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

[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.

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[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 [$\delta\iota o\ \alpha\nu\alpha\gamma\kappa\eta$] 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.

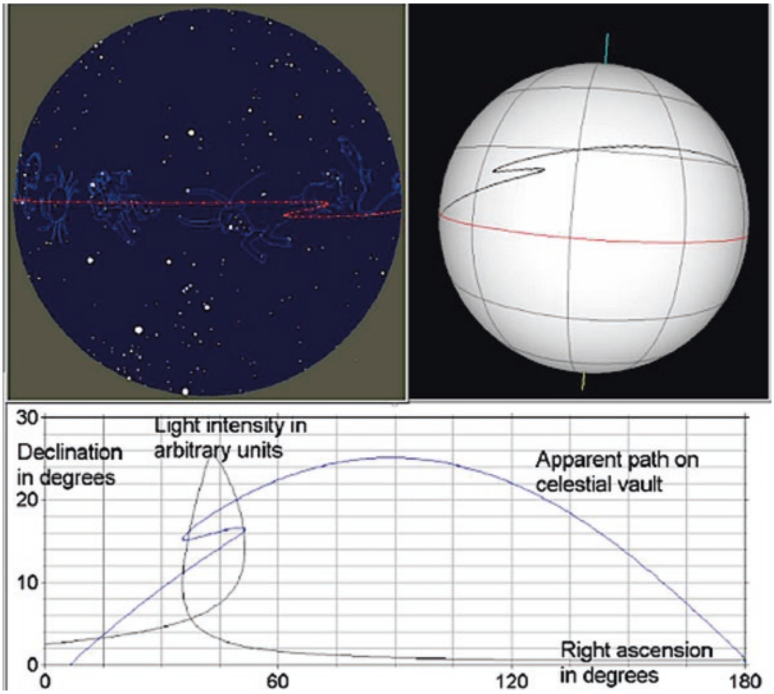

Figure 2.1 Planetary paths passing from raw data to scientific presentation. Above, left: a direct naked-eye view showing those "intricate traceries in the sky", condemned by Plato (and ignored by Scripture), but well known to antique astronomers. The figure shows the apparent path of Mars among fixed 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).

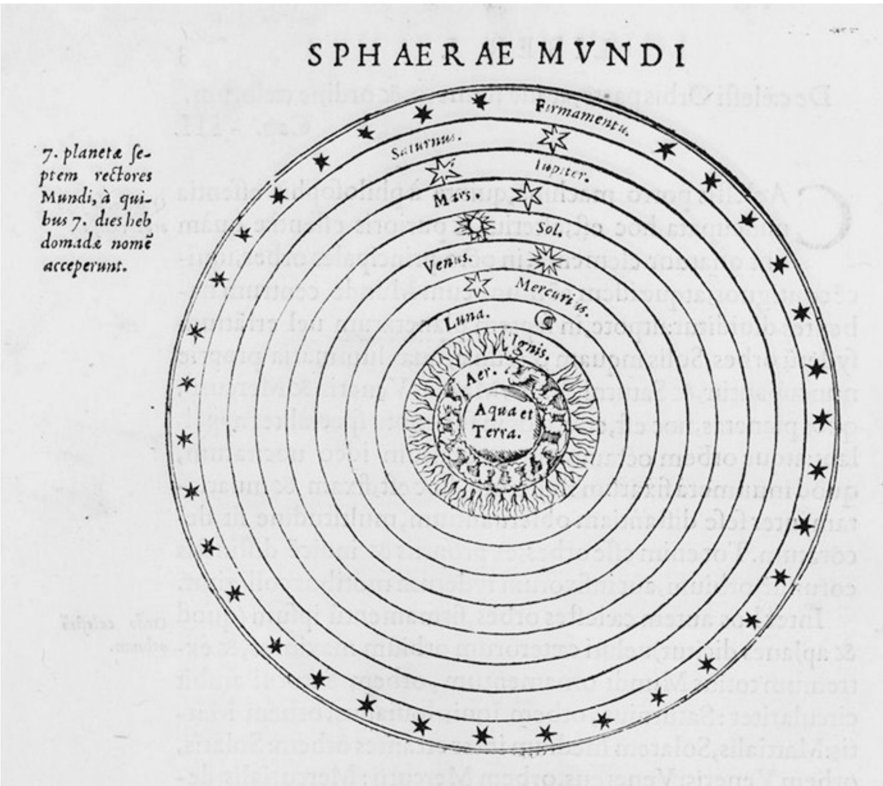

Figure 2.2 The World according to Ptolemy. This concept survived until the 17th century. Oronce Fine, who published in 1555 this engraving in his *De mundi sphæra sive cosmographia*, recalls that the seven "planets" that include the Sun and the Moon have given their name to the days of the week. © Bibliothèque 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 (*στοα*), unlike the Garden (*κηποσ*), 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.