohesion was just another name for relative rest, and in no need of a specific cause. For Huygens, it requires an additional property of particles, independent of geometry: infinite hardness (we would rather speak of perfect elasticity); this was a serious heresy, and strict Cartesians will object. Also, where Descartes had been happy with three classes of corpuscles, Huygens needed four; following the summary given by H. Snelders (*STCH* 119), one finds, in order of decreasing sizes and increasing velocities, the particles of (1) standard matter, including air; (2) ether, needed for light propagation; (3) a magnetic/electric substance which explains the corresponding phenomena; and (4) subtle matter, responsible for gravity. The last two classes, required to account for forces, act through vortices. Today, we are unimpressed by the Descartes particles and the Gassendi-Huygens atoms alike: we do not see them as necessary nor even useful steps on the way from antique atomism to modern atomic theory. Progress in the field was to arise from Baconian-type experimentation, not Cartesian a-priorism. But the Hugenian ether deserves more attention as it is vortex-free and plays the central role in his wave theory of light, which we have largely preserved, after adding vibrations and wavelengths. Thus his ether lies distinctly closer to the Fresnel-Maxwell brand than to Peripatetic fifth matter.

Not merely Huygens' ether, but also his entire method of research look modern, compared to that of Descartes. First, he granted a large place to experimentation: in 1666 he proposed a program for the future French *Académie*:

> The main and most useful occupation of that assembly should be to work on natural history according to the project of Verulamius [Bacon]. This history is made of experiments and remarks and is the only way to reach knowledge of everything we see in nature. As for instance, what is gravity, heat and cold, attraction of the magnet, light, colours, parts constituting air, water, fire and all other bodies, the use of respiration in animals, how metals stones and herbs are born, all things about which nothing or very little is known… To build a natural philosophy, one must necessarily proceed from knowledge of effects to that of causes. (*Letter to Colbert*, *OCCH* VI, 95. Quoted and discussed by Mouy 2012, 186).

Second (and here, quite unlike Bacon), he proceeded as fast as he could from experimental results to their mathematical analysis. No doubt he had learned all about geometry in Descartes, but he was also to use it proficiently for explaining Nature's ways, which Descartes had never attempted to do outside optics. Here, the model was different: "Galileo was close to the spirit and to the understanding of Mathematics, which was necessary to make progress in Physics." (*OCCH*, X, 404; quoted by Westman, *STCH*, 97). And Huygens' personal trademark will be the development of novel geometrical tools, invented for specific questions in mechanics, and leading to interconnected physical and mathematical discoveries. The case of the cycloidal pendulum illustrates well this mode of research, and is fascinating to follow. The story is made of two successive episodes; through the first, he proceeded from experiment to theory, while in the second the procedure was reversed.

In the first, the starting point was a practical problem: improvement of clocks. Galileo had been at the origin of the solution through his discovery of the isochronism of a pendulum oscillating under gravity alone; and the device had become useful to experimenters for measuring time intervals up to a few minutes. To make a true clock required a mechanism fulfilling two very different functions: counting the beats, and (in modern terms), feeding to the pendulum enough energy to compensate for natural damping, all without perturbing the motion; this last problem was to prove far more difficult. In 1657 Huygens was first to demonstrate a working solution. Galileo had understood the problem, and at the end of his life (when he was blind) entrusted his son Vicenzio and his pupil Viviani with the construction of a pendulum clock. Whether the mechanism was actually finished is unclear, but if so it was not a success (see Drake 1955, 419). Huygens published the result, took a Dutch patent and at once hoped to solve a problem of great economical importance: measuring longitude, which necessitates good, transportable clocks. His success made him famous, and mechanical clocks, which had hardly evolved since their fourteenth-century introduction, were rapidly converted to pendulum operation all over Europe. Within observatories, the change was radical, particularly through the work of another Paris colleague, Jean Picard (see Picolet 1987 and Landes 1983).

Huygens went on looking for improvements, but unlike mere artisan clockmakers, he posed the problem in terms of Cartesian analytical geometry. The main difficulty appeared to be that, for a standard pendulum, isochronism was approximately true for small oscillations only, while larger ones proved slower. Primitive escapements required large swings, and did not maintain constant amplitude, with the situation even worse aboard ships; hence he looked for a "tautochronic" device, i.e. one with a period rigorously independent of amplitude. The way to an empirical solution was obvious: slightly reducing the length of the flexible wire for larger swings, with the help of small curved metal plates (*lamellae* or "cheeks") on both sides of the pivot. In his original clocks, built in The Hague (one is surviving in the Leiden Boerhave Museum), the cheeks had already been present, but merely adjusted by trial and error. Now settled in Paris, he proceeded to ask the question: what is their ideal shape? The full answer was to take him extremely far, first to novel geometrical theorems and then to some funding principles of our classical mechanics. The cycloid curve was just then fashionable: Galileo, Fermat and Descartes had all been interested and Blaise Pascal had recently performed its quadrature, i.e. computed the enclosed area. In his 1673 *Horologium Oscillatorium*, Huygens broke new ground: he proved first, *geometrico more,* the ideal path of his pendulum bob to be a cycloid, and second the utterly astonishing result that the corresponding cheeks were also cycloidal. Showing that two equal cycloids could be involute/devolute of each other was a theorem of pure geometry; tautochronism of the cycloidal pendulum was an entry into dynamics. And the Huygens treatise went on in the same vein to more results quite unnecessary for mere time keeping: he succeeded in determining the "centre of oscillation or agitation" for some geometrical figures, plane or solid, and concluded with additional theorems on centrifugal force (see Dugas 1955, 185 ff).

The second episode took place several years later, and now the process was deductive and the starting point purely mathematical: Huygens was no longer concerned with measuring time but merely having a second look at cycloidal motion. In *Horologium*, he had overlooked the fact that the involved force (the one that brought the pendulum bob back to its rest position at the cycloid apex) was proportional to arc length. Now he discovered this remarkable property, understood it to be the key point, and predicted that in other systems endowed with a restoring force similarly proportional to elongation, tautochronic oscillations would result. At this stage, he reverted to his original concern, and started planning a gravity-independent device, intended for the longitude-at-sea application. Soon, he built his first portable clock in which the regulator was a balance with a coiled spring, and the results (at least in the long term) were to be decisive improvements of time-keeping, particularly at sea.[4]

More than horology was to be involved, and the consequences went far beyond the guesses of the inventor, as such is the tortuous path through which was unveiled one of physics most fundamental and ubiquitous tools: harmonic motion. Ironically, tautochronous oscillators had been known in all but name to Pythagoras, since vibrating strings emit a fixed note despite damping, of which the human ear happens to be an excellent judge; but nobody had ever given the case a thought before the seventeenth century.

The contributions of Huygens to modern mechanics were the corrected (and correct) collision laws, the expression of centrifugal force, and a clear understanding of mass, weight, force, work and moment of inertia, even if the modern terminology was to be developed by later scientists. These concepts will not be followed here, since we are only concerned with understanding method, and do not require a full account of results (for studies, see Gabbey, *Huygens and mechanics*, *STCH*, 166; Costabel, *Huyghens et la Mécanique*, Costabel, *HFR*, 139; Dugas 1955). However his main error, the refusal to adopt universal gravitation, will later deserve a treatment since it might be construed as a serious blemish of the Cosmos in which he had to locate his Plurality.

[4] Hooke was to claim priority for the invention of the spring balance; indisputably, he had been first to publish the well-known *Hooke's Law* for elastic bodies: *Ut pondus, sic tensio* (for details, see *England's Leonardo,* chapt. X). Altogether, Huygens was to reap mostly disappointment in the field of longitude measurement. First, the temperature sensitivity of the spring balance proved too large, and he reverted to gravity devices. Then, despite some early hopes, the final results of his clocks sea trials were always poor. Before the end of the century, the cycloidal pendulum clock vanished even in observatories, since the anchor escapement made very small oscillations practical. The longitude at sea problem was far more difficult than he or Hooke or anyone else had guessed; it was only solved by George Harrison, almost a hundred years after the first pendulum clock, not from more theorems in mechanics, but through advances in metallurgy and precision machining, and a temperature-compensation device. To follow Huygens' thought and mechanisms step by step, see Mahoney, *Christiaan Huygens: The measurement of time and longitude at sea*, *STCH*, 234; and *The Longitude Timekeepers of Christiaan Huygens*, J.H. Leopold, in Andrewes (1996). The South Kensington Science Museum exhibits working models of the Galileo clock, the Huygens 1657 and 1673 clocks (without and with cycloidal cheeks respectively), and of a 1669 Hooke experiment in which the amplitude of a 12 ft. pendulum had been reduced to about 10 arc minutes; thus, cycloidal correction was no longer needed.

Neither can his work in optics be described here apart from basic principles. Again, the starting point is Cartesian: light can only be understood as some motion propagating through a *plenum* thanks to collisions, and the Huygens attitude is already clear from his 1672 reaction when first learning of Newton's experiments on the "Phænomena of Colors." He is less than enthusiastic, because Newton does not go to the bottom of the problem:

> Even if it was true that some light rays should be red and others blue from their origin etc… there would remain the difficulty of explaining what this diversity of colors is made of…

A little later, he stresses again that only a full explanation is worthwhile:

> Until he has found that hypothesis, he will not have taught us the nature and the difference of colors, but merely that accident (admittedly a considerable one) of their different refrangibilities. (*Letters to Oldenburg*, Sept 27 1672 and Jan 14 1673, *OCCH*, VII, p. 228, 242).

Here, his attitude is strictly Cartesian, and his Master would have behaved in the same way: remember Descartes' reaction to the Galileo free-fall laws.

To these objections Newton answered:

> How Colors may be explained hypothetically is besides my purpose. I never intended to shew, wherein consists the Nature and Difference of colors, but only to shew that de facto they are Original and Immutable qualities of the Rays which exhibit them; and to leave it to others to explicate by Mechanical Hypotheses the Nature and Difference of those qualities; which I take to be no difficult matter. (quoted by Bell 1947, 72, without exact reference).

The modern verdict on this complex case is mixed: on the one hand, the Newton refusal of half-baked hypotheses was wise, and his experiment on colors has ever remained a capital contribution to optics just as it stood. But contrary to his breezy dismissal, the explanation proved a very difficult matter, indeed an impossible one within his own emission theory. On the other hand, Huygens contributed nothing to the immediate understanding of colors, even in his 1690 *Traîté de la Lumière*; but the explanation when it finally came more than a century later, was constructed by adding to his own pulse-and-wave theory the hypothesis of periodic vibrations, and this happy combination has proved definitive.

The two contrasting attitudes are clear: Newton describes a fact for which the explanation can wait; but Huygens wants it right away, and it must be complete and fully mechanical. And they will behave in exactly the same way in the case of gravitation; from these two exemplar cases of light propagation and celestial mechanics, one may even predict their respective positions concerning other planetary systems and their habitability: Newton feels no need to formulate that sort of additional hypothesis, unnecessary for explaining all known facts, while Huygens rejoices in a notion that fits perfectly within his Cartesian world model. However, in the 1713 edition of his *Principia*, p. 544, Newton added a guarded allusion to possible other planetary systems:

> This most beautiful system of the Sun, planets and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being. And if the fixed stars are the centres of other like systems, these, being formed by the like wise counsel, must all be subject to the same dominion of One…

At the time, it must have become impossible to ignore the contributions of Fontenelle and Huygens altogether. Concerning Plurality, in 2019, the majority mood is triumphantly Hugenian.

As already seen, the Huygens refusal of all explanations based on "qualities, substantial forms, intentional species…" is radical, and fully Cartesian. This guiding principle he will follow throughout his life, and it will lead him, in a perfectly logical manner, to his worst mistake: a categorical rejection of Newtonian gravitation, similar to that of the Newtonian colors, and for the same reasons. This major failure has to be discussed if we insist nevertheless on upholding him as the father of Plurality in modern garb.

Truly, can we blame Huygens? In the whole history of science, there is possibly no more ironical twist anywhere than in the devious way chosen by Fate to unveil universal gravitation. The time-worn Peripatetic qualities had just been unmasked and revealed for what they had always been: pale inconsistent shadows, cloaks for ignoramuses, scarecrows flourished by pedants, mere hollow words which had never once led to the prediction of any novel effect nor to the quantitative analysis of a single phenomenon. Half a century after Descartes' *Discours de la Méthode*, all were at long last dead and buried, and the Cartesian universe was (or tried to be) fully mechanical. And then! out of a clear blue sky, one new occult quality fell down to Earth, and presented natural philosophers with an explanation of the Cosmos more universal, more strictly mathematical and more exquisitely accurate than any of them had ever dreamed about. Einstein's famous one-liner notwithstanding, God has been in the case of gravitation not merely subtle but also malicious; and worse.

In 1669, long before Newton's *Principia* appeared on the scene, Huygens had already presented his own thoughts on gravity, when the still-young French Academy devoted a few sessions to that venerable conundrum (see Costabel in *HFR*, 139). Here are the key-points of his fully-Cartesian argument:

> In order to search an intelligible cause for gravity, one had to suppose only bodies made of the same matter, within which one considers no quality nor inclination to approach each other, but merely different magnitudes, shapes and motions… We see two kinds of motions in the world, the straight and the circular…

But the first is quite well known, together with the collision laws, and whenever closely studied "nothing is found which determines a center. Thus, one must necessarily resort to properties of circular motion." The resulting hypothesis is Cartesian: subtle matter rapidly whirling around the Earth (or other celestial bodies) pushes down heavy matter toward a centre. The advantage is that we can visualise the model, and that it obeys the Descartes golden rule: any motion is solely caused by other motions through collisions. Huygens stresses

> an experiment, rather easy but quite worthy of notice because it shows to the eye some sort of image of gravity, by rotating water in a flat-bottomed vessel after adding small particles of some matter a little heavier than water…as soon as they reach the bottom they will gather close to the center… (Huygens, *Mémoire,* Aug. 28 1669, *OCCH* XIX, 631, 633).

Actually, a similar experiment had already been at least proposed by Descartes (see the preceeding chapter), but it is here better described, since Huygens knows all about centrifugal force; still, it remains qualitative, and (to our modern eyes) completely irrelevant to gravity. The experimental tests for which Huygens is remembered as a pioneer of modern mechanics fall into an altogether different class.

When he takes up the subject of gravity again, in his 1690 *Discours de la Pesanteur,* Huygens faces a changed situation. He has received his copy of the Newton *Principia* three years before, and he is one of the few scientists able to follow its mathematics fully. On his side, Newton was fully aware of Huygens stature as a mathematician: an early biographer writes "He thought him the most elegant of any mathematical writer of modern times" (quoted by Yoder 1988, p. 145). Thus, the strength of the Newtonian argumentation is not lost on Huygens, and he will readily acknowledge "… the high esteem in which this work is held, and rightfully so, as one could not find anything more clever in these matters, nor that shows a greater acuteness of mind." The hard fact of accurate predictions of planetary motions, totally unexpected by himself, was inescapable:

> Thus I have nothing against the Vis Centripeta, as Mr. Newton calls it… by supposing such a gravity toward the Sun, and decreasing with the said proportion, it counterbalances so well the centrifugal forces of the Planets, and produces so precisely the Elliptical motion effect that Kepler had guessed and verified from observations, that I cannot doubt those Hypotheses about gravity being true, nor that the System of Mr. Newton, insofar as based on the same, is similarly true… There is found the solution of several problems that caused much pain with the supposed vortices of Des Cartes… One sees how the Comets are able to cross our System… it was difficult to conceive how they could move against the Vortex that was strong enough to carry the Planets. (*Discours de la Cause de la Pesanteur*, *OCCH* XXI, 475, 473).

However, acknowledging both convenience and accuracy of the Newtonian $1/r^2$ law did not mean for Huygens granting it the exalted status of true physical explanation; he found himself in the situation of those astronomers who had been ready to use the Copernican model as mathematical tool while refusing it all semblance of reality. For himself and all Cartesians, any sort of force at a distance remained unthinkable; the full horror of the concept has been best expressed by Leibniz: if it "is a law of God who brings about this effect without using any intelligible means, then it is a senseless occult property which is so very occult that it can never be cleared up." (*Leibniz letter to Hartsoeker*, quoted and translated by Bell 1947, p. 86). Moreover, even for those who (unlike Descartes himself) insisted on fully mathematical mechanics, the assumption of an inverse-square variation smacked of the arbitrary. Within optics, the Kepler law of illumination decreasing as the inverse-square distance from the source had been a straightforward deduction from Euclidean geometry, hence was readily granted by all without any soul-searching. But when gravitation was concerned, Newton had explicitly given up any such demonstration: *"Hypotheses non fingo…"*; and none of his followers proved able to do any better, a situation that was to persist during two very-full centuries. Thus it is hard to blame Huygens too much when he writes:

> I am not in agreement with a Principle… which is that all the small parts that may be fancied within two or more different bodies, attract each other or tend to get closer. That much

> I am unable to admit, because I believe I can clearly see that the cause of such an attraction is not explainable from any principle of Mechanics…

And the true underlying cause of gravity remained for him what it had always been: a vortex of subtle matter, invisible but easy to visualise from the mind's eye:

> to these bodies which we call weighty, gravity may be impressed by the centrifugal force of a matter which has no weight toward the centre of the Earth because of its very fast circular motion, but tends to get away. (*Discours de la Cause de la Pesanteur*, *OCCH* XXI, 474).

Conclusion: Huygens remained a vortex devotee up to the end of his life, and never realised that such pleasing tools had grown just as obsolete as the Peripatetic qualities. He failed to anticipate the revolution brought to physics by the universal gravitation concept, and the deep wisdom hidden behind the Newtonian refusal to search for a further cause. Unlike any Newton disciple, he would have been unable even to suggest the experiment (performed by Cavendish one hundred years later) which was to demonstrate and measure attraction in the laboratory. Nevertheless, the only obnoxious consequence for his world picture was that he could not provide celestial bodies with a computed mass; but Newton himself was still unable to do it, even for the Earth. Altogether, at the time when Huygens was writing *Cosmotheoros*, every part of his personal Cosmos was ruled by a universal inverse-square-distance centripetal force law; ruled, but definitely not explained. However, when everything is said, neither is ours; thus, despite his rejection of attraction and reliance on vestigial vortices, the Huygens brand of Plurality rested on physics not so distant from our own.

Cosmology From Observations

However, the Hugenian cosmos was not simply elaborated from his physics, much unlike the *a priori* construct of his master Descartes: it was based on recent observations carried out with the help of the latest and fanciest telescopes, in particular his own. Apart from mathematical problems, the very first efforts of Huygens had been devoted to optics; these ripened during most of his life, and led to his wave theory of light, which was to be presented in the 1690 *Traité de la Lumière*. There is no need to follow this line here: whether light operates through waves or particles makes no difference to the information it carries about planets or stars, and we will be only concerned with Huygens' practical achievements.

He had made an early start, long before coming to Paris, and while he published rather little about his techniques, they were closely involved in his astronomical discoveries, and helped to make him while still very young one of the best observers of the time. In his *Letters*, the earliest ones mentioning lenses and telescopes appear in 1652, when he was twenty-three. A large number of his own papers have been preserved; he had soon become interested simultaneously in lens theory and lens polishing. His numerous diagrams of optical systems, while crudely scribbled, look almost modern. Like Descartes, he was much concerned about spherical aberration and vainly looked for solutions from aspheric surfaces polished by elaborate machines. Like him (and everybody else before Newton) he did not understand chromatic aberration; still, he knew that in practice the obnoxious effects would be reduced by increasing telescope length. Unfortunately, he waited until 1690 to publish as *Dioptrica* the bulk of his studies on geometrical optics and by then much of their novelty had been lost.

Of immediate relevance to astronomy were two novel optical devices: the micrometer, and the so-called Huygens eyepiece. His very primitive micrometer was already usable at the time of his Saturn discoveries in 1655–6, and is described in his *Systema Saturnium*. The starting point had been the discovery of an unrealised advantage of the convergent Kepler eyepiece compared to the divergent Galileo type:

> There is a certain place, located about twice as far from the eye as the convex eyepiece, such that if an object as fine and small as one wants is placed there, it is seen distinctly, with an extremely sharp contour… Thus one should prepare some rod of copper or some other substance of gradually decreasing width…

Unfortunately, no drawing nor more precise description survives; King (1955, fig. 4 p. 97), gives a partly imaginative reconstruction. This tapered "rod" (more likely some sort of thin strip?) was used to occult a planet, or a pair of stars, and the corresponding width measured later. Unfortunately, such a procedure always gives an overestimate of the wanted angle: as lens aberrations invariably widen the image, trying to occult it fully is misleading, and Huygens planetary diameters all turn out to be too large, for which he was to be rebuked by Newton. Later, he proceeded to a less-clumsy form of micrometer that became better known "a small grid divided in a certain number of equal squares formed by very-fine silk or metal threads." (*Histoire de l'Académie Royale des Sciences*, I, p. 10). Ironically, the definitive mobile-wire type had been invented years before by William Gascoigne in England, but never published, and remained unknown while Huygens performed most of his work. As to the invention of the compound eyepiece, it arose from the desire of a further increase of the field of view, beyond that given by the single-lens Kepler type. Huygens arrived at his elegant combination of two plano-convex lenses partly by trial-and-error, but also from his exact computation of spherical aberration; as his solution involved only spherical surfaces, it proved easy to build. His peculiar Archimedes-like ability to solve problems involving both theory and experiment, already expressed in the cycloidal pendulum case, is found again in the Huygens eyepiece. The device was not yet available at the time of the Saturn ring observations, but remains in use today (see Acloque, *HFR*, 177).

The place of Huygens within astronomy would nevertheless remain a minor one had he not built with his own hands several remarkable telescopes; actually, four hands were involved since his brother Constantijn Jr. performed at least half of the work, and their collaboration was long and intimate, as shown by many *Letters*. They built together two telescopes, which were immediately put to excellent use, being responsible for the discoveries of the Saturn ring and satellite Titan. As early as 1656 the brothers became convinced that even longer ones would prove better: "if one could reach a hundred or 2 hundred feet, doubtless one could see the planets revolving around their axis." (*Letter from Ch. Huygens to Chapelai*, July 165, *OCCH*, I, 472). They were not alone in pursuing that goal, and fantastically long telescopes began to appear throughout Europe; today, this craze looks absurd, since we know that both resolving power and luminosity depend only on objective-lens diameter; however, as seen above, chromatic aberration was mitigated by an increase of focal length. As to Newton's much shorter mirror telescope (also built with his own hands), it remained hardly more than an interesting toy for astronomers, and never produced a single astronomical discovery before William Herschel radically increased its size one hundred years later. In Huygens' days, the most spectacular undertaking was that of Johannes Hevelius in Danzig, who managed to operate a 45 m-long telescope hanging from a vertical mast! This would be hard to believe, if it were not for the magnificent engravings. A formidable team of assistants was required; even so, pointing was extremely difficult and wind and vibrations remained a constant hindrance.

Such a brute-force approach could go no farther and a different type of mount was needed; at which point sheer instrumental ingenuity was required, and here nobody could beat Huygens. His own solution was not described before 1684, in a small brochure published in Den Haag entitled *Astroscopia Compendiaria Tubi Optici Molimine Liberata* (Abridged method for observing celestial bodies, freed from the encumbrance of the optical tube); it involved a tubeless mount. This highly-elegant device is shown and briefly explained in figure 12.1. Huygens discusses at length construction details and operating mode, ending by speculations of which at least the spirit appears wholly modern: how far is it feasible to go in the same direction? do ultimate limits exist? His own mast is merely 50 feet high, and permits the use of lenses with a 70 ft. focal length (not too close to zenith); however, by interconnecting several masts with a trestle of oblique beams "we shall easily reach a height of 100 ft… truly, I cannot impose precise limits to the art." Even so, his speculations remain far more prudent than those of Descartes writing to Ferrier, since there is no hope "to perceive with our own eyes if [moon and planets] are inhabited by living creatures." (*OCCH*, XV, 228).

However, after such a promising start, no actual results were reported; most further discoveries were to be reaped at the Paris Observatory by Cassini, whose observing assiduity Christiaan never matched. Also, brother Constantijn abandoned lens polishing and reverted to the family calling of diplomacy.

The two great Huygens astronomical discoveries are well known, and will only be mentioned here. The first one is Saturn's satellite Titan. The second is the ring around Saturn, which was seen by many before, beginning with Galileo, but not understood as such. This shows the future author of *Cosmotheoros* to have been at the frontier of astronomical research, and far more intimately acquainted with celestial observing than Fontenelle. Not merely did he build with his own hands and use with his own eyes some of the best available tools for looking at these other Worlds, but he proved himself a master at interpreting imperfect telescope images, from then on a key part of the game. His ramblings about Planetarians etc.… will of course be pure speculation, but at least based on the latest scientific data, and from the pen of a true expert. What else are we hoping for today?

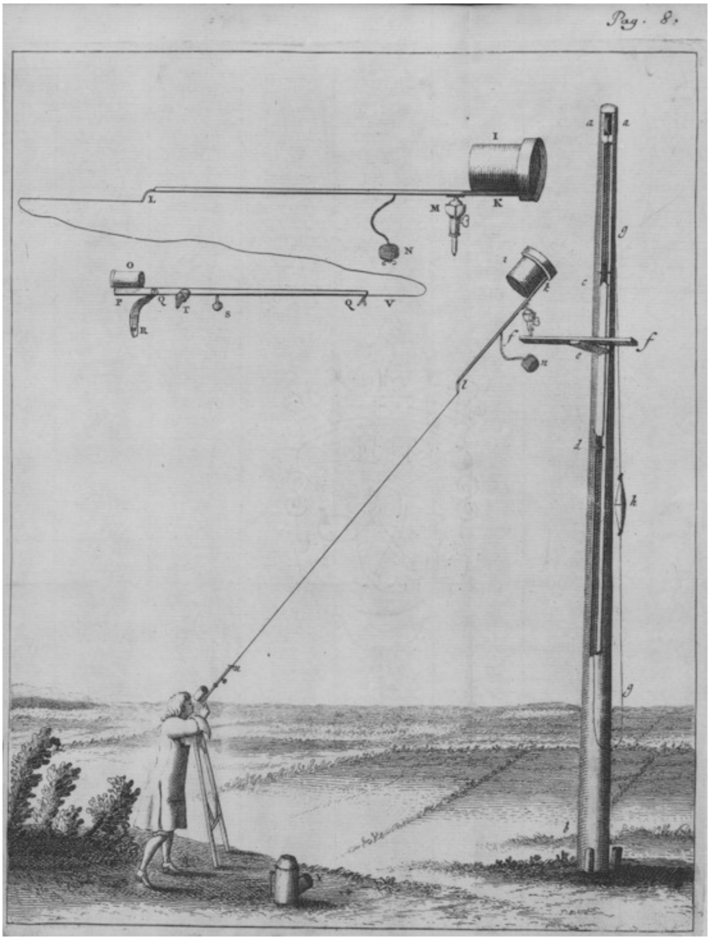

Figure 12.1 Huygens' Astroscope. The objective lens *k* (upper right) is supported by the mast; its height may be adjusted by use of a slide. The pull from the wire keeps the lens perpendicular to the light beam. The eyepiece *o* is carried on a separate stand; the complete mechanism is detailed on top. The lantern (standing on the ground) may be used for checking objective alignment through the reflected light. This astute and elegant solution, praised by Newton, had no future: Cassini was to gather better results from his own standard mounts, or absence of. www.e-rara.ch

In order to understand Huygens' development of the Plurality theme, one still has to account for his views about the size of our own planetary system, and on stellar distances. To the first subject, he contributed nothing, but used (somewhat by luck) a nearly exact figure, which provided him with roughly correct sizes for all planets, an essential parameter for proper comparison with Earth. On the second question, Huygens was first to estimate the distance of stars from a measurement of their brightness; even if his result was still very crude (and soon superseded by a better one from Newton), it provided him with adequate room to install his other planetary systems.

To start with, the solar-system picture of Huygens had by no means been free of Pythagorean-or Keplerian-like postulates. For instance, after discovering Titan, he did not hesitate to write that his new find "completes the collection of wandering stars and their number of twelve. I would almost affirm that no more will be found"[5]; alas! Cassini was to prove him wrong within a few years. On the question of solar and/or planetary distance, he had better luck, and a fundamental belief in celestial harmony led him by pure chance to an almost correct result. One remembers that Galileo, Kepler and Descartes had still relied on the old and much too small Ptolemaic solar distance estimate, which made the Earth a remarkably large planet. Huygens is free from such delusions, and stresses in *Systema Saturnium* that "no reasonable method for measuring that distance has yet been found. Whether they try to derive it from the Eclipses or from the Moon's dichotomy, it is easy to show that such efforts must be in vain" (*Systema Saturnium*, *OCCH*, XV, 347–348); in which he is fully right. Next, the only other procedure he can think of is

> to observe with the telescope the apparent diameter of planets… then to adopt for size of the Earth relative to the others that which best agrees with the order and the good disposition of the whole system [*totius systematis ordini aptæque dispositioni*]." (*Systema Saturnium*, *OCCH*, XV, 344).

Here, he drifts out of luck, neither Plato's *Demiourgos* nor the Biblical Creator having shown loving concern with *apta dispositio* in the case: the first four planets happen to be rather small, the next two are quite large, and that's that. Poor Huygens feels disappointed; where is he going to find order? There remains a saving grace:

> Nevertheless, in order to preserve as much as feasible the harmony of the entire system, it seems after all more reasonable to admit that, as the Earth is placed between Mars and Venus as to distance, it also occupies an intermediate position in size.

Now, he has a possible base for his calculation; starting from the Mars and Venus apparent diameters, and after some juggling with fractions, he is able to conclude that "the [linear] diameter of Earth is 1/12 543 of its distance to the Sun". Q.E.D! At which point, it is the modern reader who is tempted to invoke divine intervention, as the actual figure happens to be 1/11 728, a 5% error and all from an utterly fanciful argument. Admittedly, Huygens is ready to grant that "this computation relies on a shaky basis" but even so he insists that he has found the correct order of magnitude, and "there is no other method in which a ten-times larger error should not be feared"; in which he had been, so far, perfectly right.

However, within a few years, the solar-distance problem was solved, not through unearthing any further hints from Plato, but by trigonometry with decisive help from those micrometers to which Huygens had so much contributed; it is best followed through the invaluable *Measuring the Universe* of Albert Van Helden (1985). The estimate of the solar-system size relying at long last on a correct technique (a key

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[5] Dedication of *Systema Saturnium* to Prince Leopold of Etruria, *OCCH*, XV, 214. This figure of 12 comes from 6 planets, 4 Jupiter satellites, one for the Earth and one for Saturn.

step in the history of astronomy) resulted from the determination of the Mars parallax. The first step was a 1672 *Académie des Sciences* expedition to Guyana, where Jean Richer was entrusted with the observations of the planet, while Giovanni-Domenico Cassini stayed in Paris to make similar ones; next the program was pursued solely from the Paris Observatory. The positions of Mars relative to distant stars were simultaneously observed from two very distant places on Earth by two observers, hence the distance of the planet knowing the distance between the two observing sites; the subsequent Paris data used the rotation of the Earth to change the viewing-point of a single observer. The full solar-parallax story is actually more complex (and interesting!) than as summarised here: see Van Helden (1985). The young Flamsteed independently performed valuable work from Greenwich. In the short term, results seem to have appeared less decisive to contemporaries than commonly believed today; thus Huygens may be excused to some extent for paying scant attention, and sticking to his own estimate, which we have seen to differ little anyway.

Next, the angular diameter of each planet was needed; here Huygens could rely on his own figures. However, as already seen, with his primitive micrometer all such angles were over-valued; so, when Huygens plotted planetary diameters relative to the Sun (figure 12.2) they were all too large. The result is deeply ironical: the mistake does not arise from any error in distance estimates, where he had been right by sheer luck, but from optical measurements which he believed fully objective. Even so, the correct order of magnitude of all planetary sizes was now known, and the Earth at long last took its proper place among the lesser planets of our own Solar system: a thoroughly unremarkable one.

For a conception of multiple planetary systems approaching the modern one, at least rough estimates of stellar distances are needed. Previous treatments of the subject had been completely misleading, from either wrong optical arguments (Kepler), or fanciful physics (Descartes). In the first case, there had been no room at all for other systems; in the second, they were all crowded together without vacant spaces, since Descartes had simply ignored the distance problem. As to Fontenelle, we have already seen him starting from frankly confused notions about those distances, and correcting them from Huygens. From the time of Copernicus the principle of stellar parallax measurements had been well understood, and in the waning seventeenth century several attempts were made using those newfangled micrometers, which gave wild and contradictory results. Huygens was first to show that a totally different optical technique could at least give hints about stellar distance: his tool was not trigonometry, but photometry, for which no name yet existed. The question is not tackled before the final pages of *Cosmotheoros*, and may be some of the last he ever wrote.

Huygens starts from a thorough demolition of Kepler, who had wildly overestimated stellar angular diameters, and deduced all stars to be at similar distances from Earth. This is

> a thing that we need go no farther than the Lamps set along the Streets to prove. For although they are a hundred foot from one another, yet you may count twenty of them in a continued row with your eyes, and yet the twentieth of them scarce makes an Angle of six Seconds.

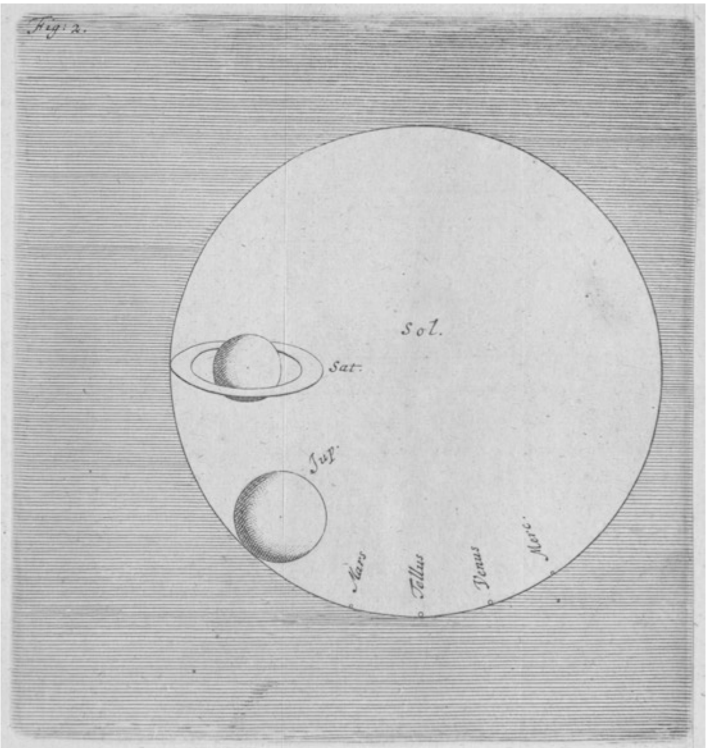

Figure 12.2 Sizes of the planets relative to the Sun. They are mostly too large, due to Huygens' primitive micrometer. www.e-rara.ch

As a consequence, he had granted the Sun a unique role and position, but his true and barely hidden reasons had not been physical:

> *Kepler* had a private design in making the Sun thus superior to all other Stars and planting it in the middle of the World attended with the Planets, a favour that he did not desire to grant to the rest. For his aim was by it to strengthen his Cosmographical Mystery… but that whole Mystery is nothing but an idle Dream taken from *Pythagoras* or *Plato*'s philosophy. (*Cosmotheoros*, 145-6).

More recent attempts by colleagues to measure stellar parallax had proved unreliable "by reason of the extreme niceness and almost impossibility of the Observations requisite for their purpose."

Now Huygens proposes a new technique, which relies on the assumption "that the Stars are so many Suns"; then, the brightest are simply the closest. He will attenuate the light from the Sun until it looks equal to Sirius in brightness: "To this purpose I clos'd one end of my twelve-foot Tube with a very thin Plate, in the middle of which I made a hole not exceeding the twelfth part of a Line [i.e. 0.17 mm]." Looking at the Sun, he concluded that such a "little piece of him was brighter much than the Dog-Star in the clearest night"; hence, much greater attenuation was still required. A longer tube was impractical and a smaller hole difficult, thus "against it I plac'd a little round Glass that I had made use of in my Microscopes. According to the rules of Dioptricks I found his Diameter now was but 1/152 part…" Finally, the Sun-hole-lens system "will send us just the same Light as the Dog-Star now doth; and his Distance then from us will be…undoubtedly as 27 664 is to 1." At which point the author breaks into dithyrambs, strangely forgetting that his *Cosmotheoros,* unlike the *Entretiens*, is written for professionals:

> And what an incredible distance that is… for if 25 years are required for a Bullet out of a Cannon to travel from the Sun to us…. [it] would spend almost seven hundred thousand years in its Journey between us and the nearest of the fix'd Stars… And what a prodigious number must there be besides of those which are placed so deep in the vast spaces of Heaven, as to be as remote from these as these are from the Sun!

The spectacle is so dramatic indeed that Huygens makes a very rare call to "consider the infinite power of God." (*Cosmotheoros*, 152–154).

Unlike him, we feel moved to admire more the power of the human mind, which had at long last measured rather than fancied the distance of the stars. Even so, the Huygens technique is still primitive, and his Sirius distance proves twenty times too small. One reason is Nature's perversity, as Sirius happens to be intrinsically much brighter than the Sun; the other, that the human eye acts as a passable photometer only when two illuminated patches are presented side-by-side; in the Sun-Sirius case, human memory (a disastrously subjective tool) had been involved. However, this defect was soon corrected by Isaac Newton, who described a safer procedure, and obtained a larger distance which has been better remembered, and proved more influential. This is found only in his posthumous *System of the World* (Newton 1728, p. 92); he does not say that he took any hint from this rather hidden passage of *Cosmotheoros*, a work that must have held little appeal for him. While Newton's understanding of photometry does not surpass Huygens', he starts from a more practical idea: comparing our Sun-illuminated planets with some bright stars; these are simultaneously visible, which provides a key advantage. He builds his case from Saturn "which receives but about 1/2100000000 of the Sun's light." Then, he knows from common observations that "Saturn… without its ring is somewhat more lucid than a fixed Star of the first magnitude." Lastly he has to make (like Huygens) an arbitrary assumption since he needs to know the fraction of the incident sunlight reflected by Saturn; he settles on ¼ without argument (the actual value is 0.75), and the conclusion is that "the distance from which the Sun would shine as a fixed Star exceeds that of Saturn by about 10 000 times," which means a 0.42 pc distance and a 2.3 arc sec parallax.

Crude as they were, the Huygens star distances had proved adequate to explain the lack of any measurable parallax and at the same time to provide enough room for multiple planetary systems. Moreover, physics acted in the same way: thanks to his acceptance of vacuum, he was freed from the necessity of filling space to the brim, and his own vortices became far less naïve than those inherited from the Master:

> For Des Cartes makes his so large, as every one of them to touch all the others round them in a flat Surface, just as you have seen the Bladders that Boys blow in Soap-suds do; and

> would have the whole Vortex to move round in the same way. But the Angles of every Vortex will be no small hindrance to such a Motion." (*Cosmotheoros,* 157).

Altogether, while still built of a fanciful subtle matter, these updated vortices generated a Newtonian-type inverse square distance centripetal force, revolved according to Kepler's Laws, and (even more important) kept decently aloof from each other.

At this point, we hold all the tools necessary to understand Huygens' adoption of Plurality, and we may tackle *Cosmotheoros*, so far barely sampled.

Cosmotheros and Plurality

Barely ten years separate *Entretiens* and *Cosmotheoros*, and no major astronomical discoveries had taken place in between; hence the two books cannot help having much in common, and superficial analyses are prone to dismiss the second as bringing in no essential novelty. However, the frivolous device of an after dinner conversation with some Marquise in a pleasant park is not used, and the few astronomical diagrams look austere when compared with the appealing theatre scenery relished by Fontenelle. The text is in Latin, apart from the title which mixes in some Greek*: Christiani Hugenii ΚΟΣΜΟΘΕΩΡΟΣ Sive De Terris Coelestibus, earum ornata CONJECTURAE,* which is freely rendered by the 1698 English translator as *The Celestial Worlds discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets.* The word *Cosmotheoros* itself is a fabrication meaning *Cosmic Observer*, thus clearly reminiscent of *Sidereus Nuncius.*(Figure 12.3)

The book is dedicated to *Constantinum Hugenium Fratrem*, and makes pretence to be written for him, or at least for "Men like you, not ignorant in Astronomy and true Philosophy": unlearned readers will not follow the technical arguments, while those who know too much risk misconstruing the purpose of the author. To the first, it is "mere Conjuration to talk of measuring the Distance or Magnitude of the Stars", indeed the one important technical novelty to be found in the book. The second are dangerous; when they learn about

> new Lands and Animals endued with as much Reason as themselves [they] will be ready to fly out into religious Exclamations that we broach Opinions directly opposite the Holy Writ. For we do not there read one word about the Production of such Creatures, nor not so much about their Existence.

For Huygens, such controversies are old hat:

> They have been answer'd so often that I am almost ashamed to repeat it: That it is evident God had no design to make a particular Enumeration in the Holy Scriptures of all the Works of his Creation. (*Cosmotheoros,* 4-8).

Moreover, telescopes have definitively killed the belief that everything in the Universe has been created for the sight or use of Man; but they have forced him to pose a new question: are all these newfangled celestial bodies intended for other

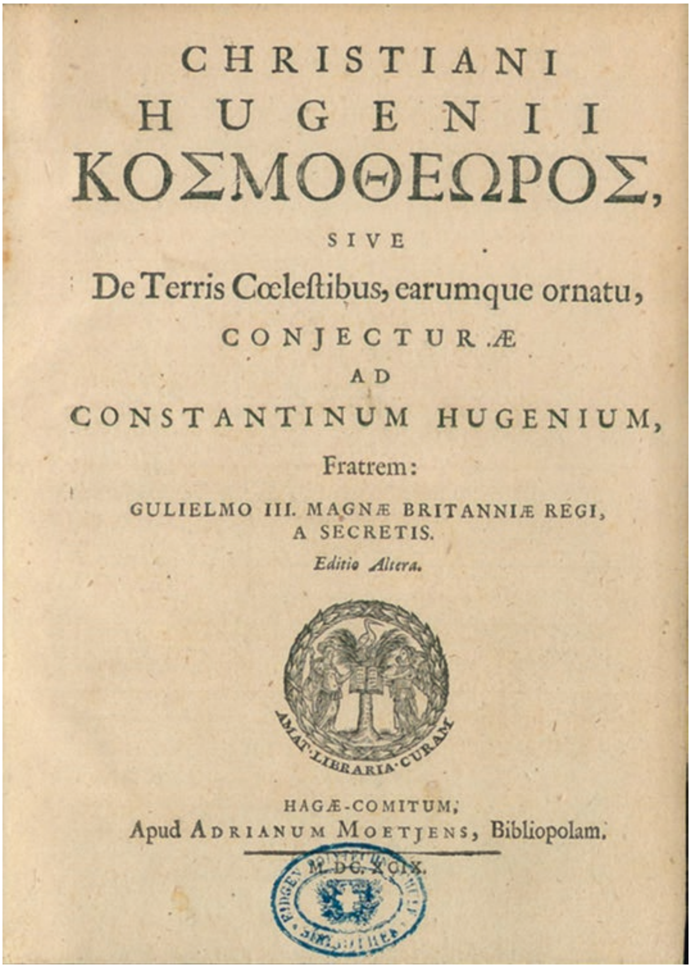
CHRISTIANI
HUGENII
ΚΟΣΜΟΘΕΩΡΟΣ,
SIVE
De Terris Cœleſtibus, earumque ornatu,
CONJECTURÆ
AD
CONSTANTINUM HUGENIUM,
Fratrem:
GULIELMO III. MAGNÆ BRITANNIÆ REGI,
A SECRETIS.
Editio Altera.
AMAT·LIBRARIA·CURAM
HAGÆ-COMITUM,
Apud ADRIANUM MOETJENS, Bibliopolam.
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Figure 12.3 The title page of Cosmotheoros. www.e-rara.ch

creatures? Such will be the basically teleological argument throughout *Cosmotheoros*; no other was conceivable at the time.

Huygens enters the subject through a detailed description of the Solar system, a modernised Copernic-Kepler one from which we have already extracted all the important elements; in particular, the distances and sizes which make the Earth a mediocre planet. Needless to say, Fontenelle's Marquise would never have survived such a preamble. The book begins to drift away from standard handbooks of astronomy when the author stresses this mediocrity, in order to hypothesise unobservable features. For instance, "the other Planets are round like [the Earth], and like it receive all the Light they have from the Sun." Jupiter and Saturn also revolve around their axis, and also have satellites, hence

> since in so many things they thus agree, what can be more probable that in others they agree too; and that the other Planets are as beautiful and as well stock'd with Inhabitants as the Earth? or what shadow of Reason can there be why they should not?…. to reason from what we see and are sure of, to what we cannot, is no false Logick. This must be our Method in this Treatise wherein from the Nature and Circumstances of that Planet which we see before our eyes, we may guess at those that are farther distant from us. (*Cosmotheoros,* 18-19).

The program is that of the entire book and will be carried to the full, step by step.

First, other planets must have a solid surface, and "they don't want what we call Gravity, that virtue which like a loadstone attracts whatsoever is near the Body to its Center." The proof is not new, being simply borrowed from Aristotle, but even today, it looks as fresh as ever: "their Roundness proceeds from an equal pressure of all their parts tending to the same Center." The next step, the introduction of Life is the most hazardous one, and Huygens is ready to confess as much:

> There's somewhat more of a Contrivance, somewhat more of a Miracle in the production of Plants and Animals than in lifeless heaps of inanimate Bodies… the finger of God, and the wisdom of Divine Providence, is in them much more clearly manifest than in the other.

Calling in the Creator was of course unavoidable at this stage; even Descartes, who had held all animals to operate as mere machines, had not attempted to account for their manufacturing process.

> Everything in [animals] is so exactly adapted to some design that they manifest an infinite Wisdom, an exquisite Knowledge in the laws of Nature and Geometry…[it is] an absurdity even to think of their being thus haply jumbled together by a chance Motion of I don't know what little Particles. (*Cosmotheoros,* 20-21).

Indeed, neither Democritus nor Lucretius had ever solved the case, and Huygens cannot be blamed for arguing as a standard seventeenth-century Creationist.

Having made this point, Huygens is convinced to have shown that Reason itself requires planetary life:

> Should we allow the Planets nothing but vast Deserts, lifeless and inanimate Stocks and Stones, and deprive them of all those Creatures that more plainly speak of their Divine Architect, we should sink them below the Earth in Beauty and Dignity; a thing that no Reason will permit. (*Cosmotheoros,* 21).

Alas! At this very instant, he is forgetting the lessons of his master Des Cartes, whose own reason had never taken him along such a dangerous path. The naive disciple is not merely ordering the Creator to behave according to his own wishful thinking, but reintroducing abolished Qualities, and final causes to boot. Descartes had needed a Creator all right, but left Him wholly free to behave as He had seen fit; here we remember

> One should not examine what the aim of God has been when he created any thing, but solely through which means He has wanted it to be produced…We shall totally exclude from our Philosophy the search for final causes, since we should not presume so much about ourselves as to believe that God was bound to make us privy to His councils… (Descartes *Principes,* I, 37; already quoted in our Chapter 11).

This departure from Cartesian orthodoxy is noteworthy; if Descartes had refrained from writing a single line about extraterrestrial life, it was in part because that pleasing appendage could not be inserted within the cosmos without presuming about God's goals. For Huygens, as indeed for Fontenelle and most of their eighteenth-century followers, the restriction vanishes and the so-called Principle of Plenitude will take its place.

Once these premises are granted, the path is clear: planets must have animals, and also the plants required for their food. Even so, efficient causes are not forgotten about: "for their Growth and Nourishment, 'tis no doubt the same with ours, seeing they have the same Sun to warm and enliven them as ours have." However, a considerable question remains "Must they be of the same nature with ours? Nature seems to court Variety in her Works… she may have made them such as neither our Understanding nor Imagination can conceive." A helpful analogy is brought in: "Who doubts but that God, if he had pleased, might have made the Animals in America and other distant Countries nothing like ours… yet we see that he has not done it… their Animals have Feet and Wings like ours." The author's sensible conclusion is that Nature has not exhibited as much variety as she could, consequently we should not suppose "everything in the Planets quite different from what it is here." The actual differences are even predictable since they should "spring from the greater or less distance and influence from that Fountain of Heat and Life the Sun"; in which line he clearly upholds Fontenelle.

In the development and propagation of living creatures, water plays the key role:

> Their Growth and Nourishment proceeds from some liquid Principle…all Philosophers agree that there can be no other way of Nutrition,

and the technical arguments still seem perfectly sound today:

> The parts of a Liquid being in continual motion one with another, and insinuating and twisting themselves into the smallest Places, are thereby very proper and apt to add not themselves only, but whatsoever else they may bring along with them to the increase and growth of Bodies.

Twenty-first century biochemists are using somewhat fancier language, but are they really saying anything else? And the first rule of the present planetary study programs seems to be: Search for Water. Huygens' only tool is his own telescope:

> That the Planets are not without Water is made not improbable by the late Observations: For about Jupiter are observed some spots of a darker hue than the rest of his Body, which by their continual change show themselves to be Clouds.

Bright spots have also been observed, which "Monsieur Cassini thinks are only the reflection from the Snow that covers the tops of the Hills", but here Huygens takes the liberty of disagreeing: "it is only the colour of the Earth [i.e., solid ground], which chances to be free from those Clouds…" Mars has dark spots too, which have pinpointed the rotation period at 24 h 40 m, still he is not confident that clouds have been truly observed. In any case, different conditions apply:

> Every Planet must have its Waters of such a temper as to be proportion'd to its heat: Jupiter's and Saturn's must… not be liable to frost, Venus' and Mercury's… not easily evaporated by the Sun. (*Cosmotheoros,* 24-28).

However, the case of our Moon is quite different:

> The Moon has no air or Atmosphere surrounding it as we have… [which] hinders all probable Conjectures about it. If we could but once be sure that it had Water… we might, with Xenophanes, furnish it with Inhabitants, Cities and Mountains.[6]

Here, Huygens confesses embarrassment:

> What! And must all those Moons round Jupiter and Saturn be condemned to the same Uselessness?… I know of nothing like them to found a Conjecture upon… Perhaps the moisture of the Earth there is just sufficient to cause a Mist or Dew, which may be very suitable to the growth of their Herbs. Which I remember is Plutarch's opinion, in his Dialogue upon this subject. (*Cosmotheoros,* 131-133).

He has not forgotten Kepler's *Somnium* either, and develops the celestial scenery observed from the surface of the Moon, but far less thoroughly than Kepler: the Copernican system no longer requires a demonstration.

Far more than Fontenelle, Huygens is concerned with presenting a likely picture of the growth and propagation of animals on planets, however not venturing into any form of evolution. He does it from a conservative viewpoint, consistently rejecting the fancy of too exotic mechanisms, either on our own Earth or abroad: "Since all Generation is performed by the impregnating of the Eggs, and the Copulation of Male and Female: Why may not the same rule be observ'd in the Planetary Words?" He refuses to have "new ones made everyday out of some such fruitful Mud as that of the Nile" and stresses that "'tis much more agreeable to the Wisdom of God once for all to create all sorts of Animals… than to be continually obliged to new Productions out of the Earth." As to the forms plants and animals may take, those which are displayed on Earth are plentiful enough, and "they must have as great a variety of both as we have." Down here, all walk "upon two feet or four, or like Insects, upon six, nay sometimes hundreds…" Others fly, or swim or "creep upon the ground without feet… I don't believe, nor can I conceive, that there should be any other way than these mentioned." However, differing physical conditions may be responsible for differences:

> The Air I confess may be much thicker and heavier than ours, and so, without any disadvantage to its Transparency, be fitter for the volatile Animals… The Sea perhaps may have such a fluid lying on it, which tho ten times lighter than Water, may be a hundred times heavier than Air.

Prudence is required:

> I think it is beyond the force of Imagination to arrive at any knowledge in the matter, or reach probability concerning the figures of these Planetary Animals. (*Cosmotheoros,* 30-34).

The next step is the introduction of "Inhabitants, not Men perhaps like ours, but some Creatures or other endued with Reason." The argumentation is both

[6] Huygens may have been first to write down explicitly that the Moon has no atmosphere *(Avertissement du Cosmotheoros*, *OCCH,* XXI, 659), but it is difficult to believe he had been first to formulate the hypothesis. As we have seen, Fontenelle was still putting air around the Moon (*Entretiens,* 63).

teleological and theological: all this "Furniture and Beauty of the Planets [would be] without any design or end unless there were some in them that might at the same time enjoy the Fruits and adore the wise Creator of them." However, Huygens stresses again and again that the principle of Earth mediocrity is just as important for him; were planets devoid of intelligent creatures

> our Earth would have too much the advantage of them…. If we should allow Jupiter a greater variety of other Creatures, more Trees, Herbs and Metals, all these would not advantage and dignify that Planet so much as that one Animal does ours by the admirable Productions of his penetrating Wit. (*Cosmotheoros,* 37-38).

After performing this leap of imagination, the wildest of them all, Huygens asks himself two sets of questions: What about their bodies and what about their minds? In both cases he will remain a conservative at heart, convinced that terrestrial samples provide an adequate glimpse of the universal blueprint.

Bodies first. Planetarians must enjoy appendages very much like hands and feet, stand erect and nevertheless may show up as extremely different from men: "T' is a very ridiculous opinion that the common people have got that it is impossible a rational Soul should dwell in any other shape than ours". The conceptual difficulty is admittedly large: "Yet me thinks this fancy has such a rule upon my mind that I cannot without horror and impatience suffer any other figure for the habitation of a rational Soul." (*Cosmotheoros*, 71–77). Still, very small sizes are ruled out, for which the argument is teleological, and seems rather weak: "our Bodies are made in such proportion to our Earth as to render us capable of travelling about it and making Observations upon it's bulk and figure." (*Cosmotheoros,* 77). Those about the senses of Planetarians (here, intelligent or not) are easier to follow: "Their Animals are like ours in all that relates to the Senses: without the power of Seeing we should find it impossible for Animals to provide Food for themselves." Hence they must have eyes, and even two of them, "otherwise they would not perceive some things close to them, and so could not avoid Mischiefs that take them on the blind side." They must possess a sense of hearing, which "when Seeing is no use it supplys its place and gives us seasonable warning of any imminent danger"; later on, being endowed with ears will take them quite far, indeed to language and society. Next, there is an "inevitable necessity for all creatures that live by feeding to have both Taste and Smell… as for Feeling all Creatures [should be] covered with a fine and sensible Skin." Actually, speculations along those lines must have been rampant, since "it hath been a question with many, whether there might not have been more Senses than those five"; a fancy which Huygens rejects as superfluous, the standard five having proved fully adequate for him. And as a further step on the way to full humanisation of Planetarians: "the senses were not wholly designed for use: Men from them… reap Pleasure as well as Profit", thus the said Pleasure must be universal, as Providence cannot possibly have designed "the Earth, the smallest part almost of the Universe, to monopolize so great a Blessing." (*Cosmotheoros,* 43–53). Altogether, these senses must have led them to "maintain a Society and Fellowship, and afford mutual Assistance and Helps to one another", from which arises the appealing picture of a wholly virtuous Cosmos. Alas! It is at once sadly dismissed:

"Perhaps they may be so just and good as to be at perpetual Peace… But still it's more likely they have such a medley as we, such a mixture of good and bad, of wise with fools, of war with peace." (*Cosmotheoros,* 79–80).

The minds of these exotic intelligent creatures should not be unfathomable either:

> Allowing these Planetarians some sort of Reason, must it needs be the same with ours? Why truly I think 't is, and must be so; whether we consider it as applied to Justice and Morality, or exercized in the Principles and Foundations of Science.

Good and Bad are truly cosmic values: "can what we call just and generous, in *Jupiter* and *Mars* be thought unjust Villany?" This is impossible, because the same Creator has been at work everywhere, and his sole design has been "the preservation and safety of his Creatures." One should allow that "Morality and Passions with those Gentlemen [may be] somewhat different from ours", but at least Science is bound to be truly universal: "in reasoning [about] Magnitude and Quantity… their Reason must be exactly the same, and go the same way to work with ours, and what's true in one part will hold true over the whole Universe." Whatever difference exists "must lie in the degrees of Knowledge, which will be proportional to the Genius and Capacity of the Inhabitants." (*Cosmotheoros,* 41–43). Which is as close to the modern viewpoint as Huygens will ever get; while not making any explicit mention of Biblical chronology, he remains constrained by its time frame, thus none of his alien civilisations ever gets a chance to grow older and wiser than our own.

Even so, an essential question remains: "Whether they have made as great advances in Arts and Knowledge as we in our Planet." (*Cosmotheoros,* 58). Astronomy must have played the central role, because Planetarians cannot help watching those same phenomena that are available to us. Some of them are even luckier: on Earth "Amazement and Fear at the Eclipses of the Moon and the Sun gave the first occasion to the study of Astronomy", but such providential accidents are far more frequent on Jupiter and Saturn, thanks to their swarms of satellites. Wherever astronomy develops, it is bound to require tools, material or mental: observations cannot be made "without Instruments, nor can these be made without Metal, Wood…. Carpenter's Tools, the Saw, the Ax…. these Instruments can't be without a Circle divided into equal Parts… Here's a necessity for introducing Geometry and Arithmetick." Marking and transmitting the observations will require "the Art of Writing; I won't say the same with ours, but I dare affirm not more ingenious or easy", and Huygens mentions disparagingly those unwieldy Chinese characters, and the "Knots tied in Cords or Pictures in use among the barbarous People of *Mexico* and *Peru*." (*Cosmotheoros,* 64). Today, we feel less contemptuous about the *khipu*, and we still have not managed to unravel completely its meaning.

Nevertheless, for reasons which are never cleared up, Huygens is not willing to grant Planetarian astronomy equal status with our own: "But for all our large and liberal allowances to these Gentlemen, they will still be behind-hand with us… we have so an admirable an Invention of Telescopes… we must necessarily be far their Masters in that Knowledge." That Planetarians cannot have telescopes of their own is an unexpected deduction, and the attitude proves quite surprising, since in other places Huygens is willing to grant that "there's no reason to think the Planetarians less ingenious than our selves… It is probable that they are as skilful Astronomers as we can pretend to be." (*Cosmotheoros,* 70). In the same vein "they are as good Architects, have as noble Houses and stately Palaces…. have the use of all those Arts subservient to it and whatsoever else is necessary for it, as Iron, Lead and Glass." (*Cosmotheoros,* 82). More fundamentally, they are just as good mathematicians, and have managed to acquire all the latest tricks:

> They have our Inventions of the Tables of Sines and Logarithms and Algebra." As to geometry, Nature itself "presents us with Geometrical figures… [which] makes it not improbable that there are in the Planets some who partake with us in these delightful and pleasant Studies… It's the same with Musick as with Geometry. (*Cosmotheoros,* 84-86).

Altogether, within all fields Planetarians prove equal, but not better.

Why are telescopes, and more specifically better telescopes, excluded from such pleasant achievements? Was Huygens feeling jealous about all colleagues, either human or planetarian, or simply allergic to science-fiction? On Jupiter he might have erected futuristic versions of his beloved aerial telescope, growing to "one hundred or two hundred feet… [showing] planets revolving around their axis"; he held all the technical data for discussing both possibilities and difficulties, e.g. local winds and gravity. In any case, something prevented him from any steps along this obvious path, and even from asking whether aboard planets anybody was interested in that "delightful Study" of detecting Life on Earth. Fontenelle had proceeded farther, since his Jupiterians might have been embroiled in "some lawsuit against philosophers who have asserted that we exist." Likewise, he had considered at least cases of cosmological changes, and we remember his fable of the rose garden with attendant gardener. Within Hugenian Plurality is found no hint of a past nor any prospect of a future.

In Book II of *Cosmotheoros*, Huygens is mostly concerned with providing the serious astronomical data he needs to erect his fancies; for instance, here are found the planetary sizes and the stellar distances we have quoted before, together with some *Somnium*-like descriptions of the celestial show as observed from the surface of the planets. He provides no further speculations about the nature or life style of Planetarians; for us, the new point of interest lies solely in the extension of his visions to other planetary systems.

Huygens enters the fray by deriding the *Iter Extaticum* of the Jesuit Athanasius Kircher, who (amongst others) had been rejecting all motion of the Earth as late as 1656 through adoption of the Tychonic system. His cosmic-exploration device had been equally orthodox: an angel-powered journey through the Heavens, on which way he had incidentally observed numerous planets circling around each star. However, Kircher had failed to notice his own absurdity: "When he supposes all the fix'd Stars to be Suns and round each of them places their Planets… he has unawaredly made an infinite number of *Copernican* Systems." (*Cosmotheoros,* 102). A more serious criticism is that of Kepler's Sun-centred star distribution, which had solely proceeded from his "idle Dream taken from Pythagoras or Plato." Huygens' own pet dream arises from the opposite conviction: our Sun is a wholly-common star. His fancy of solar-system Planetarians had been based on a Principle of Earth Mediocrity; his extrasolar planetary systems rested on an unexpressed Principle of Sun Mediocrity. Up to a very recent date, we had no more solid ground for erecting our own fancies.

Admittedly, Cusanus and Bruno had fancied as much. The difference is that Huygens is an expert optician and a consummate astronomer, with all the resources of the waning seventeenth century at his disposal. He is still unable to see with his own eyes those hypothetical planetary systems, just like Cusanus and Bruno; but he understands the precise optical reasons for this failure, and presents the problem in terms so modern that hardly any word has to be changed today:

> Why may not every one of these Stars or Suns have as great a Retinue as our Sun, of Planets, with their Moons to wait upon them? Nay, there's a manifest reason why they should. For let us fancy our selves placed at an equal distance from the Sun and the fix'd Stars; we should then perceive no difference between them. For, as for all the Planets that we now see attend the Sun, we should not have the least glimpse of them, either that their Light would be too weak to affect us, or that all the Orbs in which they move would make up one lucid point with the Sun. (*Cosmotheoros,* 149).

Cusanus and Bruno had never posed the problem in terms of material facts fitting or not their metaphysical notions; Kepler had missed it altogether by operating from Pythagorean dreams; Descartes had filled his own Universe with multiple and analogous Vortices, but side-stepped the final question of their content because of theological fears and intellectual restraint; Fontenelle had provided a pleasing, but hazy and qualitative picture for *les gens du monde*. Huygens is a professional astronomer who means precisely what he says. When he sees himself "placed at an equal distance from the Sun and the fix'd Stars", he has measured these distances; when stressing that "Their Light would be too weak to affect us", he means that the light flux collected by the aperture of the largest telescopes is just too faint. Last, "The Orbs… would make up one lucid point with the Sun" means that, given (1) distance of star and radius of planetary orbit, (2) intrinsic luminosities of planet and star, and (3) resolving power of telescope, the proposed observation is not feasible; Q.E.D. While no summary of all those technical points is given within *Cosmotheoros* (except for star distances), the educated reader knows that every single one has been handled in other works of the same author.

Nevertheless, there is still a great deficiency in the Huygens account: the complete absence of all speculations about future technical possibilities. In the above summary, the astronomical parameters are permanent; the distances and angles involved in any attempted search have not become more favorable for the twentieth-century planetary seeker. But the optical devices have grown far more complex and their performance immensely better. During his lifetime, Huygens did witness spectacular improvements of telescopes, many of them his own. His finding of Titan, the biggest satellite of Saturn, had been a great achievement, but at the end of his career, the last Saturn satellite discovered by Cassini showed up as ten times fainter. He had unveiled the Ring, but some years later Cassini proved it to be double, with a very faint gap between the two parts. Thus some modest conjectures about the feats that would hopefully become achievable in the future would not have been out of place *in fine*; and the Saturnians might have been granted right away larger and better telescopes, leading (why not?) to the discovery of cities on Earth; however, Huygens does not proceed beyond Fontenelle. Such speculations, through which any similar modern text would unavoidably conclude, are not attempted. We are left with the feeling that *Cosmotheoros* is, on that count, frankly incomplete.

Last act: the long-awaited introduction of more Planetarians around those other Suns presents no difficulty. We must

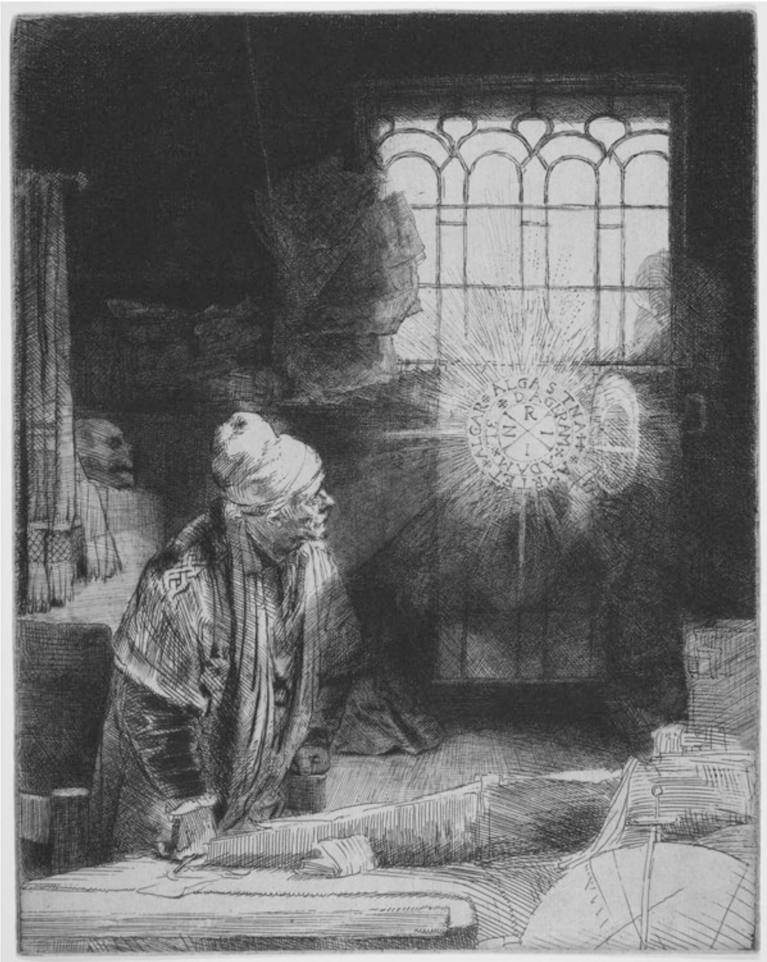
> conclude that our Star has no better attendance than the others…those Planets… must have their Plants and Animals, nay and their rational ones too, and those as great Admirers and as diligent Observers of the Heavens as our selves.

And the closing encomium is not unexpected:

> What a wonderful and amazing Scheme have we here of the magnificent Vastness of the Universe! So many Suns, so many Earths, and everyone of them stock'd with so many Herbs, Trees and Animals… (*Cosmotheoros,* 150).

Indeed, the news trumpeted by that *Cosmic Observer* were even more startling than all those from the *Starry Messenger*. Alas, unlike them, they were to prove premature, the Creator having grievously failed to oblige; unlike Huygens, He had been a philosopher, and not one from any deviant Cartesian school. That "wonderful and amazing scheme" lacked all substance, and *Cosmotheoros* would have shown himself wiser had he remembered the advice of his earthly Master "One should not examine what the aim of God has been when he created anything, but solely through which means He has wanted it to be produced."

Chapter 13
Plurality Enters the Scientific Era



Faust receives an extraterrestrial message (engraving by Rembrandt van Rijn, ca. 1652). Metropolitan Museum of Art

P. Connes, *History of the Plurality of Worlds*, Historical & Cultural Astronomy,
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It is when we consider recent discoveries in their relation to the existence of other worlds, when we attempt to form a conception of the immense varieties of the forms of life corresponding to the innumerable varieties of cosmical structure disclosed by modern researches, that we recognise the full significance of those discoveries.

Richard Proctor, *Other worlds than ours* (1870).

Is it not a mere dream of human vanity, to make the Moon a celestial Earth, to fancy mountains and valleys over there like Anaxagoras? To erect human dwellings of habitations, and to institute colonies for our convenience?

Michel de Montaigne, *Essais* (1595).

After Huygens, the history of Plurality becomes relatively uninteresting for almost two centuries, for lack of new data. The Hugenian Plurality was practically identical to our modern view, except for being limited to a static picture, in which the time coordinate held no place at all. It was already known that even the nearest stars are extremely distant, so that in spite of the high velocity of light any interstellar communication would be very slow at the human scale. A new perspective arose from the laborious unveiling of a very large time-scale, for astronomy, geology and biology together. The short biblical age of the Universe extended progressively to million, then to billion years, leaving much room for evolution and for possible birth and death of distant worlds and civilisations. [1]

Then, at the end of the last century, came the events expected for so long: the discovery of planets about other stars than the Sun, and the realization that the conditions in many of these planets might be favorable for life. Some might actually harbor life, but this still remains to be demonstrated. Thus, while the exploration of the Solar system has shown that Internal Plurality can only be limited to primitive forms of life, External Plurality might flourish: what has long been a dream might become reality, perhaps even during the present century.

This is the story told in the present chapter. But let us first go through some fancies that occurred after Huygens.

Plurality in the Last Three Centuries

At the beginning of the 18th century, it was generally taken for granted that the planets and their satellites might harbor plants and animals, even the Moon in spite of its known lack of atmosphere. What is more surprising to us is that life was also considered possible on the Sun in spite of its high temperature. The idea was

[1] *This chapter has been arranged by the Editor, using elements left by Pierre Connes.*

developed by Johann Elert Bode and William Herschel and survived until the middle of the 19th century. A model for the surface of the Sun was developed by Alexander Wilson and Bode in the 1770s, and perfected by Herschel. For them, the Sun has a solid surface and a very hot, luminous atmosphere (Figure 13.1). The surface can be seen directly in the central parts of sunspots, which are holes in the atmosphere, while in the external parts of the sunspots (the penumbra) we see an intermediate, reflecting layer: according to Herschel (1795, 51), "the luminous shelving sides of a spot may be explained by a gentle and gradual removal of the shining fluid, which permits us to see the globe of the Sun." As remarked by Arago (1842, 486), "the cores of sunspots, even if they look dark, would dazzle by their very bright light those who would see them separately." Indeed, he notes that Herschel has estimated their brightness as 7/1000 of that of the photosphere, a reasonable but still very high figure. For Herschel, the light of the Sun comes from "decompositions [chemical reactions] of the elastic fluids of the sun,… of a phosphoric nature, and attended with lucid appearences…".

For him, this light does not heat the surface, in the same way as the terrestrial clouds do not heat the soil of the Earth, so that life is possible: Herschel pretends that

> heat is produced by the sun's rays only when they act upon a calorific medium; they are the cause of the production of heat, by uniting with the matter of fire, which is contained in the substances that are heated: as the collision of flint and steel will inflame a magazine of gun powder, by putting all the latent fire it contains into action… We have only to admit, that on the sun itself, the elastic fluids composing its atmosphere, and the matter on its surface, are

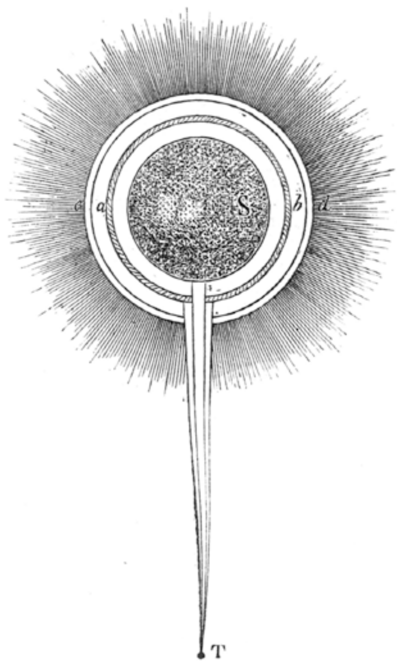

Figure 13.1 The Sun according to Herschel and Arago. The dark globe of the Sun is surrounded by an opaque and reflecting layer, then by a light-producing layer. The sunspots are holes in these layers allowing to see either the reflecting layer (penumbra) or the surface of the globe (center of the sunspot). From Arago's *Astronomie populaire*

> of such a nature as not to be capable of any excessive affection from its own rays… (Herschel 1795, 63).

Of course, this poor physics will soon be superseded by the works of Sadi Carnot and Joseph Fourier. Herschel concludes:

> The sun, viewed in this light, appears to be nothing else than a very eminent, large and lucid planet, evidently the first, or in strictness of speaking, the only primary one of our system; all others being truly secondary to it. Its similarity to the other globes of the solar system with regard to its solidity, its atmosphere, and its diversified surface; the rotation upon its axis, and the fall of heavy bodies, leads us on to suppose that it is most probably also inhabited, like the rest of the planets, by beings whose organs are adapted to the peculiar circumstances of that vast globe… I thing myself authorized, *upon astronomical principles*, to propose the sun as an inhabitable world…

Then he goes on to suppose that the Moon, the planets and their satellites are also inhabited "with a high probability." As the stars are other suns, they might also be inhabited as well as the planets which are expected to orbit around them, except in dense star clusters, where

> it will hardly be possible to assign any sufficient mutual distance to the stars composing the cluster, to leave room for crowding in those planets, for whose support these stars have been, or might be supposed to exist." (Herschel 1795, 69).

Strangely enough, these ideas were still vivid more than fifty years later. One can still find in the second edition of Arago's posthumus *Astronomie Populaire* (1865, t. 2, 181), and even in the third edition of 1867, which was supposed "to take into account the progresses of science":

> If one would ask me simply the question: is the Sun inhabited, I would answer that I don't know. But if one were to ask me if the Sun can be inhabited by beings organized in a similar way as those that live on the Earth, I would not hesitate to give an affirmative answer. The existence in the Sun of a dark central core surrounded by an opaque atmosphere, far from which is the luminous atmosphere, is not at all opposed to such an idea.

Clearly Arago had forgotten Joseph Fourier, who he had however met very often at the Academy of Sciences, and the editor, Jean-Augustin Barral, although a good physicist, did not dare to correct the text. In his famous *La pluralité des mondes habités*, the young Camille Flammarion stays silent about the inhabitability of the Sun, but for a remark on its very high gravity, that would crush any being falling on its surface (Flammarion 1862, 31).

The digging of the channels of Mars by intelligent beings is another "scientific" fancy that was very popular at the end of the 19th century. The story is well known. It starts with a 1858 drawing of the planet by Father Angelo Secchi at the Vatican observatory, in which he describes an extended feature that seems to separate two continents, that he calls *"canale atlantico"*. The italien word *canale* means *channel*, and not *canal*, but it will later take the second, restrictive meaning. In 1877, Giovanni Schiaparelli, director of the Brera observatory near Milan, announces that he sees many dark, straight lines on the surface of Mars, the so-called *canali* (the plural of *canale*). They soon become the dominant features of his maps. Two years later, he claims that some of them are double (Figure 13.2). These results make a scoop, and will be a major incentive to built the big telescopes of the end of the 19th century.

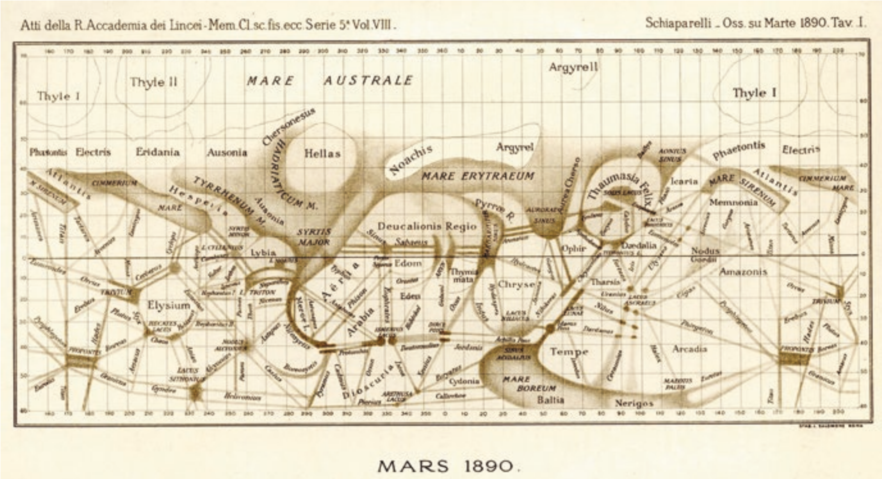

Figure 13.2 Map of Mars drawn by Schiaparelli in 1890. Many canals are double. Bibliothèque de l'Observatoire de Paris

Many professional and amateur astronomers rush to observe Mars. One of them, William Henry Pickering, in 1880 spent a year in the southern station of the Harvard observatory at Arequipa (Peru). He did not honor his assignment, which was to photograph the spectra of many stars, and was instead captivated the discovery of Mars *canali*, which he confirmed through many observations with his telescope, larger than Schiaparelli's. In 1890, after his return in the United States, he met a wealthy amateur, Percival Lowell; they decided to build on the latter's money a specialized observatory at Flagstaff (Arizona), where observations (mainly by Pickering, by a named Douglass then by Lowell himself) began in May 1894. Lowell was convinced that *canali*, now become *canals* in English, were dug by Martians. He believed that visual inspection of Mars was all he needed to confirm his hypothesis that life was present there: there is no trace of photographic or spectroscopic observation in his records.

The fidelity of a drawing to reality is highly dependent of many factors, in particular to expectations of what would be seen; yet, at this time, drawing was widely considered the best means to record what an eyewitness saw. Lowell was convinced that it was possible to control the validity of observations by comparing drawings made at two different dates by the same observer using the same telescope, with similar atmospheric conditions. Of course, this does not help fighting physiological and psychological idiosyncrasies. In any case, "through October and November [1894] Mr. Lowell saw… a number of double canals… They appeared like railroad tracks, straight and closely parallel." (Douglass 1895, 401). Ultimately, Lowell came to believe that Martian engineers were responsible for creating canals as a means of water transport, to irrigate vegetation with water originating in the melting of the polar "snow" caps. In case of obstruction of one canal, they could use the parallel one as a spare! Lowell was followed by many amateurs. These included

Camille Flammarion, who confessed however that he barely saw the canals himself, but was confident in Schiaparelli! Richard Proctor, a prolific English popular writer about astronomy and plurality, was considerably more sceptical. The future showed that he was right. The best observers of the time, Edward Maunder in England, Edward Barnard in the USA, as well as Gaston Millochau and Eugène Antoniadi in France, failed to see any canal even in the best observing conditions and with the largest telescopes. It was clear for them that the canals were optical illusions. However, Lowell, as well as his collaborators Vesto Slipher and Clyde Tombaugh, the discoverer of Pluton, continued to believe in canals for a long time.

Another fancy is concerned with a possible vegetation on Mars. Lowell believed that what he actually saw on Mars was not directly canals, but vegetation on their shores, and his collaboratoer Vesto Slipher tried without success to detect chlorophyll by spectroscopy. Pickering as well as the French astronomer Emmanuel Liais thought that the changing colors of Mars had something to do with vegetation. More seriously, in the same context Gavriil Tikhov in USSR studied the adaptation of plants to extreme conditions, creating “astrobotany” in 1945. Then, the German physiologist Hubertus Strughold published in 1954 a book entitled *The green and red planet* in which he addressed the habitability of planets from the biological point of view.

More than one century later, some of the above ramblings sound frighteningly familiar. Today, we are ready to take as proof of intelligent origin in a radio signal some type of regular pattern; and we do not even wait for the detection of a single one before granting our putative Aliens a quasi-Godlike status. The risk is clear: this mathematical mastermind that Lowell unveiled on Mars, geometrising out of natural chaos, had merely been his own: truly, he was not looking through a telescope, but into a mirror.

This ends the “scientific” attempts to Internal Plurality before the direct space exploration era. Of course, many science-fiction writings or movies have been and are still devoted to Plurality, but they are outside the scope of the present book.

The Time Coordinate of Plurality

As said before, there was no place for time in Plurality for Huygens and his predecessors. By the end of the 17th century, it was known that the stars were very distant and the velocity of light had been determined. Did one realize at the time that this would imply long delays in communication with distant civilisations? We don’t know, but for sure such considerations played no role in the Hugenian concepts: he never connected them with his own speculations about Planetarians.

Similarly, all distant worlds, if they existed, were implicitely supposed to be simultaneous, and made of unevolving beings. Some idea of evolution had been present with Anaximander and the Atomists (see Chapter 1), but nobody during the Huygens era would have wasted thought on such a notion unconnected with the then exploding science, but (even worse), an anti-Christian myth. However, it was progressively realised that the Universe is much older than the Biblical time-scale, leaving room for time-demanding evolution. The *Discovery of Time*, a title we borrow from Stephen Toolmin and June Goodfield's fascinating book (1965), is an immense subject: the laborious unveiling of an universal time-scale, from astronomical, geological and biological time changes. The development, which could not have been perceptible to Huygens, extends to the present day; our aim will be to show how the main concepts were slowly acquired, but no more than a rough outline can be drawn here.

The Discovery of Time is still a very recent conquest of the human mind, and outside the narrow world of scientists the consequences have been far from completely digested. Space as inherited from the Renaissance, the space within which the Earth moves with its fellow planets, nowadays escorted by an armada of man-made hardware, has become a concept easy to grasp, and we do not have religious sects battling for the right to teach the Ptolemaic system as solely compatible with Scripture. However, all scientific proofs of antiquity of Earth and Universe are recent, indirect and elusive; their contradiction of the Bible is still widely felt as a serious threat, largely because of their clear connection with the origin and history of Man himself. Within a large modern country, noticeable for widely available higher education and splendid museums everywhere displaying the proofs of Earth's and Man's age (plus overwhelming contribution to scientific research), the teaching of Darwin's ideas remains under attack; sometimes, within limited communities, it becomes blocked by a majority of citizens, all through the most democratic processes. Moreover, this popular phenomenon is not limited to the USA nor to Biblical fundamentalism. It is general in Islamic countries: the position they defend is very different from the Christian fundamentalist one, the history and age of the Earth not being Quoranic constraints. Evolution is categorically rejected, and Darwinism is supposed to lie at the root of fascism, communism… plus present day terrorism. For fellow humans, the most sophisticated spaceships have become hackney carriages, but any sort of Time Machine is still unimaginable mystery. As for the scientists who have been involved in the Discovery of Time for two centuries, most of them were devout Christians and found considerable difficulties in delineating an acceptable path.

Newton himself is the first one we will mention. He was convinced that the Earth started as a fully molten and quasi-spherical, white-hot body, and has cooled through the ages to the present temperature. He thought that the Earth cooling time could actually be computed, leading to a scientific estimate of its age, but he had refused to trust his own result! Within a discussion of comets, he speculated about their temperature and remarked that

> a globe of iron of an inch in diameter, exposed red-hot to the open air, will scarcely lose all of its heat in an hour's time; but a greater globe would retain its heat longer in the proportion of its diameter;

the reason is that cooling losses are proportional to surface, while "the quantity of included hot matter" increases as the volume. At which point, very much as a sudden afterthought and without even a paragraph or sentence break, Newton launched an immense program, one ultimately fated to kill the *Genesis* story altogether (of which demise he would have felt considerable dismay): "…therefore a globe of red-hot iron equal to our Earth, that is about 40 000 000 feet in diameter, would scarcely cool in an equal number of days, or in about 50 000 years." He must have felt badly frightened by the implications since he had always refused any venture into cosmogony. Obviously, there was something wrong about such a simplistic cooling-time computation:

> But I suspect that the duration of heat may, on account of some latent causes, increase in a yet less ratio than that of the diameter; and I should be glad that the true ratio was investigated by experiments. (*Principia*, Book II, 522).

These experiments were to be conducted by Georges-Louis Leclerc, Comte de Buffon by royal favour. He is remembered as a universal naturalist, and also as *Intendant du Jardin du Roy*, which has become the Paris *Museum d'histoire naturelle*. He studied in the laboratory the cooling time for a set of spheres of increasing sizes and various materials, and established empirical time/diameter laws; next, he derived by extrapolation plus some reasonable assumptions the Earth cooling time from its known size. While Buffon's laboratory experiments prove relevant, well conducted and even surprisingly accurate, he made gross errors in the extension to the Earth's case. The program, the description of the numerous tests, the detailed results and the derivation of the Earth's age were to be published within the Supplement tomes of the *Histoire Naturelle* in 1774 and 1775 (*Œuvres complètes* T.1 p. 337–414 & T.2 p. 271–335). Buffon says explicitely that he was inspired by Newton to perform his experiments. Here, we present only the main results, i.e. some of his computed planetary ages: the Earth is presently 74,000 years old; the Moon cooled faster and is granted but 16,000 years, while Jupiter required a whopping 240,000 years. Buffon also obtained times for the initial stage, before temperature became low enough for the apparition of Life, and for the ultimate one, up to Life's final disappearance by freezing. The conclusions are quite specific:

> Life is not yet born on Jupiter; it has been extinct on Mars for 145 006 years, on the Moon for 2 318 years… [however] on Mercury, the Earth, on the first three satellites of Jupiter and Saturn, on planets Venus and Saturn, on the Saturn ring … living Nature is presently in full existence, & consequently these planetary bodies may be populated just as the earthy globe; which increases and multiplies almost to infinity the extant of living nature, & at the same time raises the greatest of monuments to the glory of the Creator.

However, Buffon's estimates of the age of the Earth and of the Universe were soon to suffer a sizeable inflation, and the constraints did not come from physics. In the manuscripts preserved at the Muséum d'Histoire Naturelle in Paris, the figures (not to be printed in his lifetime) became much larger. Apparently, no new experiments were ever made in his smithy, but Buffon seems to have felt dissatisfied with his previous linear extrapolation to the Earth diameter. However, the main reason is that he had become more sensitive to the import of geological evidence. This was the first time that age estimates provided by geology clashed with those imposed by physics, but definitely not the last. The geological data interpretation had been largely subjective, while those from physics almost appeared handed-out by God himself. In the waning years of the eighteenth century, the conflict between the two disciplines took place only within Buffon's own mind; during the next century, it will come out into the open, and become a considerable issue.

The central place now must be granted to the geologist James Hutton who in his 1795 *Theory of the Earth* proposed that, given enough time, presently acting forces might account for all Earth surface features. It was completely clear for him and a part of his successors that the implied time-scale had to be considerably larger than that of the Scriptures, but wisely enough, he attempted no numerical estimates, and the Buffon figures were not recalled. However, others like Georges Cuvier still held on the biblical time-scale.

More evidence for a long time-scale next came from an different discipline: biology. When Darwin proposed his theory of evolution, it was clear that a long time was required. How long? Darwin merely requested one from geologists and physicist colleagues, who had already been at odds on the problem, but discreetly so. After Darwin's 1862 *Origin of Species*, the disagreement was to become a considerable public issue. Geologists had no objections to a long time scale, but physicists adamantly refused. The successors of Buffon had inherited the Earth cooling problem, but turned into the opposite camp. The thermal analysis had originally shown that the Earth was far older than allowed by the Bible; now Lord Kelvin had demonstrated, using unanswerable thermodynamic proofs, that both the Earth and the Sun were far too young for Darwin. Physicists being the undisputed experts in the case, evolution through natural selection was revealed as sheer nonsense: Q.E.D.

To understand the situation faced by Darwin, one must return to the physics of the early nineteenth century, and tackle the Earth-cooling problem just where Buffon had left it. Joseph Fourier, born in 1768 and a Burgundian like Buffon, might conceivably have met him when still a young man. Luckier than Lavoisier, he narrowly escaped the guillotine, and survived to join the Egyptian expedition of Bonaparte in 1798. He then turned to physics and mathematics, and his most important work was published in 1822 as the *Théorie Mathématique de la Chaleur*, considered at the roots of modern heat theory. His starting point had been the same one used by Buffon fifty years before: the temperature of the Earth, but he held no new experimental data. Then, neither the laws of thermal radiation, nor the two great Principles of Thermodynamics were yet formulated. Heat itself remained a mysterious fluid, but Fourier himself correctly pointed out that his own calculations were independent of assumptions about its nature. His paper (Fourier 1824) is one of the most remarkable of the history of physics, except for an error on the "temperature of interplanetary spaces". His tools were his own heat-conduction laws, plus the basic fact of the temperature increase in mine shafts by one degree per thirty meters, i.e. the geothermal gradient. From them, he calculated the heat flux reaching the surface of the Earth from its hot interior, and found it very small: in modern units 0.3 watt per square meter, to be compared to the modern value of 0.08 W m^{-2} as an average on the globe, half of which we know now is due to radioactivity (the difference is due to the fact that Fourier only determined a local value). Thus most of the heat comes from the Sun: indeed, the French physicist Claude Pouillet measured for the first time in 1838 the solar radiation reaching the soil and found 307 W m^{-2} averaged on the globe (modern value 342 W m^{-2}).

Fourier's conclusions: in the present state

> one cannot doubt that the interior of the globe has preserved a very high temperature, while its is almost fully cooled at the surface.

As to past history,

> If all the dynamical and geological facts prove that the Earth globe originally had a very high temperature, as that of melting iron… one must conclude that a very long sequence of centuries must have passed before reaching the present state … from the Greek School of Alexandria to our own time the loss of central heat cannot have given a decrease as much as 1/300 degree. (Fourier 1824, 160).

Fourier still balks at giving a specific Earth age, because of the uncertainties on the parameters, but it is clear that it is at least several millions years. So far, Fourier had merely extended Buffon, just as Buffon had upheld Newton.

The final and seemingly definitive Earth age from classical physics was to be provided by William Thomson, who later became Lord Kelvin; he dominated the field (plus many others) during the second half of the century. J.D. Burchfield in *Lord Kelvin and the Age of the Earth* (Burchfield 1975) provides a detailed history of the case. The essence of the demonstration was still the Buffon-Fourier postulate: Earth-cooling from a melted original state down to the present temperature gives a maximum possible age; but Kelvin could rely on vastly advanced physics in all its branches. Of direct relevance to Earth-cooling were the radiation laws of Stefan and Boltzmann, and of Lord Rayleigh and James Jeans.

First, the cooling of the Earth down to its present state. Kelvin perfected Fourier's method with some educated hypotheses on the nature of the interior of the Earth.

A second argument is solely mechanical, and does not involve thermodynamics, only the assumption of an early molten state. From the observations of solar eclipses in ancient times, Halley had concluded that the length of the day was slowly increasing, while Kant already proposed that the effect might be due to the tides. In the nineteenth century, the mechanics of the phenomenon had become clear enough: fluid friction from the tides dissipated some of the Earth kinetic energy, hence rotation was slowing down. Unavoidably, there was a reacting torque on the Moon, and Kepler's Laws plus conservation of total kinetic momentum implied a slow decrease of the lunar velocity and an increase of its distance. Kelvin's contribution was a detailed study of the effect, and the idea that it reacted on the estimated date of Earth solidification, even if he was unable at first to derive a precise age. The problem was passed to a follower, the astronomer George Darwin (second son of Charles), who exhaustively studied the Earth-Moon system, starting from a fluid state. He proposed arbitrarily that an early state might have involved a revolution period of the Moon and a day both equal to 5 h 36 m, from which tides within the still-molten Earth body slowed the two motions to their present velocities in about 50 million years (see Burchfield 1975, p. 112–115).

The third argument involved the maximum permitted age for the Sun itself, which geologists had never worried about: their uniformitarian Earth just kept roasting under a constant Sun. What was the mechanism for solar heat generation? Chemical reactions were out: a solid-coal Sun (given adequate oxygen) would have lasted 5000 years, not even enough for the Bible! A more suitable mechanism was the fall of meteorites, which could produce up to 6000 times more energy than coal for a given mass, and Kelvin initially proposed a swarm of Sun-plunging meteorites, but there were not found, and Kelvin passed to a new and more solid hypothesis. If one admitted a small cooling of the Sun, it would contract; as the contraction was a slow fall, potential energy would be converted to the kinetic form, and ultimately to heat. Thus, a slow reduction of the diameter explained the heat output; still, it could not last forever and also implied an age of its own.

Altogether, the Earth ages provided by Kelvin varied through his long career, but this variation itself showed consistent trends. In 1862, arguing solely from Earth cooling, he was willing to put the age within 20 to 400 million years. Making use of the other arguments, in 1868 he reduced the upper limit to 100 million years, and in 1897 felt confident enough to impose 20 to 40 million years. Thus, only the maximum permitted age changed, and it went down continuously. The precision finally achieved was remarkable, and one of the most fundamental problems in the Universe seemed as good as solved.

On their side, the geologists considered the time scale for erosion of the mountains, or the time needed to bring the salt from the rivers into the ocean. As might be expected, the ages quoted by different geologists varied, at first widely. Nevertheless, they tended to decrease, and it is clear that each author felt the heat from Kelvin and did his possibly unconscious best to conform. A 1893 reviewer says of their estimates that he is "convinced of their approximate truth by their somewhat good agreement … all coming within the limit of 100 million years which Sir William Thomson estimated upon physical ground." (Warren Upham, quoted by Burchfield 1975, 108). The trouble was, as we have seen, that the said William Thomson, lately transmuted to Lord Kelvin, was no longer willing to allow geologists that much leeway. The intransigence of the physicists was best expressed by Peter Guthrie Tait, friend and disciple of Kelvin: geologists were still at the "beetle-hunting and crab-catching stage"; let mathematicians "be lauded for condescending from their proud preeminence to help out of a rut the too ponderous waggon of some scientific brother." (quoted by Burchfield 1975, 93). For Tait, there was no possibility of error whatsoever from the cooling-time treatment. Opponents, unable to fault the Kelvin computations, were reduced to arguments that must have felt dismally vague at the time, but are seen today as truly prescient. The Scottish geologist James Croll, who first connected the ice ages with Earth orbital vagaries, disputed the gravitational explanation of solar heat: "The utmost that any physicist is warranted in affirming is simply that it is impossible for him to conceive of another source…. His inability cannot be accepted as proof…" (Quoted by Burchfield 1975, 126). Thomas Chamberlin, an American geologist, hit remarkably close to the future explanation through hydrogen fusion: considering the interior of the Sun, one should not assert "that no unrecognised sources of heat reside there… it is not improbable that [atoms] are complex organisations and seats of enormous energies… the extraordinary conditions which reside at the center of the Sun may set free a portion of this energy."[2] Another Scotsman, Archibald Geikie, Head of the Geological Survey, summed up

[2] Quoted by Burchfield (1975, 143–4). Barrow & Tipler (1986, 165), interestingly treat the Chamberlin prediction as proceeding from an early form of their own Anthropic Principle.

the position of Kelvin's opponents: "The geological record constitutes a voluminous body of evidence which cannot be ignored and must be explained in accordance with ascertained natural laws. There must be some flaw in the physical argument…" (quoted by Burchfield 1975, 131). In the long and laborious but essential discovery of Time, geologists understood the way of the future better than any physicist. Surprising? Not so much; apart from Buffon alone, they had been first to enter the field.

The rest of the story is well known. It starts with the discovery of radioactivity by Henri Becquerel in 1896, and the constatation by Pierre Curie and his collaborator Albert Laborde that radium emits heat (1903). This must have resonated like a gong: spontaneously generated heat, from any origin whatsoever, was precisely what Chamberlin and others had been hoping for in order to explain the solar output. Curie's paper (Curie 1903) provoked instant excitement, and within a few months the venerable Buffon-Fourier-Kelvin edifice had been overthrown by a torrent of papers, mostly *Letters* to *Nature,* which make the December volume for that epochal year well worth browsing through. Initially, radioactivity was supposed to supply energy for the Sun, but the definitive explanation would involve neither uranium nor radium but the Einstein mass-energy equivalence plus hydrogen fusion as a mechanism. All of which lies beyond the bounds of the present story: when the Sun output finally became understandable, from the work of Arthur Eddington, Hans Bethe and Carl Friedrich von Weizsäcker, the age problem had already been solved both for the Earth and the Universe; at least, such is the common present belief.

Nature proved no kinder to Kelvin (and all brother physicists) than to Descartes: she obviously chose the Earth-age case to demonstrate again her devastating irony, just as she had done with gravitation. Cartesians had just done away with all occult properties, and accounted for the Universe from understandable collisions, when a wholly mysterious attraction was found able to predict all celestial motions far more accurately. Similarly, the nineteenth century Cosmos formed a complete mind-pleasing system, ruled by conservation of energy and laws of thermodynamics; and then, all a sudden, energy refused to be conserved! It just flowed out without any explanation in some of the simplest laboratory experiments ever performed. The solutions in both cases, at least temporary ones, were rather similar: attraction at a distance did not have to be understood to be used, and neither did radioactive energy. Taking this spontaneous heat output and atomic disintegration as facts of Nature, physicists were to renovate the Earth-age problem entirely and at long last reach the present-day estimates.

The development of the modern time-scale from radioactive dating unveiled more Natural irony: during this last episode of our story, physicists were to provide far more time than geologists were willing to use. The ultimate solution was the work of a hybrid species, geophysicists skilled in both sciences, willing and able to start from physical theory and use data gathered both in their own laboratories and in the field. Their efforts will not be detailed in these pages: the Buffon-Fourier-Kelvin story was a simple one, easily accessible to the non-specialist and an adequate notion of the Becquerel-Curie experiments could be given in a few lines; but the unravelling of radioactive families was to prove a highly complex business, which could not be fairly told without straying too far from our main subject. Only the conclusion needs to be recalled here. Presently, the figures quoted both for Earth and meteorites cluster around 4.6 billion years, while the age of the Sun is slightly larger: the planets formed almost simultaneously with the Sun.

How Life Appeared on Earth

As we know nothing about the apparition of life in other planets, our knowledge of what happened on the Earth might help. And here, we will see that the long time span since the formation of the Earth was actually needed to produce the life as we see it at present.

This knowledge is recent. Until the 19th century, the general idea was that, in addition to the habitual mechanisms by which a living being is born by reproduction of organisms of the same species, fully formed living things can appear spontaneously, usually from mud or putrefying material. Already Anaximander of Miletus, in the 6th century before our era, thought that fish were born from the action of the Sun on a humid medium. Aristotle, in his *History of Animals*, observed that insects and worms often appear in the morning dew and that mice, frogs and fish seem to be born from the mud of the rivers. Spontaneous generation remained the commonly accepted theory for the origin of life until the 17th century. Then this hypothesis became subject to debate and experimentation. The doctor Jean-Baptiste van Helmont found that by disposing a dirty garment with flour for 21 days, it turns into adult-sized mice. But other experiments, led by Francesco Redi, showed that spoiled meat does not produce maggots if protected with gauze. The ensuing controversy gave rise to many variations of these experiments. With the microscopic observation of microorganisms, bacteria and spermatozoa by the Dutch scientist Antoni van Leeuwenhoek, one began to suspect that the case might be more complicated.

In the nineteenth century, no one believed anymore in the spontaneous generation of adult animals, but that of micro-organisms was still controversial. The French Academy of Sciences offered a price of 2500 francs to “the one who, by well-done experiments, will throw a new light on the question of so-called spontaneous generations”. Louis Pasteur produced these “well-done” experiments and won the prize in 1862: spontaneous generation was dead. But then, how did living beings appear? Apart from divine intervention, there are only two possible answers. The first is that the first living beings were brought to Earth from other planets by comets or meteorites, and that others have thus reached at different times: it is the theory of panspermia, which has had its hour of glory. However, it only displaces the problem, because it was necessary that life appeared elsewhere, for example on Mars, from which we receive from time to time a fragment expelled by the fall of an asteroid or a big meteorite. The other possible hypothesis is that life appeared on Earth following a long process that gradually passed from inert matter to micro-organisms and more evolved ones, through mechanisms to be specified. This is the favorite theory nowadays.

It is presently possible to outline what happened on Earth. 4100 million years (MY) before present (BP), hence 500 million years after the formation of the planet, there was liquid water on its surface and it is possible that the first unicellular beings appeared. This becomes a certainty 3700 MY BP, where methanogene bacteria were present. At 3000 MY came the first bacterias able to produce oxygen by photosynthesis. This oxygen destroyed the methane synthetized by the previous bacteria and stayed in the atmosphere. Methane being responsible for a strong greenhouse effect, its disappearance led to cooling and a first ice age at 2300 MY BP. Life developped in the oceans. Around 2000 MY the first cells with nuclei (eucaryotes) appeared, and the first multicellular beings at 1200 MY. At 540 MY came the Cambrian biological explosion with giant plants, insects, amphibians, fish and reptiles. Life was again cut down to a large extent by two successive glaciations, to reappear later: this was the dinosaur era. A catastrophic event destroyed all evolved terrestial life 65 MY BP, leaving only some small rodents. Then mammals reappeared, including man a few MY ago. Figure 13.3 sumarizes this evolution and the corresponding composition of the atmosphere.

Several facts are striking in this evolution. 1. A very long time was needed to go from primitive, unicellular beings to more complex ones. 2. The evolution from the first multicellular beings to very complex ones was faster, while still needing many tens of million years. 3. Life is very resistant to catastrophic events. Although we know nothing on evolution on other planets, we can conceive that it follows a similar pattern.

How did life arise? This is a complex subject that cannot be developed here, but deserves however a few comments (for a detailed account see e.g. Rothery et al. 2018, or, in French, Encrenaz et al. 2019). Life needed prebiotic molecules that were formed either in situ, as demonstrated by laboratory experiments, the best known being those of Stanley Miller and Harold Urey, or brought on the Earth by comets. We now that the interstellar medium and the comets that were directly formed from it contain a large variety of prebiotic molecules, including amino acids. These amino acids are the basic constituents of proteins. It was also necessary to synthetize lipids to form the cell walls, as well as sugars and nucleotids that are the basic elements of DNA. This obviously required water and energy, and a certain concentration of the products. These conditions can be found in the hydrothermal springs on the bottom of oceans, or in some ponds at the surface. This was already suspected by Darwin who wrote in 1873 to Joseph Hooker:

> But if (and oh what a big if) we could conceive in some warm little pond all sorts of ammonia and phosphoric salts, light, heat, electricity *et cetera* present, that a protein compound was chemically formed, ready to undergo still more complex changes…

Of course, he would never have written publicly such heresies!

There is still a lot to do to understand all the processes involved in the generation of the first cells, and in the evolution to intelligent beings. However the result is there on our own planet, and there is no reason why life could not appear and evolve in other worlds, even if in different ways. It should be remarked that the conditions on the Earth have been extremely favorable: oceans, mild temperature all along the

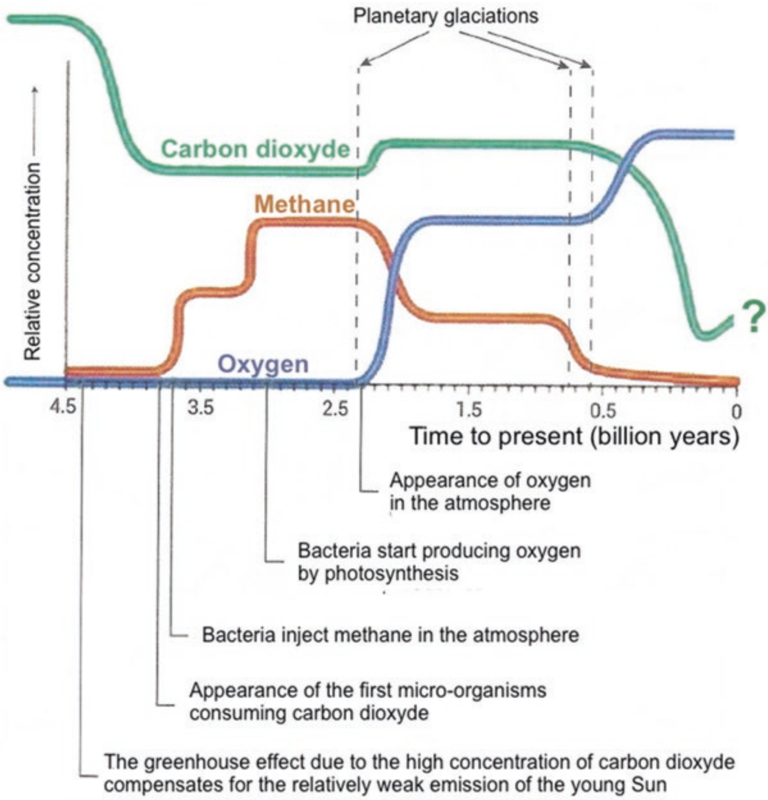

Figure 13.3 Evolution with time of the composition of the Earth atmosphere. Initially dominated by carbon dioxyde, the atmosphere is enriched into methane by cyanobacteria, then in molecular oxygen by other bacteria 2.4 billion years ago. From G. Ramstein, with permission

history but for some glaciation episodes, and the presence of the Moon, which stabilizes the orientation of the rotation axis of the Earth. In the other planets of the Solar system and their satellites, the situation is much less favorable; indeed, space exploration has shown that life can only exist at present under the form of primitive, unicellular beings, and only in some locations (see Encrenaz et al. 2019). Mercury and the Moon are so hostile that life cannot be, and has never been present. Life might have existed on Venus in the past, but has certainly disappeared at present on the surface where conditions are literally infernal. Some primitive life might have existed and is perhaps still present on Mars, but it has not been found yet in spite of many comprehensive efforts. The more distant planets are not at all suitable for life because of too cold temperature and lack of solid or liquid surface; there are however some possibility for primitive life in Jupiter's and Saturn's satellites Europe, Encelade and perhaps Ganymede, Callisto and Titan. Thus, Internal Plurality as dreamed of for so many centuries has completely collapsed.

Life on Exoplanets?

This might not be the case of External Plurality. After the discovery in 1995 of the first planet around a solar-type star, an exoplanet, a new universe has opened. This discovery is the final step of more than one and half century of efforts that are worth summarizing here.

In order to understand the difficulty of this research, let us consider the Sun and Jupiter, the biggest planet of the Solar system. The diameter of Jupiter is ten times smaller than that of the Sun, and the planet a thousand times less massive. In the visible range, the radiation that it emits is the radiation reflected by the Sun; seen from outside the Solar System, it is more than a million times weaker than solar radiation. Moreover, when seen from a nearby star, a few light years away, the angular distance between the Sun and Jupiter is only a few tenths of a second of degree. Impossible to discern it from its star, it is too close and drowned in the starlight.

The astronomers of the last centuries like Huygens have understood this problem well and, to circumvent it, have considered to resort to an indirect method. It consisted in considering the movements on the sky of the star-planet system: the star orbits around the center of gravity of the system with a period that is that of the planet around the star (Figure 13.4). The method has been used successfully since the early nineteenth century in the case of binary star systems, to detect the stellar companion; the principle here is the same, with the difference that the orbit described by the star is much smaller than that described by the planet, by the ratio of the masses planet/star. It is therefore necessary to measure a very small movement of the star with respect to the neighboring stars, during a period of time unknown *a priori*.

In the course of the nineteenth and twentieth centuries, several detections of exoplanets by this method were successively announced and then questioned. The most famous case is that of the Barnard star, one of the closest to us, observed by Peter van de Kamp for several decades. His discovery of two planets around this star announced in 1975 has finally been invalidated: the effect was due to an instrumental error related to the telescope he was using. Other methods had to be looked for. In a pioneer paper of 1952, the American astronomer Otto Struve writes:

> There seems to be at present no way to discover objects of the mass and size of Jupiter; nor is there much hope that we could discover objects ten times as large in mass as Jupiter, if they are at distances of one or more astronomical units [the radius of the orbit of the Earth] from their parent stars. But there seems to be no compelling reason why the hypothetical planets should not, in some instances, be much closer to their parent stars than is the case in the solar system… It is not unreasonable that a planet might exist at a distance of 1/50 astronomical unit, or about 3,000,000 km. Its period around a star of solar mass would then be about 1 day… Our hypothetical planet would have a velocity of roughtly 200 km/sec. If the mass of this planet were equal to that of Jupiter, it would cause the observed radial velocity of the parent star to oscillate with a range of ± 0.2 km/sec, a quantity that might just be detectable [by spectroscopy, through the Doppler-Fizeau effect]… A planet ten times the mass of Jupiter would be very easy to detect, since it would cause the radial velocity of the star to oscillate with ± 2 km/s." And he adds "There would, of course, be eclipses [of the star by the planet]. The projected eclipsed area is about 1/50th of that of the star, and the loss

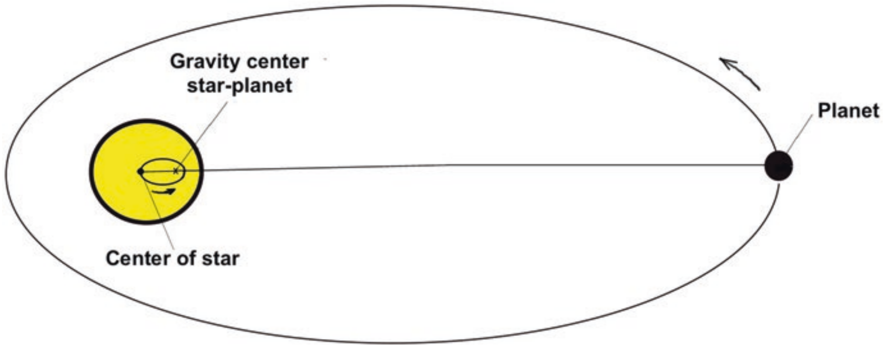

Figure 13.4 A star and an orbiting planet. The gravity center around which the two objects revolve is located inside the star, which follow a small-amplitude orbit around it

> of light in stellar magnitudes is anout 0.02. This, too, should be ascertainable by modern photoelectric methods… (Struve 1952).

Struve has perfectly foreseen the two principal methods presently used to discover planets around other stars. The vast majority of the discoveries of these objects have been made, and are still made, by sophisticated observations from the ground and specialized satellites. The "astrometric" method used initially has not yet given any result, but we hope that it will soon lead to many discoveries thanks to the European astrometric satellite GAIA. Without entering into the details of these discoveries, we will simply summarize the results.

About 4250 exoplanets have been discovered at the time of writing (Spring 2020), about 880 by the radial velocity method, 3000 via their transit in front of the parent star and the rest by other methods. Nearly 700 planetary systems contain more than one exoplanet. There are clear and severe biases in the detections: it easier to discover an exoplanet if it is big and massive, and if it orbits close to its parent star. A planet similar to Jupiter at the same distance from the parent star can be detected, but the equivalent of the Earth and of all other planets of the Solar system are presently undetectable (Figure 13.5). However, we already know that there are at least as many planets as stars in our Galaxy, which number around a hundred billions!

The variety of the exoplanet systems is amazing (see Lequeux et al. 2017, annex 2). About 1% contain a hot Jupiter very close to the parent star and raised to high temperature by the stellar radiation: such a planet cannot have been formed there, but must have migrated from more distant, cold regions. These migrations are well understood: they result from the gravitational interaction of the planet with what remains of the protoplanetary disk that was formed at the same time as the central star by the collapse of an interstellar cloud of dust and gas. Other exoplanetary systems contain high-mass planets, or super-Earths with roughly 10 times the mass of our Earth, or even planets with terrestrial masses. Some are made of very massive planets very distant from their star. Others contain planets with a wide variety of masses, etc. Quite often, the orbits of exoplanets are very eccentric (elongated

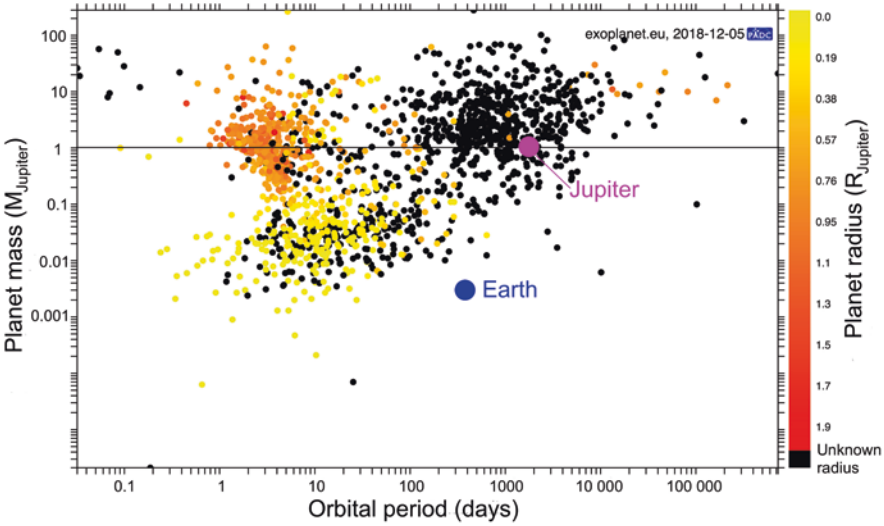

Figure 13.5 Mass of confirmed exoplanets as a function of their orbital period. The radius, when determined, is indicated by the color (black if not determined). The planets grouped at the upper left are "hot Jupiters", while those at the upper right are more similar to our Jupiter. The lower cloud of points correspond to "super-Earths" with up to 10 times the mass of the Earth. Between them and the Jupiters are the "Neptunes". Note that a planet like Jupiter at the same distance from a parent star similar to the Sun is presently detectable, while a Earth is undetectable. Europlanets.eu

ellipses), due to gravitational interaction between them at some stage of the formation of the system.

Amongst all these exoplanet systems, none is similar to the Solar system. The probability of occurrence of a planetary system similar to ours can be estimated from the available exoplanet statistics: it is certainly much less than 1/1000, and most probably even less than 1/10,000. Thus, the Solar system is an exception rather than the rule, contrary to what our anthropocentrism had predicted. There are reasons for this exceptional configuration, the most important being the presence of two massive planets, Jupiter and Saturn, whose mutual gravitational interaction and interaction with the remnants of the protoplanetary disc has impeded their migration close to the Sun and preserved the terrestrial planets.

Now about life on exoplanets. Life almost certainly requires liquid water, hence temperatures between 0 °C to 100 °C or perhaps a bit higher. It also requires carbonaceous pre-biotic molecules, possibly coming from the interstellar medium, hence the necessity of a surface, solid or liquid, for their deposition and preservation. The best candidates are thus rocky planets located at the distance of the star such that their temperature is in the right range. In the Solar system, only the Earth is presently at the right distance, in what we call the habitability zone (the situation of Mars is rather marginal in this respect). Only the planets with mass lower than about 10 times that of the Earth are rocky, and those with a mass not too small compared to the terrestrial mass can keep an atmosphere. Their orbit should not be too eccentric, in order to avoid large variations of temperature. Also, the direction of the rotation axis should be stable, which is insured for the Earth by the presence of the Moon but is not the case for Mars whose axis wanders considerably with time. Finally, the planet should not be too close to its star: such planets would always present the same side to the star, like the Moon to the Earth, and this does not seem to be very favorable for life.

From these criteria, we see that the Earth is ideally, perhaps uniquely, placed for the development of life. Amongst the exoplanets discovered today, only a few are in the habitability zone around their parent star and have masses in the right range (but there are probably many more). We know nothing of their surface, and we don't know either if they have an atmosphere containing water vapor, or a satellite like the Moon. However, water vapor has just been discovered around a habitable super-Earth of 8 terrestrial masses. Some exoplanets orbit around a solar-type star, and some around a less massive, colder star radiating mainly in the infrared. This does not seem to be an obstacle for the development of life, but what is bad is that such dwarf stars often produce a large amount of X-rays able to kill any sort of life. Finally, it is perhaps not too surprising that we live in a very peculiar planetary system, whose structure might be particularly favorable or perhaps even essential for housing a really habitable planet. If this is true, the implication is astounding: life is rare in our Galaxy. But perhaps this is too pessimistic.

Searching for life in exoplanets is extremely problematic. For the moment, only a clearly anthropocentric procedure seems possible: the search for oxygen in an exoplanet atmosphere. Anthropocentric because it is far from certain that life in other worlds works in the same way. We know that, in the case of the Earth, atmospheric oxygen comes from plants through photosynthesis by chlorophyl. It seems impossible to detect safely chlorophyl in the spectra of exoplanets, and the direct detection of molecular oxygen by spectroscopy is also almost impossible because of the weakness of the spectral lines of this symmetrical molecule. Fortunately the ultraviolet radiation of the parent star of an exoplanet is able to produce from oxygen the ozone molecule O_3, and ozone is considerably easier to detect spectroscopically: it produces a strong absorption in the mid-infrared at a wavelength of 9.6 micrometer. This absorption has been clearly seen in the spectrum of the Earth seen from far away while it is absent in that of Mars and of Venus (Figure 13.6). Given the presence of ozone in the Earth's atmosphere, its detection in exoplanets must be attempted from space. For the moment, no space facility allows this detection, for lack of sensitivity. It might be made possible by the James Webb Space Telescope (JWST), the successor of the Hubble Space Telescope, currently scheduled for March 2021. However, any such detection is likely to need several tens of hours, a goal difficult to reach due to the extreme competition foreseen for this space telescope. There would be no place for error, hence we have to be sure to observe the right target, a choice still quite uncertain at present.

Then, if ozone is detected, we will know that organisms able to perform photosynthesis are present. They could be cyanobacteria, and we have seen that they have been the only form of life on the Earth for more than 2 billion years over the

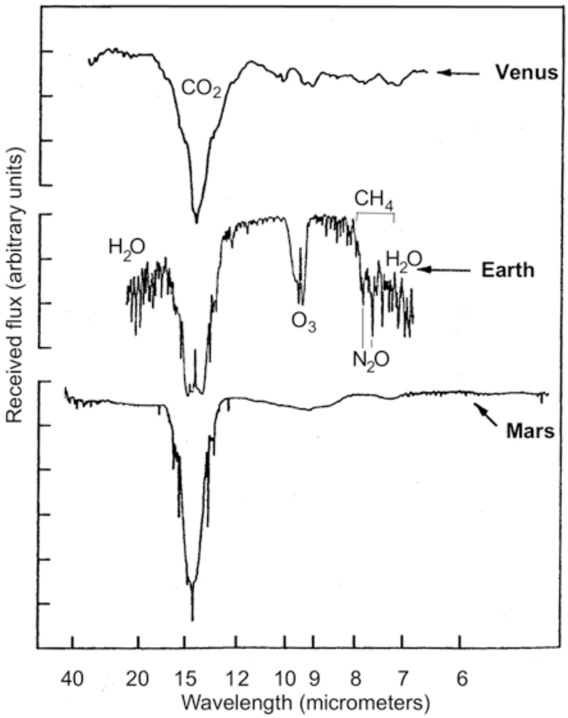

Figure 13.6 Spectra of Venus, the Earth and Mars observed in the infrared by the Voyager space probes. Only CO_2 is seen in the spectrum of Venus and Mars, while the spectrum of the Earth shows not only CO_2 but water vapor and products origining from life, in particular methane CH_4 and ozone O_3. Ozone gives a strong absorption at 9,6 micrometer wavelength. Adapted from Hanel et al. (1992) *Exploration of the solar system by infrared remote sensing*, Cambridge University Press

4.6 billion years of existence of our planet. But no information on plants or animals. At present, we do not know how we could detect directly any form of evolved life. In this respect, we are no more advanced as our Greek ancestors. We have only learned that planets surround most of the stars of our Galaxy and that some of them might harbor life, but also that the direct detection of any form of evolved life is an essentially hopeless task. One might of course contemplate an interstellar travel to nearby habitable planets, just to check; but this is also an unreachable dream, at least for the time being.

SETI and Interstellar Communication

There remains a hope, however: that intelligent beings on other planets would send a signal to us, or be kind enough to answer a message from us. Mere patient listening may bring its reward, a very faint chance no doubt, but still non-zero. On the other hand, because of that ridiculously small velocity of light and enormous distances, the amount of time required for any meaningful two-way communication is large compared to the lifetime of intelligent individuals down here; and quite possibly, even with that of all civilisations in their ultimate communicating stage… Communication with other civilisations, if ever achieved, will share many features with the study of ancient strata, and even more so with archaeology and palaeontology. Vanished animal species or humanoids would talk to us; we cannot answer back, and old Kronos is the culprit.

Still, this has not deterred Man to try: some people believe that

> the consequences for our own civilisation will be stunning –insights on alien science and technology, art, music, politics, ethics, philosophy and religion, and most of all, a profound deprovincialisation of the human condition. (Sagan 1980, 311).

First, sending signals, with or without the hope of an answer. This was apparently first proposed by Carl Friedrich Gauss in 1822, who wanted to send light signals to the Moon with a set of mirrors reflecting the solar rays. In 1869, Charles Cros made a similar proposal with a simple message consisting in a series of flashes. In 1901, at a time when radio was developing, Nikola Tesla felt able to demonstrate that

> with an expenditure not exceeding two thousand horsepower, signals can be transmitted to a planet such as Mars with as much exactness and certitude as we now send messages by wire from New-York to Philadelphia.[3]

Nothing followed, and we have to wait for 1974 to see a message issued from the Arecibo 300-m diameter radio telescope towards M13, a globular cluster located at a distance of 20,000 light-years, which contains about 300,000 stars. The emission had a power of several megawatts and could have been easily detected from any point of the Milky Way. The message consisted of a succession of 1679 bits distributed in 73 lines of 23 characters each (they are prime numbers, which would have supposedly allowed to decode the message more easily). It thus forms an image reproduced Figure 13.7. The problem is that it would take 40,000 years to get a response! What is the use? Moreover, deciphering the message is far from being trivial, and we must hope that the aliens are smarter than us in this respect…

More messages were transmitted in 1999 and 2003 to nearer stars using the 70-m diameter Evpatoria planetary radar in Ukraine, and in 2017 using the large EISCAT radar antenna in Tromsø (Norway), etc. A non-profit organization named *METI International* (Messaging to ExtraTerrestrial Intelligence) was created in 2015 to foster similar attempts.

In the same spirit, NASA placed in 1972 and 1973 on each of the two Pioneer probes a plate (Figure 13.8) which is perhaps easier to decipher than the Arecibo message. It reiterated by placing on board the two Voyager probes, which left the Solar System for an infinite journey into space, a message for possible extraterrestrial civilizations, for the unlikely event that they manage to recover it. Like Arecibo's message, it pretends to offer them a description of our own civilization. The Voyager message is in the form of a video-disk (the *Golden Record*) where are recorded various informations on the Earth and its inhabitants in the form of images (prudish, we are in the USA!), recordings of sounds of animals, cries of infants and different natural noises. Also included are the recordings of the word "Hello" in 55 languages, excerpts from literary texts and classical and modern music. On the lid of the box that contains the disc are engraved some of the symbols that were inscribed on the plate of the Pioneer probes, as well as an explanatory diagram of

[3] Tesla, Talking with Planets, *Collier's Weekly*, XXVI, p.12, February 91,901.

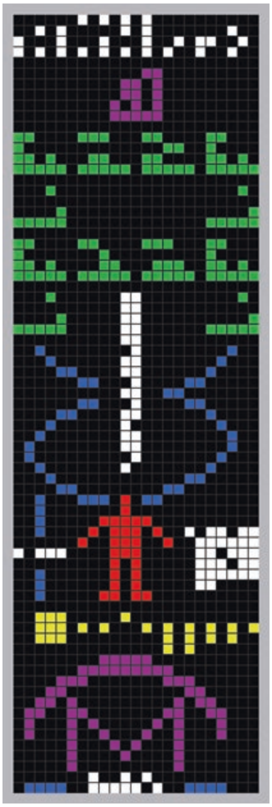

Figure 13.7 The Arecibo message. Colors have been added to facilitate understanding. Are represented, from top to bottom: in white, from left to right, the numbers 1 to 10 in binary format (the bottom line shows the vertical position of each number); in purple, the numbers 1, 6, 7, 8 and 15 respectively represent hydrogen (H), carbon (C), nitrogen (N), oxygen (O) and phosphorus (P); in green, the formulas of the nucleotides in the configuration incorporated in the DNA; in blue, the double helix of the DNA, the vertical white bar representing the number of nucleotides; in red, silhouette of a man; on the left, in white the number 14 representing its size (in blue), the wavelength of the message (12.6 cm) serving as a unit; on the right, in white, the human population coded in 32 bits, i.e. 4,292,853,750; in yellow, the solar system (still with Pluto), the Earth being slightly shifted upwards; in violet, the Arecibo telescope with some rays, and underneath in white its diameter (2430 in wavelength unit); the lines in blue on each side are apparently meaningless. Wikimedia Commons

the way of reading the disc (Figure 13.9). We only hope that the possible readers will be able to understand from these rather obscure drawings how and at what speed they must read the disc, using a stylet included in the probe!

With hindsight, these bottles at the sea seem very naive. Can we really believe that they will come to an end one day? Their motivation was philosophical, as evidenced by this excerpt from President Carter's official statement, placed on the Voyager probes: "This is a present from a small, distant world, a token of our sounds, our science, our images, our music, our thoughts and our feelings. We are attempting to survive our time so we may live into yours."

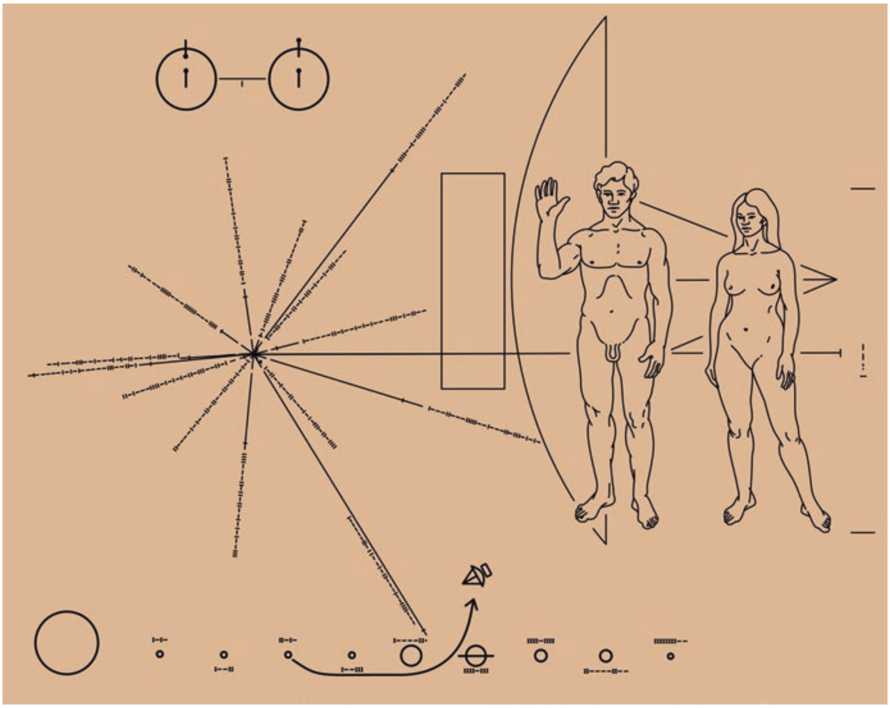

Figure 13.8 The plate placed onboard the Pioneer probes, designed by Carl Sagan and Frank Drake. On the top left, a small diagram shows that the line at 21 cm of hydrogen results from the transition between the two indicated configurations of the atom H, where the spin of the nucleus and the electron are respectively antiparallel and parallel. Below, diagram showing the direction, the distance and the period of 14 pulsars. Behind the man and the woman, a diagram of the probe at the same scale. Below, the Solar System with near each planet a binary number proportional to its distance from the Sun; we see the probe leaving the Earth. NASA

More serious perhaps is the other side of the story: *SETI* (Search for ExtraTerrestrial Intelligence). Contrary to UFOs fans, we don't believe in visits by aliens and we have to be content with radio or optical signals. We simply consider Aliens who have mastered optical and radio telescopes, and do take a vivid interest in Earth (a kind of anthropocentrism in reverse!). Then of course, their telescopes or radiotelescopes are looking down at us and sending us messages. Once again, Gauss seems to have been first to make in 1826 a proposal intended for lunar inhabitants: to draw on the Earth by cutting trees in the Siberian forest, an immense right-angle triangle with squares attached to the sides, in order to illustrate Pythagore's theorem. Karl Ludwig von Littrow had a similar idea in 1840, now by lighting fires in the Sahara desert.

This looks like science-fiction, but what is the difference? Admittedly, science tries to understand and science fiction to entertain, and also in past achievements; but when a guide to the future is sought, the science community is notoriously unable to predict its own, while novelists may claim at least some lucky hits. Moreover, science fiction sometimes reaches the level of true literature, and the author (Connes) has to confess a distinct partiality to Herbert George Wells, about

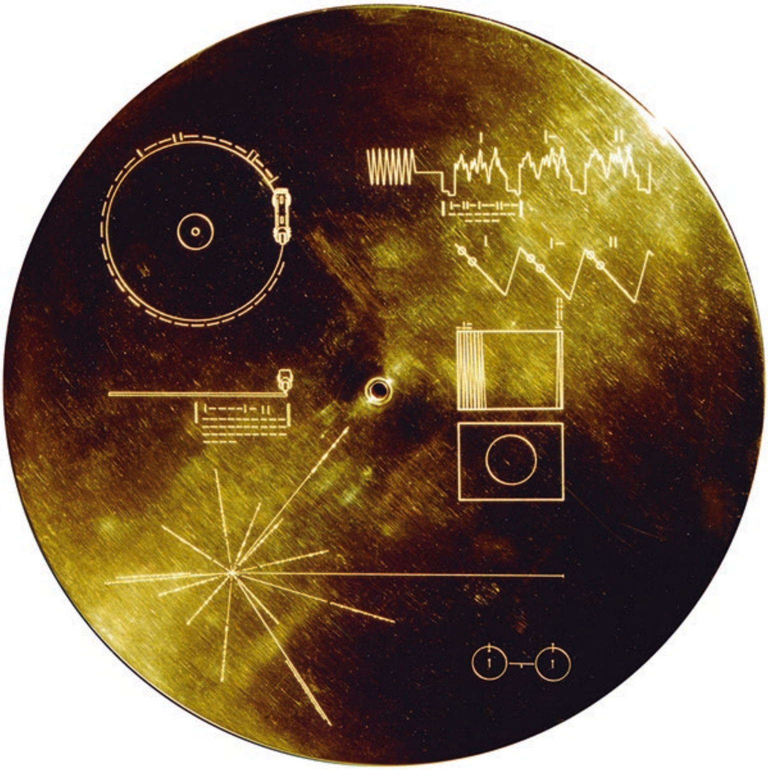

Figure 13.9 The lid of the box that contains the "Golden Record" aboard the Voyager probes. There are some symbols of Fig. 13.8, and also a number of diagrams indicating how to read the disc. The story does not say if humans who did not know the corresponding technology were asked to understand these patterns… NASA

whose work his father wrote a most learned PhD thesis (Connes, G. 1926). Nowhere is the confusion of the two genres more obvious (and perhaps more dangerous) than in the Plurality problem as perceived in the present century. Any serious treatment is bound to involve a risky navigation between the Charybdis of wild futuristic speculation, and the Scylla of grossly deficient imagination; with countless foaming shoals in between.

Lowell and his followers had shown great naivety when they believed their visual observations far superior to those of Huygens and Cassini. However, the 1888 discovery of Hertzian waves introduced within the search for extraterrestrial life a tool that would have been pure magic to preceding generations. Progress was rapid, and the connection with possible interplanetary signals, natural or artificial, was soon made. Sir Oliver Lodge, who had started with experiments parallel to those of Hertz, sensibly attempted to detect the Sun at centimetre wavelengths; he is also sometimes quoted as the first (human) to propose similar means for transmitting or receiving interplanetary signals. Unfortunately, he also took a deep interest in psychical communication, even became President of the Psychical Society, and one cannot escape some fear that the two subjects were not totally disconnected in his mind; the same may be noted of Camille Flammarion. As to Tesla who proposed to send radio signals to other worlds, he detected strange radio signals during his experiments. The intelligent origin of those signals was quite unmistakable!

> The changes I was noting were taking place periodically, and with such a suggestion of number and order that they were not traceable to any cause then known to me… Although I could not decipher their meaning, it was impossible for me to think of them as entirely accidental.

At which point, the inescapable explanation must have come in a flash:

> I had been the first to hear the greeting from one planet to another. A purpose was behind these electrical signals…

There is nothing new under the stars. Just as geometry had fooled Lowell about the Mars canals, that "suggestion of number and order" proved the downfall of Tesla. Has the lesson been learned? One full century later, our greatest radio experts, with the most exquisitely advanced receiver technology at their fingertips, are still hoping to detect order and purpose within their noisy signals.

More apparent detections were to be reported during the new century, in particular by Marconi, but we seem to have nothing from his own pen, only rather vague newspaper accounts, one as late as 1921. But believers flourished, in particular Carl Sagan who, as late as 1974, was able to point out at the yet unexplained decametric emission from Jupiter, and stress (with tongue deep in cheek) that the evidence did not rule out intelligent senders (*An Introduction to the Problem of Interstellar Communication*, in Ponnamperuma 1974, 21). Vain quest! No organized radio signal has ever been received from Solar-system planets, and one had to look for more distant worlds.

Soon after the end of the last War, radioastronomers detected the radio emission of a variety of astrophysical sources with immense success. Then, in the late fifties and the early sixties, the pioneering papers in the *SETI* field were published: those of Cocconi & Morrison, Drake, Sagan, Bracewell, Von Hoerner…, nowadays referred to by all writers in the field.[4] In 1959, physicists Giuseppe Cocconi and Philip Morrison investigated the best ways to search for signals from possible extraterrestrial civilizations, and concluded that the best solution would be to use radio telescopes at the wavelength of 21 cm, that of the line of atomic hydrogen discovered eight years before. According to them, any advanced civilization would have noticed this property of the most abundant element in the Universe, and would choose this wavelength to communicate.

As early as the following year, Drake and his team launched the *OZMA* program (named after the legendary Oz country princess), which used the 25-m radio

[4]A particularly readable informal history of the early years, written by a pioneer, is Drake's *Is Anyone out there?* (Drake & Sobel 1994). An account of all early searches, up to 1981, is given by J. Tarter, *Searching for extraterrestrials*, in Regis (1985), 167; it contains excellent tales of thrilling discoveries, which turned out due to CB radios, or artefacts of the tape recorder etc.…

telescope of the National Radio Astronomy Observatory at Green Bank (West Virginia): during two months, they observed at 21 cm τ Ceti and ε Eridani, two very close stars, both at about 10 light years from us. It was the first attempt of this kind, and the targets were well chosen, at least τ Ceti that is surrounded by at least four planets, some in the habitable zone. But no signal was observed.

After *OZMA*, other projects were proposed, including in 1971 NASA's major project *Cyclops*, which involved the construction of thousands of radiotelescopes, with a total surface area of 8 km^2; it could have detected radio and terrestrial TV broadcasts a distance of 1000 light years. Its cost, estimated at $ 10 billion, was such that it has not materialized, but the studies that have been carried out for this project are the basis of subsequent achievements. The longest observations made to detect extraterrestrial life were conducted with the Ohio State University radio telescope: a signal was received with this radio telescope on August 15, 1977, but it was not repeated and it is probable that it was terrestrial emissions reflected by an artificial satellite or a space debris. Further observations are still being made today at Harvard, the University of California at Berkeley, Italy, and Australia (project *Serendip*, for serendipity).They are made in parallel with the classic radio astronomical observations, without vasting telescope time. This is a good idea, since the radio astronomers have often been reluctant to devote time of their large radio telescopes to such uncertain research.

All these projects have been coordinated since 1984 by the *SETI Institute,* initially funded and financed in 1985 by NASA but which now relies entirely on private funds, with the collaboration of a few American universities. It has organised and partially financed about fifty different searches for extraterrestrial signals, altough without any detection. Among the most important of these searches is the *Phoenix* project, which used from 1995 to 2004 several large radio telescopes (Arecibo in Puerto Rico, Green Bank, Jodrell Bank in England, Parkes in Australia, incidentally Nançay in France). They analysed radio signals between 10 and 22 cm wavelength received from the direction of 850 solar-type stars located at less than 150 light years. In 2007, a network of 42 steerable antennas 6.2 m in diameter, the *Allen Telescope Array*, originally funded by Paul Allen, a co-founder of Microsoft, was commissioned. Located in Hat Creek, California, it is the only instrument devoted full-time to *SETI* in radio. In addition, an optical extraterrestrial signal research program exists since 1998. It uses a 1.8 m diameter specialized telescope (the *OSETI* telescope), built with private funds. This telescope remains fixed overnight, and searches the sky for short optical signals, which would be laser pulses deliberately emitted by extraterrestrial civilizations in the direction of the Solar system. None has been observed so far.

The choice of targets for *SETI* is a difficult problem. At the beginning, the researches were fully blind, but now they concentrate on known exoplanets supposed to be in the habitability zone of their star. Unfortunately we know only a few of these planets, while there must be plenty of them not yet discovered. What are the chances of detection? They can be expressed mathematically by the famous equation proposed by Frank Drake in 1961, which is actually a way of organizing our ignorance. It is discussed in the Appendix to this chapter. The conclusion is: we still don't know. The only progress since Drake is that we have already found some exoplanets in the habitable zone and that we may have in the near future a more or less complete inventory of these objects near the Sun: so we will better know where to look.

Today's Plurality Myth

Forget for the moment the mere communication problem, and let us consider *ETI* in itself, here mostly from the perspective of the Believers. The mental images of these extraterrestrial intelligent beings which we presently carry in our minds form a most curious picture, one that is sure to interest historians in our own future, should such a doubtful privilege be granted to humanity. Still, as they coalesced quite rapidly during those first few years after electromagnetic signalling became a serious possibility, we may already revisit the scene with up to fifty years of hindsight, which is slightly better than nothing. These pictures appeared independently, but an attempt is made here to put them in some sort of logical order; they have become associated with the names of their (human) inventors, under which they will be recalled.[5] Such is the substance out of which the present Myth is built.

The first step is trivial in the extreme: considering that we already have our own Space Station, no great mental effort is required to fancy *O'Neill's Space Colonies*. When implemented in our own future these delightful devices will solve the overpopulation problem of the home planet; obviously, Aliens merely a little more advanced than ourselves have long enjoyed such conveniences. Next, their Galaxy itself becomes fully colonised. The past history of our own planetary surface ecosystem demonstrates living species invariably expanding to fill any suitable medium, whether solid, liquid or gaseous: thus land, sea and atmosphere were originally colonised. Intelligence has now made vacuum a handy abode for life; *ergo,* life must fill vacuum, and no other mechanism nor argument is required. Eukaryotic cells did it with membranes, aliens just don space suits, the tools are almost the same. One minor trouble: in the immediate future, we do not quite seem to know what to do with our Space Station.

Wait a minute, we are scientists: how much of that colonising process is observable? A most sensible question: it might indeed be detected if those Aliens are obligingly building *Dyson's Spheres.* At some stage, they will run out of energy sources; what could be simpler than capturing the entire light output of their home star, disassembling some spare planet, and erecting with the materials a thin spherical bubble; the whole space inside is then made habitable. The 300 K temperature which happens to be comfortable for humans being postulated, and the laws of physics (i.e. twenty-first century human laws of physics) remaining supreme, the exterior

[5] For a collection of papers by such people, see Goldsmith (1980). All topics mentioned in italics here are developed by them in this book.

surface of that sphere becomes an infrared source, which is conveniently observable from far-away Earth. The argument is faultless, both energy and matter would indeed behave as pictured by Dyson. However, should any human astrophysicist worth his salt stumble on such a radiation source, he would immediately provide it with one, or many natural explanations.

Next, we need to inject some kind of order within our own ideas about these extraterrestrials. When you do not yet understand, at least name and classify: a rule as old as Science itself. A very convenient method is offered by considering the *Kardashev Civilisations.* Alien polities are most sensibly sorted according to their energy consumption: Type I, comparable to Earth at the present epoch; Type II, able to harness the energy of its own star, i.e. of the Dyson type; Type III, merely doing the same with its entire Galaxy. Observe how satisfying is the whole approach, and how strictly objective. Poor Linnaeus had to make do with flimsy criteria, arbitrarily chosen and often contradictory, while here pure thermodynamics lie at the root of the whole business. There is no question that these civilisations, while perhaps not yet fully delineated, have already found stable resting places within numerical taxonomy: all you need is a decent wattmeter. Next, cladistics will be applicable.

Still, should such civilisations be treated as independent or forming a whole? Here we are offered another appealing picture, that of the *Bracewell Galactic Club* (Bracewell 1976). Each civilisation expands its own sphere of knowledge and influence, these spheres ultimately intersect, and interfere most amicably; their owners form a Club which newly discovered families are invited to join. In the original scheme this is all done by automated probes instead of light signals, which appears a dismally slow process, but probes have the advantage of being far more durable than electromagnetic waves just streaming along. In any case, the proposed tools are inessential, but the spirit proves most praiseworthy. Maybe They also have their own League of Nations, and have found the trick to make it quasi-eternal?

The scene appears crowded, but there is yet room for more. Now enters the troop of the Sceptics, running loops around the protagonists while carefully avoiding any vicious circles of their own. They wear garments of various colours, but all brandish the same placards bearing the sign: *Fermi Paradox* (enounced orally in 1950, no clear written reference). The common message: if Aliens exist, the Earth should have already been visited by them, or at least their probes? Adequate means for achieving Galactic colonisation may already be described by humans: just think of those nearly-omnipotent *Von Neumann probes*, i.e. "self-reproducing universal constructors with human level of intelligence", able to survive and multiply while drifting around Space without outside help or guidance. Such appealing devices are allowed by logic and already modelled by mathematics, thus may be just waiting for more mature technology; for an account (and enjoyable guide to Charybdis coastal navigation), follow Barrow & Tipler (1986, see also Tipler in Regis 1985, 132–150), prominent Sceptics. Since no such probe has been seen working within our Galaxy so far, some of the assumptions of the Believers must be wrong somewhere. Even so, a wide choice of counter-strokes is available, and a popular one is the *John Ball Zoo Hypothesis*: humans are far too immature to join that *Club*, thus they are left free to manage their own little Solar system in their own puny way without outside interference. A perfect natural preserve being one in which inmates are not even aware of keepers, We are unable to observe Them. Still, that *Zoo Hypothesis* proceeds even farther than the others as it gives a revealing insight not merely of Their technology, but also of Their psychology; no mean achievement. Alas, it remains in essence impossible to demonstrate; other far less palatable solutions of the Paradox emerge, and intrinsic contradictions within the orthodox view of *SETI* imply that "If we were typical, we should not exist", the thought-provoking summary of Sebastian van Hoerner; they will be followed later.

Indeed, there are more urgent tasks. At the very root of the philosophical thought of all present astronomers lies the Cusanian-Copernican principle, which has led them through an unbroken line of successes for half a millennium. To start with, the Earth was unveiled as a common planet, next the Sun proved an unremarkable star, and as soon as the bounds of the Galaxy were defined, many quite similar whorls materialised outside. Our Epoch is nothing to be proud of, being adjacent neither to Creation nor to Apocalypse or Last Judgement. All the laws of physics and chemistry that have been checked at cosmic distances (and they do make an impressive package) have proved identical with those current down here; and they do not vary with Time either. Hence (here astrophysicists enter turf not their own), Biology had better conform: it has no other basis, and all its operations must ultimately reduce to chemical reactions working under whatever shreds of deterministic control quantum mechanics still allow; including of course that most interesting but so-far indeterminate step: the birth of life itself.

First, let us give a brief (and rather standard) summary of the case for *SETI*. Considering that (1) the number of stars in the Galaxy is about 10^{11}, and perhaps about 10^{21} in the visible Universe at the latest count, and most of them have planets of their own; (2) among these planets, many are bound to be at a suitable distance from their star and fall in the so-called habitable zone, which roughly means: able to preserve some liquid water; (3) while the mechanism of Life's origin on Earth is unknown, the phenomenon itself is roughly datable, and appears to have been remarkably rapid once a decent enough temperature had been reached; thus (in a large logical leap) the generation of life must be deemed a probable happening on the surface of suitable planets; (4) the progression of life to intelligence has been a very slow process, but the major steps are well known, and the mechanism is broadly understood as evolution controlled by natural selection, thus it also appears a highly-probable phenomenon; (5) the last step, from intelligence to "advanced" technology has been so rapid that it must be simply unavoidable. These points are given a quantitative form, compact and mind-pleasing, through the famous *Drake Equation*, in which actual numbers are daringly injected (see the Appendix). Conclusion: even within the Galaxy, the number of potential message senders remains very large. *Ergo, SETI* is a legitimate scientific undertaking; since the potential human benefits are immense, give us the funds and we will build the tools.

Interestingly, the recent discoveries about exoplanets and life, have not marked a conceptual change within *SETI*, as there is still no observational basis for life in other planets. However, the third step (widespread apparition of life) now appears somewhat more probable than it did a few years ago.

The next steps, the birth of complex forms of life and of intelligence, are highly controversial; here, we keep for the moment following *SETI* advocates. For Carl Sagan, Philip Morrison and others (see Ponnamperuma 1974) "intelligence is an inevitable consequence of biological evolution given enough time." Drake used his equation with optimistic figures, and much enthusiasm, to foster *SETI* with success.

Admittedly, Fermi-type doubters creep in through every crack. For instance, Frank Tipler argues that in the history of any advanced civilisation, interstellar travel cannot materialise more than a few centuries after the radiotelescope, and for tools there are the Von Neumann robots (Tipler in Regis 1985, 133, 150). When both abilities are combined, the entire Galaxy is colonised in a few million years; which has not happened. A similar line is followed by Michael H. Hart who, after giving a summary of all the Drake-equation probabilities (in Papagiannis 1980, 19), refuses to make any use of any; he prefers to work backwards and conclude from the obvious absence of galactic colonisation that advanced civilisations must be very scarce indeed. If we follow these arguments, our signal-detection attempts are never going to work. Nevertheless, Sagan manages to turn the tables, as *SETI* remains "one of the few human endeavours where even a failure is a success." If a thorough search does not produce any positive result, the negative one is nevertheless of immense value: "it would speak eloquently of how rare are the living things of our planet, and would underscore, as nothing else in human history has, the individual worth of every human being." (Sagan 1980, 314). Such a risky mode of reasoning was bound to raise eyebrows in the opposite camp.

Optimists are not limited to a belief in the mere existence of Alien intelligence: they proceed to argue that it will exhibit enough common features with our own to make dialogue possible. For instance Marvin Minsky (artificial-intelligence specialist) explains *Why intelligent Aliens will be intelligible* (in Regis 1985, 117). His arguments will not be given here (one must confess them somewhat hard to follow for merely-natural intelligence) beyond the main postulates: "all intelligent problem-solvers are subject to the same ultimate constraints – limitations on space, time and materials." As to the key point, the definition of intelligence, the near-universal view of *SETI* converts is "the ability to built a radiotelescope." The Author profoundly dislikes that formula, having only built mere optical telescopes himself.

Let us conclude: what is in essence the common argument of all Believers? As very well put by Carl Sagan: "No convincing resolution of the [*SETI*] issue is likely to come from protracted debates carried on with great passion and sparse data. We have an alternative denied to the medieval scholastics: we are able to experiment. We can organise a scientifically rigorous search…" (C. Sagan & W. Newman in Regis 1985, 161); the key point indeed, and one with which it is hard to disagree, particularly after suffering through so many pages of quasi-scholastic discussions. *verba*. Even so, Concerning Plurality, our own epoch is well poised to take up again the Royal Society's *Nullius in*: what are the chances of that search succeeding? No answer.

On the other hand, the central point of all sceptics is made by the philosopher Michael Ruse (in Regis 1985, 46): "Unless one has a either a theory to back up one's hypothesising, or some empirical evidence to show that one's probabilities have some possibility of being reasonable, any supposed probabilities that one pulls out of thin air are no more than that." Biologists, evolutionists, human-science specialists and philosophers all came second to the *SETI* field, but they have since been broadly invited to the conferences; while never questioning the astronomical data which lie at the root of the whole subject, they at once took a dim view of all those probabilities that fell within their own fields, and of the resulting construct. In particular, they have taken to pieces one key pro-*ETI* argument: Rise of intelligence slow, but mechanism (through natural-selection) broadly understood and automatic, hence probable. From their vantage point, far outside astronomical Space, there are many ornaments that do make the cases of Earth and Man highly special. This has been since vastly confirmed by geologists and astronomers (see for example Ward & Brownlee 2000). Still more recently, as we have seen, astronomers have remarked how peculiar is the Solar system compared to the known planetary systems around other stars.

The most severe blow has yet to come, and it will be dealt by the philosopher Edward Regis in his devastating *SETI debunked* (in Regis 1985, 231–244): the Extraterrestrial Intelligence hypothesis is branded with an epithet far worse than just False: it proves Irrelevant. Whatever that dedicated search is going to unveil, it cannot unravel any of the great human puzzles, past, present or future. Surely, that much had already been obvious as far as current worldly affairs go, but the same applies to the world of thought itself, which will come as a severe letdown to all *SETI* fans. Granted that a message lands on Earth, and that it is demonstrably intelligent, then what? Merely learning that another civilisation exists is not going to shake the world: "the discovery of the Americas did not have anything like the effects upon Europeans that *SETI* advocates insist on." To proceed any further, we still have to pass a series of branching points. First, is that message understandable? "The resistance to decryption of even some earthly texts … does not inspire confidence." Should we manage to extract some sense, it may prove to be merely "a prime number series, or π to a thousand decimal places", nothing to shake the world either. Next (and hardest case) we do manage to learn substantial facts about the emitting civilisation; then, it proves either totally unlike ours, totally similar or half-half. Only the third case is of any interest: "the others must be like us only in certain essential and relevant respects… discrete individuals having the same types of needs, drives and desires … interests sometimes in agreement sometimes not… a language that we can understand…" The chances are pretty low; still, once more, let us assume that the point is granted, and that we do receive a message which "conveys a detailed account of the Aliens ethical and political system." Then, do we adopt or reject? Unavoidably, "in doing this, we would be using our own pre-contact standards. Call it provincial, reactionary, chauvinistic … we'd be evaluating other theories by reference to our own… [and not] get outside the earthbound perspective from which Alien communications are supposed to liberate us". Want a plain example? "If the Others handle their population problem by practising infanticide [etc, etc…] do we courageously throw off chauvinistic moral objections to these practices and institute them for a while on Earth?" Perhaps, here Regis is missing another point, for which the hint might have come from Huygens: all those Aliens, "it's more likely they have such a medley as we, such a mixture of good and bad, of wise with fools, of war with peace."

Let Ernst Mayr provide the conclusion of sceptics: "The assumption that any intelligent extraterrestrial life must have the technology and mode of thinking of late twentieth century man is unbelievably naive." (in Regis 1985, 28). My own *résumé* of their case: that present craze is just one more case of cosmic anthropomorphism; merely, the least subtle ever. Altogether, *SETI* is a pleasurable game for whoever has spent a lifetime watching the comedy of circles within Heavens rather than that of Life around his own feet; and such is the way Thales fell into his pit.

SETI opponents have built a very solid case for Alien intelligence arising (if ever) through totally unfamiliar paths and reaching such unpredictable forms that not only communication with us is impossible, but the urge to communicate may be absent. Let us have another look at the arguments from both sides.

All players begin by paying lip-service to the most-regrettable uniqueness of the case they have to start from, and then try to do their best. Astronomers tend to argue that intelligence is bound to evolve almost everywhere because it definitely did so once on Earth, a place about which there is nothing special. Evolutionists answer that the process must be grasped as a whole, since all end-products of evolution are incomprehensible when only seen in isolation; each one is the result of a large number of independent chance events, and remains improbable in the highest degree; improbable in the sense of nearly impossible to reproduce. Their picture is that of a huge tree with each species occupying the end of a small distinctive twig, while astronomers seem ready to plant an immense forest in which the tips of the twigs from many separate trees come so close that they cannot be discerned. Evolutionists retort they do know how twigs from different branches mix: that is bread-and-butter for them. Even from their single trunk, they hold many twig-mixing cases, and they have statistical proof that it happens often in likely cases, but fails in that of intelligence. Astronomers so far have no ready answer, as they have never bothered about the actual steps within a field so far from their own. For them, the precise mechanism that has built Intelligence is unimportant; what really matters is that it exists, is reliable, and its end result certain, all because it did work once. One feels that here minds trained in natural sciences work their way up that tree step by step, because they know all the forks and branches intimately; while physicists and/or astronomers, convinced they hold an universally valid principle, skip all those laborious steps, and jump to the final conclusion. Final or definitive? Might there be again a hidden flaw in their argument? About the age of the Earth, the nineteenth-century physicists were wrong, and rather disastrously so; but physics still won out in the end, by supplying objective and accurate dating techniques. How definitive is our beloved Cusanian-Copernican principle? It has lasted five hundred years, which is less than Peripatetic truths, far less than recorded history and trifling compared to the age differences between Alien civilisations; and as long as one of these does not obligingly provide the hoped for message, we will be left wondering.

Then, in the optimistic case, will that signal itself possess a convincingly artificial character? It has been argued that the only certain proof would be dialogue, and that the test has been provided by Descartes: "A machine can speak, but not discourse." (quoted without reference and argued by L.W. Beck in Regis 1985, 11). Old-style astronomy, a purely observational science, cannot solve the problem and it must first turn experimental. In practice, we should answer the supposed message (e.g. by return to sender, with modest additions of our own), and wait for the response, a slow process as there is no hope to short circuit the two-way light travel time. An example: when pulsars (and also spectral lines from the OH radical) were detected, an artificial origin was at once considered but very soon dismissed. A far better example, taken from a distant field, illustrates the extreme difficulty of proving any puzzling novelty found in Nature to be an artefact. During World War II, the achievement of a chain reaction by uranium fission proved a highly-complex undertaking: it required elaborate theorising and painstaking experimentation, a well-designed pile lay-out with a precise lattice of highly-purified uranium and graphite blocks watched over by up-to-date measuring instruments. German physicists, no simpletons, understood the theory and even began to build a pile, but never reached success. Altogether, that accomplishment appeared at the time as the acme of modern science. Thirty years later came the news that a natural fission reactor had been operating within a seam of uranium ore at Oklo in Gabon two billion years ago: plain rainwater (if you insist, *aqua simplex mirabilis*) had proved a perfectly adequate moderator. The twentieth-century discoverers were so stunned that, at first, they refused to believe their own evidence. Conclusion for *SETI*: even if that hoped for interstellar message comes as a steady-state phenomenon, freely observable by all and sundry over many years, demonstrating artificiality may prove hard.

Altogether, the wait may prove a wearying one, leaving listeners with plenty of time to re-examine their own postulates, hidden or not. The first postulate, namely that Intelligence has lasting value, is by no means hidden, since that Lifetime of intelligent civilisations finds itself invariably injected in the Drake equation as the last parameter. All disputants sensibly admit this to be a difficult point, since nothing whatsoever is known about it, and then proceed on their way as before, a third lip-service case. The sore point here is not one about our unknown future, but rather the teachings of the past. There has been on Earth a single case of an intelligent species, and its age is of the order of a million years. The date of origin of intelligence on Earth is difficult to specify with any accuracy; the best trace is artificial tools and fire, while some correlation with *Homo habilis* brain size is also postulated. Those tools certainly helped survival, and so did complex language and the formation of society; still, is it clear that intelligence is bound to last? One million years lapse of time is far too short for a proof, and many species (both extant and extinct) have done better by two orders of magnitude using paraphernalia of non-intelligent devices. The human technical achievements of the last few centuries are indeed remarkable, but is extrapolation from such an short period a sensible attitude? Take the case of human population growth, a phenomenon clearly traceable to technical progress: it just cannot go on for very long, and no mathematically sound curve fitting has any chance of predicting the actual future. Some limiting factor, palatable or not, is bound to appear that will curb that growth. However, scientists devoted to *SETI* prefer mostly to let their extrapolations run wild. The test for human intelligence, at the present time, might be the ability to take an outsider's viewpoint, and not to behave as intelligence chauvinist.

For two civilisations attempting to communicate, the coincidence-in-time difficulty is the fundamental one, far greater than all technical limitations together; at least from our side, it appears impossible to solve. Why should any signal land on Earth during those particular few thousand years? And the actual completed surveys have been performed merely over a few years, with at most a few hours spent on each star, which gives a feeling for the enormity of the task. Future surveys, for which the planning or even the funding are well advanced, will greatly increase the coverage of both the sky and the frequency domain. Alas, any order-of-magnitude improvement is here not merely beyond present human capability, but beyond human thinking. That is the painful fact behind that Search; and the worst part is that this deep insight is no novelty, it is Democritus' own! Among these Worlds, infinite in number, "… some are growing, others are at their prime, and others again declining, in one direction coming into being, in another ceasing to be."

One has now to ask the hard question: might all of *SETI* be the latest and worse case of wishful thinking? Actually, *SETI* does involve wishful thinking in a subtle sense: the reintroduction of teleology itself through a side door. To say that our own utter mediocrity entails other intelligent species appearing elsewhere just like we did, seems to be guided by both teleological and wishful thinking. The thought processes of evolutionists lie far closer to strict causality, and they reject any guiding principle making intelligence not merely inevitable, but even probable. And here is at least one philosopher who agrees, L.W. Beck:

> I suspect that deep-seated philosophical, religious and existential commitments… are still silently effective in guiding the Lucretian argument and keeping alive the archetypal idea that man is not alone…. Even responsible scientific speculation and expensive technology of space exploration in search for other life are the peculiarly modern equivalent of angelology and Utopia, or of demonology and apocalypse. (in Regis 1985, 13)

Now has come the time to conclude that no self-consistent and mind-pleasing conclusion about Plurality lies in view. However, "It is not necessary to hope in order to undertake, nor to succeed in order to persevere". Should this old proverb[6] fail to provide a noble-enough incentive, flaunt that *Search* as nothing less than the Godless form of Pascal's bet. Search not for political, economic nor even moral baubles, search not because those putative Aliens are itching for Galactic communication channels to be opened. Search because we are bound to try out such a *Search* as part of unravelling the Cosmos puzzle, which remains the prime excuse for human existence. Remember Anaxagoras, born "to study Sun, Moon and Heavens", and Democritus: "Rather discover one cause than gain the kingdom of Persia." Modestly try aping Descartes: "Quaero ergo sum." And as an *in fine* positive contribution to our quest for Aliens, I suggest that all human devotees should adopt and

[6] Proverb variously attributed to Ulysses, Charles the Bold, Pascal, and Wilhelm of Orange. From my own checks: wrong for both Ulysses and Pascal. As to Charles the Bold, he is usually remembered in Franco-Burgundian history for great strokes rather than great thoughts.

cherish that delightful piece of Kipling poetry, *We and They*, which is just made to order (*Debits and Credits,* Macmillan, 1926).

WE AND THEY
Sister and Auntie say
"Father, Mother and Me,
All the people like us are We
And everyone else is They.
And They live over the sea,
While We live over the way,
But – would you believe it ? - They look upon We
As only a sort of They !

We eat pork and beef
With cow-horn handled knives.
They who gobble Their rice off a leaf
Are horrified out of Their lives;
And They would live up a tree,
And feast on grubs and clay,
(Isn't it scandalous?) look upon We
As a simply disgusting They!

We shoot birds with a gun.
They stick lions with spears.
Their full dress is un-.
We dress up to Our ears.
They like Their friends for tea.
We like Our friends to stay;
And after all that, they look upon We
As an utterly ignorant They!

We eat kitcheny food.
We have doors that latch.
They drink milk or blood,
Under an open thatch.
We have Doctors to fee.
They have Wizards to pay.
And (impudent heathen!) They look upon We
As a quite impossible They!

All good people agree,
And all good people say,
All nice people, like Us, are We
And everyone else is They:
But if you cross over the sea,
Instead of over the way,
You may end by (think of it!) looking on We
As only a sort of They!"

Alas, the complete *motto* should leave room for *SETI in æternum.* Close you ears, but keep your minds open: why do some of the basic assumptions remain so abysmally naive, and a true "modern equivalent of angelology and Utopia"? In fact, merely childish, and it so happens that it is Kipling again, with his *Just So Stories,* who provides the fitting image. Start by remembering that famous Sagan-designed plate aboard a *Pioneer* spacecraft (figure 13.8), which was the result of a highly-serious effort at sending an interstellar message; it had been designed to be understood by Aliens having nothing in common with humans except the physical Universe. Of course, both Sagan and NASA were well aware that the chances of their probe actually reaching some habitable abode remained infinitesimal, and the more-immediate goal was just *SETI* propaganda down here; these are trivial points. The one that deserves reflection is: may adult minds truly hope for cosmic intelligibility of such inspired scribbles? The criticism is not intended for the authors of that most praiseworthy attempt, but for all of us, and here the ironic analogy with Kipling's *First Letter* jumps to the mind. His inventive Taffy wants to convey a message through the mute and mysterious Stranger-man, and tries to do her best through deeply thought-out drawings; the results are wholly unexpected… Re-read that delightful story, and while the final imbroglio is still fresh in your mind, have another look at the *Pioneer* plate. Maybe this supposedly obvious pulsar diagram on the left will be deciphered as a nuclear explosion threatening the two shapes on the right, much like the Stranger's harpoon stuck in Daddy's back? Will those twin friendly silhouettes be construed as forms of peculiar planetary nebulae or supernova remnants? Will the hoped-for recipients unravel 2-D drawings of 3-D objects? Worse, will they enjoy any form of vision at all?

This is perhaps a good place to recall that messages encoded by Incas within *khipus* made of strings and knots are still mostly mysterious, even if they were created by human minds and hands, using commonplace Earth materials. The *khipu* was still operational a mere five centuries ago; Spaniards watched it being read partly by eyes and partly using fingers, and a rare few of them even took interest. Garcilaso de la Vega (half-Inca himself) writes that "all the Inca really knew was recorded in the *khipus*." Prior to the arrival of the conquerors, Incas had enjoyed a burst of *khipu*-burning (and wholesale purge of the *khipukamayuqs*) by one of their own rulers bent on rewriting history to his personal taste; which sounds comfortingly familiar to intelligent moderns. Today, we understand at least that this recording system used three dimensions, while all other modes of writing are happy with two; that it was based on a kind of binary coding involving knots, but the string itself (particularly its 24 colours) also held information. It seems that 2^6x24 = 1536 "characters" were achievable, which is more than Egyptians or Mayas ever used. Nevertheless, up to the present day, only some numerical and calendric data have been fully decoded. Any relevance to the problem of deciphering Alien messages? Current *SETI* technology implies that Earthlings should expect to receive not pieces of material strings but strings of bits encoding photons; thus the message will be one-dimensional anyway, with Time the sole parameter. Even so, if the Alien radio-astronomer in charge has trained on *khipu* at local elementary school, his mode of expression may prove hard to crack for alphabetically-minded humans.

For ultimate help, I will call in three thinkers both more ancient and more profound than brave little Taffy. First, the German poet Sebastian Brant who put astronomers aboard his *Narrenschiff,* one of the greatest best-sellers from the early printing presses, soon translated to most languages e.g. as *Stultifera Navis*, *Shyp of Folys* or *Shyppe of Fooles* and *Nef des Fols*. He singled out *The vayne cure of Astronomye* for ridicule, but he was of course thinking of mere astrology. Today, we deride easily enough that primitive folly, but our own desperate search for Aliens is naught but a poorly-disguised attempt at peering into our own future. We might do well by pondering on Brant's opening stanza[7]:

> He is, forsooth of purpose vain and blind,
> Of mind misbelieving and without advisement,
> Which steadfastly thinks in his mind
> To know things to come plain and evident
> Only by the stars of the firmament.
> Yet, churls void of cunning and wisdom
> Are nowadays astronomers become.

We are still passengers on that Ship.[8] Exobiology exacerbates eschatology.

Next, Michel de Montaigne, who wrote in the later and faster moving times between Copernicus and Galileo but nevertheless preferred to scrutinise the wisdom of ancient sages. For him, these Other Worlds are just the fruit of wishful thinking, a mere fool's paradise:

> Is it not a mere dream of human vanity, to make the Moon a celestial Earth, to fancy mountains and valleys over there like Anaxagoras? to erect human dwellings or habitations, and to institute colonies for our convenience, like Plato or Plutarch?[9]

Thus, unlike Brant, he is thinking about real astronomy, not astrology, and even considers (but rejects) Aliens. Altogether, maybe human vanity is the sole needed key for understanding both ancient and modern Pluralities?

Last, the basic hopelessness of any attempt at cosmic communication makes me turn to the romantic poet Alfred de Vigny in *Le Mont des Oliviers* (Vigny 1837). In the Garden of Gethsemane, abandoned by his Father, Christ cries out his ultimate despair:

> Blind, deaf and dumb to the cries of creatures
> If Heaven dropped us like an aborted world
> The Just will oppose contempt to absence
> And will answer only by cold silence

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[7] The 1508 translation by Alexander Barclay *The Shyp of Folys* is as follows: "He is forsoth of purpose vayne and blynde / Of mynde mysbeleuynge and without aduysement / Whiche stedfastly thynkyth in his mynde / To know thynges to come playne and euydent / Onely by the sterrys of the firmament / Yet churlys voyde of cunnynge and wysdome / Ar nowe a dayes Astronomyers become." It has been itself translated rather literally in modern English here (thanks to Françoise du Sorbier). *Narrenschiff* contains many beautiful original woodcuts, possibly by Albrecht Dürer.

[8] This most-appropriate aphorism is shamelessly stolen from the *Introduction* of Katherine Anne Porter's excellent *Ship of Fools*, and she did steal her own title from Sebastian Brant.

[9] *Essais* (1595); quotation in the *Apologie de Raymond Sebon,* II, XII, p. 415 of the 1872 edition. I have failed to find a corresponding Plato passage; it is not mentioned by Plutarch himself, nor by Kepler, Huygens or Fontenelle. A slip of the Montaigne pen for Anaxagoras? Here, one might also quote Pope's *Essay on Man*, which gives a similar warning against human vanity: "He, who through vast immensity can pierce, / See worlds on worlds compose one universe, / Observe how system into system runs, / What other planets circle other suns, / What vary'd being peoples ev'ry star, / May tell us why Heav'n has made us as we are."

The eternal silence of the Divinity.

To eternal silence Man has been sentenced. Vigny notwithstanding, that inescapable fact of Nature is far older than Christianity; it was already lying at the core of the favoured Myth among those Ionians who had succeeded in unmasking Zeus as a dumb God, but could only substitute their own equally silent Vortex.

Before taking leave, a childhood reminiscence. As a boy of perhaps six or eight, I (the Author) was fascinated, and at first not a little frightened, by a statuette of the Loch-Ness Monster keeping watch over some dark grotto within my grandfather's immense and mysterious bookshelves. The lovely figurine has vanished through the intervening ages; but in my memory, this Monster still glows as a sort of chimera born of the union between a dolphin and a crocodile (not any fancy plesiosaur!), sporting a luscious green gleaming hide and a flaming scarlet throat. And even so, with an appealing softness in his gaze; after close study, a nice and friendly Monster… I felt far too old for fairies or dragons, earnestly requested the full story and pestered grown-ups for all the serious explanations they could devise. Of which I remember only the least implausible one: the envelope of a burst balloon or downed Zeppelin, so that Monster was unveiled as a mere human artefact! Today, at ten times the age, I often fear that my own fascination with Aliens has been nothing but another fancy from an immature mind; alas, I can no longer find elders to explain.

There is a saving grace, and all of us scientific Plurality fanciers hold a common excuse. In essence (though not in minutiae), it is the same as for the custom of playing with mathematics. Is that bizarre game a mere human invention, or an actual fact of Nature? Here, we feel back to Pythagoras, and still no final answer lies in view, as Platonists, formalists and intuitionists remain locked in endless battle; but that elusive tool daily proves irreplaceable for understanding Nature. A similar conclusion applies to the whimsical Plurality of Worlds, which should no longer be branded as mere Myth: it has grown to the stature of a solid thought experiment, and the most thought-provoking of them all. None seems better designed to provide an objective view of our position in the Cosmos; nor to illustrate better the limits of human knowledge. Exobiology illuminating epistemology?

Appendix: The Drake Equation

This equation was proposed by Frank Drake in 1961 as an incentive for SETI. It expresses the number N of planets in the Galaxy that house a technologically advanced life form and are able and willing to communicate as the product of a number of factors:

$$N = n_* f_p \, n_h f_l f_t f_c \, (t/10^{10}),$$

where:

$n*$ is the number of stars in the Galaxy;
f_p is the percentage of stars with planets;
n_h is the average number of habitable planets among them;
f_l is the fraction of the preceding planets where life actually appeared;
f_t is the fraction of the preceding planets where life is technically advanced;
f_c is the fraction of the preceding planets wishing to communicate;
$t/10^{10}$ is the ratio of the average life span t of the corresponding civilizations, in years, to the average lifespan of the stars and their planets, estimated roughly at 10^{10} (10 billion) years.

In 1961, the quantities f_p and n_h were totally unknown, as were all the other factors but $n*$. In his original article, Drake adopted the following values:

$n* = 10^{11}$ (all the Galaxy)
$f_p = 0.5$;
$n_h = 2$;
$f_l = 1$;
$f_t = 0.01$;
$f_c = 0.01$;
$t = 10{,}000$ years,
which gives $N = 10$.

Given the immensity of the Galaxy, in which the Sun is just an ordinary star that distant aliens have no reason to chose as a target, this figure does not leave much hope. But of course many of the values above are eminently debatable! Let us propose some anew, just as a game. Every reader is free to contemplate alternatives.

Limiting to 1000 light years, a very optimistic value, the distance of stars such that their inhabitants have noticed the Solar system as a target, we take $n* \approx 15{,}000$.

All stars have planets, so that $f_p \approx 1$.

If we suppose that only systems more or less similar to the Solar system contain really habitable planets, the product $n_h f_l$ is smaller than 10^{-4} as we have seen. But it might be somewhat larger.

The probabilities f_t and f_c are even more problematic. In a later study, Drake took very optimistically both of them to be equal to 0.3; let us keep this value.

Finally, we are in complete darkness as to the average life span of an advanced civilization. The example of our own civilization does little to encourage optimism: less than two centuries after the appearance of the first machines, man has built nuclear bombs capable of destroying himself, and the overpopulation and global warming that we are responsible for can also destroy our civilization someday. The 10,000 years of Drake, if they look short, could be an upper limit of the life span of our civilization. We do not believe like Stephen Hawking in a migration of the man towards Mars, where life would pose insurmountable problems. However, if we are wise enough not to destroy ourselves, we could be impacted by an asteroid or a cometary nucleus, which would eliminate all evolved life on Earth. The last of the great extinctions of advanced life, that of dinosaurs, goes back to 65 million years, and it is estimated that similar phenomena occur on average every 100 million years. Some attribute these extinctions to volcanism, against which nothing can be done; if, as others think, they are due to the fall of a projectile, perhaps we will be able to divert this projectile and avoid them in the future. There is also another limit: the inevitable increase in the brightness of the Sun is such that the Earth will emerge from the habitable zone in about 1.5 billion years. This would be a strict upper limit for the life-span of man, but it seems more reasonable to take it as 100 million years. Even so, we arrive at $N = 13$. Pretty small, but is it not still optimistic?

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[1] As recalled in the Notes, many texts in various languages are now available in fac-simile and a large number in world-processor form) from Gallica.bnf.fr, and other WEB sites. They are indicated by ∗ for Gallica, ° for Google Books and ⁺ for others.

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