# Chapter 12
# Christiaan Huygens: Humans Give its Present-Day Form to Extraterrestrial Intelligence

*Should we allow the Planets nothing but vast Deserts, lifeless and inanimate Stocks and Stones, and deprive them of all those Creatures that more plainly speak of their Divine Architect, we should sink them below the Earth in Beauty and Dignity; a thing that no Reason will permit… What a wonderful and amazing Scheme have we here of the magnificent Vastness of the Universe! So many Suns, so many Earths, and everyone of them stock'd with so many Herbs, Trees and Animals…*

Christiaan Huygens[1]

Huygens discovers the rings of Saturn, anonymous painting (ca 1820). Bibliothèque de l'Observatoire de Paris

[1] *Cosmotheoros,* 150.



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I have felt considerable misgivings about this lengthy chapter title, and the choice of *present day* was most laborious. *Definitive* was tempting, but obviously preposterous. The said title is also meant to make understandable my choice, which was to make this chapter the last one in the story. (A final chapter was however added by the editor, using elements left by the author.)[2]

When Christiaan Huygens was born in 1629, Kepler was still alive and Galileo had not yet faced his trial, while the greater part of the Descartes opus remained unwritten. The Dutch physicist was to acknowledge his debt to all three, and more explicitly to the French philosopher; however, the greatest and most durable Hugenian contributions to science had little to do with his Cartesian convictions, which anyway soon drifted far from the orthodox path. But when he died, five years short of the new century, the structure of Plurality developed in his *Cosmotheoros* had almost reached the modern form, largely from his own contributions. His Universe is filled with stars that he was first to locate correctly, through an astute method for determining their distances. Those stars are equipped with planets orbiting according to Keplerian laws, and enjoying quasi-Newtonian mechanics; and their invisibility is accounted for by optical explanations. Thus, when Huygens describes his planets as lavishly furnished with life forms progressing from vegetal to animal and from intelligent to civilized, *Cosmotheoros* stands in respect to the Fontenelle *Entretiens* like the *Proceedings* of a twenty-first century Extraterrestrial Life meeting compared to Jules Verne.

Except for two severe limitations. First, Huygens' understanding of the Sun and neighbouring stars in relation to each other is indeed spatially correct; today we consider that sampling such a small fraction of the Universe is adequate for asking, and maybe later answering, all relevant questions about extraterrestrial life. But the Huygens outlook is still static, as it was bound to be in the waning seventeenth century: the time element is lacking. The origin, the age and any possible evolution of these planetary dwellers are not discussed, as for Huygens they do not even pose a problem worth considering. Along this line Fontenelle had proceeded farther by wondering about possible changes in Nature over long periods of time. While the Creator makes remarkably few explicit apparitions through most Huygens works, he is still very much required in *Cosmotheoros*, behind which he lurks as the

[2] The complete works of Huygens have been published in the 22 volumes of *Œuvres Complètes de Christiaan Huygens*, by H. Nijhoff, 1888–1950 (here referred to as *OCCH*). They contain mostly French and Latin texts, and provide French translations of the latter. Of particular interest here are Vol. I to X (*Letters* plus many fragments and even observing or laboratory notes), Vol. XV (*Systema Saturnium*), Vol. XVI (*De Motu* and *De vi centrifuga*), Vol. XVIII (*Horologium Oscillatorium*), and Vol. XXI (*Cosmotheoros*). However, all quotations of *Cosmotheoros* will be from the 1698 English translation *The Celestial Worlds Discover'd*.

Two interesting conference proceedings are: *Studies on Christian Huygens* edited by Bos & al. (*STCH*); and *Huygens et la France*, introduced by René Taton (*HFR*). For biographical information, we have mostly used *Christian Huygens and the development of science in the seventeenth century* by A.E. Bell (Bell 1947); *Christiaan Huygens, a biographical sketch,* by H.J.M. Bos in *STCH*; *Huygens, the Man behind the Principle* by C.D. Andriesse (Andriesse 2005, translated from the Dutch), valuable because written by a physicist.

ultimate explanatory device; the author does not think he has to account for the rise of his fancied planetarians any more than for very real fellow humans. More than three hundred years later, after having groped our way through the time-scale of the Universe and at least some of the main rules for geological, cosmological and biological evolution, we have far more questions to ask than either Fontenelle or Huygens. And since we have given up all recourse to final causes, the answers are far more difficult to unveil.

The second clear limit of the Huygens anticipation is that he fails to consider any possible travel or contact between planets or planetary systems. Here, it is not Huygens but Kepler who had shown the way; admittedly, his Duracotus had required some help from witchcraft to reach the Moon, but the physical conditions of the trip had been sensibly described. For interplanetary communication, Huygens at least held the suitable tools: light beams and waves, which he wielded expertly throughout his life. Still, his prescient wave theory is less relevant to our subject than his awareness of the finite velocity of light, the discovery of which he learned with the greatest delight from his Paris Observatory colleague Ole Rømer. Even so, he never formulated the basic rule limiting contact between alien civilisations scattered through the Universe: that of the unavoidable and catastrophic time delay involved. Had he merely asked the relevant question, he might today be presented as the discoverer of both Space and Time Pluralities in their modern forms; truly, he anticipated the first, never the second.

After a brief account of his life and works, we will present enough of his method, and of his views on matter, mechanics and the Cosmos, to prove that *Cosmotheoros* is built over the same hopefully firm soil upon which are grounded similar grand extrapolations today. Huygens marks the transition of Plurality from the metaphysical to the scientific age, and thus nearly ends the present historical account.

## Christiaan Huygens' Life and Works

The Huygens family has been a most remarkable one: his father Constantjin, distinguished diplomat and fair poet, also showed concern for such technical problems as lens grinding and longitude determination, an interest which he transmitted to his two first sons. The collaboration between the eldest, Constantjin junior and the second, Christiaan, is one of the best remembered in the annals of science. Their joint efforts were responsible for the polishing of some of the most excellent objective lenses of the period, which were to be used in the sensational astronomical discoveries of Christiaan. Their father had been a friend of Descartes and corresponded also with Mersenne, to whom he underlined the accomplishments of his two sons while still in their teens: see Bachrach, *"The role of the Huygens family in seventeenth–century Dutch culture"*, *STCH*, 27. He was to call Christiaan *Mon Archimède*; no doubt this was a piece of paternal boasting but a singularly apt one, and Mersenne was to concur: "If your Archimedes comes with us, we shall show him one of the most beautiful treatises on geometry ever seen, just written by the young Pascal." (*Letter to Constantjin Huygens*, 17 March 1648, *OCCH* I, 83). The resemblance between Huygens and Archimedes was to be often stressed later, as both brought to mechanics and physics a happy mixture of fundamental intuition and experimental skill. At the age of sixteen, in 1645, Christiaan entered the University of Leiden where he was to spend two years with two subjects: law and mathematics, the latter under a convinced Cartesian teacher, Frans Van Schooten; but the boy had already read the Descartes *Principia* just off the press. The University climate must have proved exciting; merely a few years before, all teaching had remained strictly Peripatetic, and considerable opposition to all novelties, Cartesian or Baconian, was still extant.

Huygens began to work on mathematical problems, followed by others in optics and physics. Two remarkable results soon made him famous all over Europe: the invention of the pendulum clock, and the discovery of the Saturn ring in 1655-56. At about the same time, he made his first visit to Paris, to be followed by many others; he settled there in 1663 as founding member (and a very active one) of the new Académie des Sciences, largely thanks to the patronage of Colbert, the intelligent Louis XIV minister. The fact that he was a Calvinist proved at the time no hindrance; unlike for Galileo, Kepler and Descartes, theological constraints played little role in his career, and he also kept largely aloof from politics. Moreover, he had been born in a wealthy family, always lived in a favourable atmosphere and received adequate support. Still, in the climate that arose in Paris around the 1685 Révocation de l'Edit de Nantes, and also because of the death of Colbert, he was to prefer return to his own country, where he was soon followed by a crowd of Protestant intellectuals and artisans; altogether, a disastrous loss to France.

The most important Huygens books were the 1659 *Systema Saturnium*, in which a full account of his telescopic observations and ring hypothesis is given; the 1673 *Horologium Oscillatorium* where, starting from the technical problem of improving clocks he proceeded to some of the basic theorems of classical mechanics; and the 1690 *Traîté de la Lumière*, in which he gave the outline of his wave theory: he was able to explain the novel and puzzling phenomenon of double refraction in Iceland spar, which defied the Snell-Descartes laws. The first two books were well received and abundantly discussed; but to the prescient achievements of the third, relatively little attention was paid at the time, as the Newton emission theory seemed so much more obvious for explaining the major known fact about light: rectilinear propagation.

Huygens entertained fair and lasting relations with the major English scientists of the period, and went twice to Britain (see Hall, *Huygens scientific contacts with England, STCH*, 66). The first time was in 1661, and his travel journal is preserved. After Paris, he was not exactly impressed by the pre-Great Fire London "the reek of the smoke is unbearable and very unhealthy, the city poorly built, the streets narrow and badly cobbled…" Much worse, "women have very poor conversation, and show far less wit and animation than they do France." (*Letter to Lodewijk*, June 9 1661, *OCCH* III, 275). On the other hand, scientific contacts were at once pleasant and fruitful. At Gresham College he discussed clocks and the longitude problem, and attended vacuum experiments with Boyle's pump; as soon as he was back home, he was to build an improved version of his own (see Bell 1947, 162). He was elected F.R.S., and ever after remained in close touch with the Royal Society.

Just before his second visit to London, in early 1689, there had been a notable upheaval in royal circles. Brother Constantjin and Christiaan came over for a three-month summer visit. "I would like to be in Oxford, merely to get acquainted with Mr. Newton, whose beautiful inventions I greatly admire in the work he has sent me." (Andriesse 1993). Actually, he did speak at some length with Newton, and even rode with him from London to Hampton Court. No close relationship nor correspondence developed between the pair, as the two views of Nature were thoroughly incompatible. Still, the meeting may have goaded Huygens to publish the *Traîté de la Lumière* soon after his return (Hall, *STCH*, 78, 79), while he was usually rather slow to print.

Thus Huygens, who had rather narrowly missed meeting Descartes in person[3], only managed a rather superficial encounter with Newton, but with Leibniz the case is quite different. Leibniz first visited Paris in 1672, at the age of twenty-six when he was still unknown within science (see Heinekamp, *Christiaan Huygens vu par Leibniz*, *HFR*, 99). Huygens, seventeen years older and a famous scientist, helped him to make a start with mathematical problems; a friendly correspondence developed, which was to last until his death and be well preserved. However, the pupil was soon to surpass the master: Huygens always had difficulty in grasping the point and handling the tools of differential calculus, either in the Leibniz or Newton forms. He used it rather little himself, preferring the traditional-style geometrical or algebraic demonstrations, in which he excelled (see Bos, *Huygens and mathematics, STCH,* 126-146).

After leaving Paris, Huygens settled in the Hague, or in his nearby manor of Hofwijck, perfecting solutions to his old problems in optics and mechanics; no more astronomical discoveries were made. Still, during the last year of his life, he attacked a novel subject by writing *Cosmotheoros*, which remained a mere manuscript at the time of his death in 1695. Brother Constantjin was entrusted with the publication of the Latin text, three years later, and popular success was immediate, much like that of the Fontenelle *Entretiens*; English, Dutch, French and German translations appeared within a few years. Immediate, but not lasting: Huygens, who

[3] Andriesse (p. 46) speculates that Huygens may have met Descartes in 1632 at the age of three. Surprisingly, when attending the University of Leiden, he did not attempt to see his father's old friend who was staying at Egmond-Binnen, sixty km to the North. In late 1650 Huygens went to Copenhagen and definitely planned to visit Descartes, who had just arrived in Stockholm; but the philosopher died in February 1651, and the young Huygens was reduced to writing an excellent epitaph (quoted by Andriesse, 96): *"Cette âme qui toujours en sagesse féconde / Faisait voir aux esprits ce qui se cache aux yeux, / Après avoir produit le modèle du monde, / S'informe désormais du mystère des cieux"* (This soul, that with fertile wisdom / showed to the minds what was hidden to eyes / after having produced the model of the world / is now learning the Heavens mysteries). Which proves that, among many other accomplishments, boy Huygens expertly manipulated French versification.

had never constructed a system nor led a school of his own, was to lay largely forgotten during the eighteenth century, to be rediscovered after the revolution in optics due to Young and Fresnel, but merely as an optician.

Thus, his brief venture into Plurality did not exert any real influence over the next three centuries. The reasons why it should be recalled and treasured today will hopefully be made clear.

## Physics Without Metaphysics

"*Il n'avoit point de goust pour la Metaphysique*" (He lacked all taste for metaphysics), (quoted by Heinekamp, *Christiaan Huygens vu par Leibniz*, *HFR*, 106), was to complain friend and disciple Leibniz, who himself never suffered from any like deficiency. This judgement was one written merely a few years after Huygens demise, but the modern view is exactly the same: "Of all the major figures in seventeenth century physical science, Galileo, Gassendi, Pascal, Descartes, Huygens, Leibniz, Newton, the Netherlander is the only one who is not markedly a philosopher…" (Hall, *Summary*, *STCH,* 304). This limitation is in no small part responsible for the thoroughly modern view of Plurality the said Netherlander was to develop; and, incidentally, makes him far easier to deal with for some poor scientists lacking all metaphysical training. Moreover, Huygens was never caught up in any theological controversy, even if his brand of religion was too liberal, and his approach too rationalistic to make it palatable for many fellow Calvinists; he may be understood as precursor to the Encyclopaedists. Still, he never suffered from persecution, and he has been seen moving easily from Holland to France and England; Italy might have proved different, but merely one generation after Galileo's demise, it no longer held a major scientific appeal.

Thus, unlike in the case of our previous heroes, we can pass directly to Huygens' picture of the material world; with the usual caveat that the frontier line between physics and metaphysics is often hazy. On the key issue of God's role in Nature, it is however clear; Burtt (1954, p. 101, 292): "It is in Huygens and Leibniz that we first meet spirits adventurous enough openly to confine the divine activity to the first creation alone… The conception of the world as a perfect machine is thus rendered inevitable." Then, how did this machine work? Here, the question of Descartes' influence is central: was Huygens a true Cartesian or not? His initial debt had been openly acknowledged: "I am one of those who have profited from the wisdom of that great man" (quoted by Bell 1947, p. 80, without reference); however, nearly at the end of his life, he scribbled voluminous and highly critical *Notes* on his copy of the Baillet biography *De la vie de M. Des Cartes* that he had just received. From these comments, the progression from student enthusiasm to mature disenchantment is easily followed, and they deserve extensive quotations (Ensuing quotations found in *OCCH,* X, 399–406):

> M. des Cartes had found the way to have his fictions and conjectures taken for realities… When I read his book of Principles for the first time, it seemed to me that all was for the

> best, and whenever I found any difficulty, I believed this was my own fault from not understanding his thought. I was only fifteen or sixteen. However, having since discovered visibly false things now and then, and others very unlikely, I have felt much estranged from that belief, and presently I find almost nothing that I can approve as true within all his physics, metaphysics and meteors.

This Huygens frustration with Descartes is essentially our own, and he finds the exact words to convey both the magnitude of the Cartesian achievement in his pioneering rational description of the World, and the ultimate failure of his physics. He makes us feel the excitement of intelligent students, who had so far been fed by routine Peripatetic stuff, when discovering the *Principia*:

> What has been most pleasing at first when this philosophy began to be published, was that one understood what Mr des Cartes was saying, while the other philosophers merely gave us incomprehensible words like these qualities, substantial forms, intentional species, etc…More universally than anybody else, he has rejected that impertinent hotchpotch… he has dared to substitute understandable causes…

Alas! that demolition of the Scholastics had been most enjoyable, but the Cartesian construct built on the ruins did not hold together: those hopefully understandable causes proved seldom so in practice. With one notable exception:

> The finest thing he has found within physics, and maybe the only one in which he was right, has been the reason of the double rainbow as far as angles and apparent diameters go, but as for his causes of the colours, nothing is less likely…

The great French champion of rationality, who had proclaimed that pure arguments starting from clear and distinct visions would be enough to reconstruct the World, had failed to demonstrate most of his cases or even sometimes to achieve clarity himself:

> … he went on blathering about the things he had once asserted, often quite false ones… He gave his conjectures for truths, as appears from his grooved particles which he uses for explaining the magnet… and a hundred others without ever stopping to consider the mass of absurdities these hypotheses implied. He certified some things without any demonstration, for example…

And the example selected at this point is not just any trifle about magnets or meteors, but a tool lying at very core of the Cartesian physics: the collision laws themselves:

> …for example those laws of motion for colliding bodies; which he believed to have made acceptable as true by implying that his entire physics would be false if these laws were so. Which is about the same as if he wanted to prove them by taking an oath. Nevertheless only one of these laws is true, as I shall easily prove.

Indeed, Huygens was the expert in the case, having corrected Descartes in his own *De motu*, and provided our theoretical mechanics with their definitive collision laws.

What Huygens cannot stand from Descartes is that intolerable assertion of utter certainty in all his deductions:

> He should have proposed his system of physics as an attempt to speak plausibly within that science from admitting only the principles of mechanics, and invited other fair minds to

> search in the same way…. However, when making believe that he has found the truth, as he does in all occasions, and glorifying in the smooth flow of his own arguments, he has done great harm to philosophical [scientific] progress… his sectarians believe they know the causes of everything, waste their time upholding their master's doctrine, and do not attempt to penetrate the true reasons of these many natural phenomena about which des Cartes has merely spouted chimeras.

No more devastating (or apter) criticism of Descartes can be found than under the pen of the ex-disciple. Moreover, still in the same *Notes*, he admitted other influences:

> Verulamius [Francis Bacon] also has seen the inadequacy of that Peripatetic philosophy, and moreover has given very good methods for building a better one through making experiments and using them correctly… However he did not understand mathematics… and was unable to conceive the motion of the Earth which he mocks as an absurdity.

And Bacon had not been the sole renovator of natural philosophy:

> Galileo possessed in the way of mind, and of knowledge of mathematics, all that was required for progress in physics, and one has to grant that he was first to make beautiful discoveries about the nature of motion, even if leaving room for other considerable ones… To me, it appears that M. des Cartes has been highly jealous of Galileo's fame…

All these thoughts were those of an ageing man; but when still fresh from the University Huygens had already been dreaming about a necessary reform of Cartesianism; this was shortly after the Master's demise, and at a time when prevalent attitudes were either total rejection or slavish acceptance. Here, we must understand the resulting Hugenian concepts, on which he will much later base *Cosmotheoros*; how much of the Descartes cosmos did he throw out, and which tools did he preserve? His limitations and guiding lines are simple: he was not himself a system builder, thus to the end of his life he used the main principles at the base of the Cartesian system. However, he became a highly skilled problem solver, which led him to reject all the specific mechanisms developed by Descartes.

What kind of matter does Huygens require to build this cosmos? Unlike Descartes, he sees no logical impossibility in the existence of a vacuum; furthermore, he requires matter to possess at least one additional property beyond extension:

> As to a vacuum, I accept it without difficulty, and I believe it is even necessary for the mutual motion of the small corpuscles, not sharing the opinion of Monsieur des Cartes who wants extension alone to constitute the essence of the body; but adding perfect hardness which makes it impenetrable, and impossible to break or damage. (*Discours de la Cause de la Pesanteur*, *OCCH*, XXI, 473).

Which is unsurprising: at long last, the consequences of the Torricelli discovery had become difficult to escape. Moreover, Huygens' view of matter is also influenced by that of Parisian philosopher-scientist Pierre Gassendi, who had opposed both Aristotle and Descartes by modernising Epicurean atomism. The Gassendi atoms are thoroughly Christianised, since God had been responsible for their creation, but ever after they

> cannot be created or destroyed, are primordial, impenetrable, simple, unchangeable and cannot be subdivided into smaller parts; degrees of hardness were due to varying amounts

of empty spaces between the solid atoms (see Snelders, *Christiaan Huygens and the concept of matter, STCH*, 104);

moreover, they also are endowed with weight, unlike the strictly-geometrical Descartes particles. Still, no attractive forces are postulated, and cohesion is due to shape, acting through a handy assortment of made-to-order hooks and eyes.

For Descartes any motion had been explained by some other motion, thus cohesion was just another name for relative rest, and in no need of a specific cause. For Huygens, it requires an additional property of particles, independent of geometry: infinite hardness (we would rather speak of perfect elasticity); this was a serious heresy, and strict Cartesians will object. Also, where Descartes had been happy with three classes of corpuscles, Huygens needed four; following the summary given by H. Snelders (*STCH* 119), one finds, in order of decreasing sizes and increasing velocities, the particles of (1) standard matter, including air; (2) ether, needed for light propagation; (3) a magnetic/electric substance which explains the corresponding phenomena; and (4) subtle matter, responsible for gravity. The last two classes, required to account for forces, act through vortices. Today, we are unimpressed by the Descartes particles and the Gassendi-Huygens atoms alike: we do not see them as necessary nor even useful steps on the way from antique atomism to modern atomic theory. Progress in the field was to arise from Baconian-type experimentation, not Cartesian a-priorism. But the Hugenian ether deserves more attention as it is vortex-free and plays the central role in his wave theory of light, which we have largely preserved, after adding vibrations and wavelengths. Thus his ether lies distinctly closer to the Fresnel-Maxwell brand than to Peripatetic fifth matter.

Not merely Huygens' ether, but also his entire method of research look modern, compared to that of Descartes. First, he granted a large place to experimentation: in 1666 he proposed a program for the future French *Académie*:

> The main and most useful occupation of that assembly should be to work on natural history according to the project of Verulamius [Bacon]. This history is made of experiments and remarks and is the only way to reach knowledge of everything we see in nature. As for instance, what is gravity, heat and cold, attraction of the magnet, light, colours, parts constituting air, water, fire and all other bodies, the use of respiration in animals, how metals stones and herbs are born, all things about which nothing or very little is known… To build a natural philosophy, one must necessarily proceed from knowledge of effects to that of causes. (*Letter to Colbert*, *OCCH* VI, 95. Quoted and discussed by Mouy 2012, 186).

Second (and here, quite unlike Bacon), he proceeded as fast as he could from experimental results to their mathematical analysis. No doubt he had learned all about geometry in Descartes, but he was also to use it proficiently for explaining Nature's ways, which Descartes had never attempted to do outside optics. Here, the model was different: "Galileo was close to the spirit and to the understanding of Mathematics, which was necessary to make progress in Physics." (*OCCH*, X, 404; quoted by Westman, *STCH*, 97). And Huygens' personal trademark will be the development of novel geometrical tools, invented for specific questions in mechanics, and leading to interconnected physical and mathematical discoveries. The case of the cycloidal pendulum illustrates well this mode of research, and is fascinating to follow. The story is made of two successive episodes; through the first, he proceeded from experiment to theory, while in the second the procedure was reversed.

In the first, the starting point was a practical problem: improvement of clocks. Galileo had been at the origin of the solution through his discovery of the isochronism of a pendulum oscillating under gravity alone; and the device had become useful to experimenters for measuring time intervals up to a few minutes. To make a true clock required a mechanism fulfilling two very different functions: counting the beats, and (in modern terms), feeding to the pendulum enough energy to compensate for natural damping, all without perturbing the motion; this last problem was to prove far more difficult. In 1657 Huygens was first to demonstrate a working solution. Galileo had understood the problem, and at the end of his life (when he was blind) entrusted his son Vicenzio and his pupil Viviani with the construction of a pendulum clock. Whether the mechanism was actually finished is unclear, but if so it was not a success (see Drake 1955, 419). Huygens published the result, took a Dutch patent and at once hoped to solve a problem of great economical importance: measuring longitude, which necessitates good, transportable clocks. His success made him famous, and mechanical clocks, which had hardly evolved since their fourteenth-century introduction, were rapidly converted to pendulum operation all over Europe. Within observatories, the change was radical, particularly through the work of another Paris colleague, Jean Picard (see Picolet 1987 and Landes 1983).

Huygens went on looking for improvements, but unlike mere artisan clockmakers, he posed the problem in terms of Cartesian analytical geometry. The main difficulty appeared to be that, for a standard pendulum, isochronism was approximately true for small oscillations only, while larger ones proved slower. Primitive escapements required large swings, and did not maintain constant amplitude, with the situation even worse aboard ships; hence he looked for a "tautochronic" device, i.e. one with a period rigorously independent of amplitude. The way to an empirical solution was obvious: slightly reducing the length of the flexible wire for larger swings, with the help of small curved metal plates (*lamellae* or "cheeks") on both sides of the pivot. In his original clocks, built in The Hague (one is surviving in the Leiden Boerhave Museum), the cheeks had already been present, but merely adjusted by trial and error. Now settled in Paris, he proceeded to ask the question: what is their ideal shape? The full answer was to take him extremely far, first to novel geometrical theorems and then to some funding principles of our classical mechanics. The cycloid curve was just then fashionable: Galileo, Fermat and Descartes had all been interested and Blaise Pascal had recently performed its quadrature, i.e. computed the enclosed area. In his 1673 *Horologium Oscillatorium*, Huygens broke new ground: he proved first, *geometrico more,* the ideal path of his pendulum bob to be a cycloid, and second the utterly astonishing result that the corresponding cheeks were also cycloidal. Showing that two equal cycloids could be involute/devolute of each other was a theorem of pure geometry; tautochronism of the cycloidal pendulum was an entry into dynamics. And the Huygens treatise went on in the same vein to more results quite unnecessary for mere time keeping: he succeeded in determining the "centre of oscillation or agitation" for some geometrical figures, plane or solid, and concluded with additional theorems on centrifugal force (see Dugas 1955, 185 ff).

The second episode took place several years later, and now the process was deductive and the starting point purely mathematical: Huygens was no longer concerned with measuring time but merely having a second look at cycloidal motion. In *Horologium*, he had overlooked the fact that the involved force (the one that brought the pendulum bob back to its rest position at the cycloid apex) was proportional to arc length. Now he discovered this remarkable property, understood it to be the key point, and predicted that in other systems endowed with a restoring force similarly proportional to elongation, tautochronic oscillations would result. At this stage, he reverted to his original concern, and started planning a gravity-independent device, intended for the longitude-at-sea application. Soon, he built his first portable clock in which the regulator was a balance with a coiled spring, and the results (at least in the long term) were to be decisive improvements of time-keeping, particularly at sea.[4]

More than horology was to be involved, and the consequences went far beyond the guesses of the inventor, as such is the tortuous path through which was unveiled one of physics most fundamental and ubiquitous tools: harmonic motion. Ironically, tautochronous oscillators had been known in all but name to Pythagoras, since vibrating strings emit a fixed note despite damping, of which the human ear happens to be an excellent judge; but nobody had ever given the case a thought before the seventeenth century.

The contributions of Huygens to modern mechanics were the corrected (and correct) collision laws, the expression of centrifugal force, and a clear understanding of mass, weight, force, work and moment of inertia, even if the modern terminology was to be developed by later scientists. These concepts will not be followed here, since we are only concerned with understanding method, and do not require a full account of results (for studies, see Gabbey, *Huygens and mechanics*, *STCH*, 166; Costabel, *Huyghens et la Mécanique*, Costabel, *HFR*, 139; Dugas 1955). However his main error, the refusal to adopt universal gravitation, will later deserve a treatment since it might be construed as a serious blemish of the Cosmos in which he had to locate his Plurality.

[4] Hooke was to claim priority for the invention of the spring balance; indisputably, he had been first to publish the well-known *Hooke's Law* for elastic bodies: *Ut pondus, sic tensio* (for details, see *England's Leonardo,* chapt. X). Altogether, Huygens was to reap mostly disappointment in the field of longitude measurement. First, the temperature sensitivity of the spring balance proved too large, and he reverted to gravity devices. Then, despite some early hopes, the final results of his clocks sea trials were always poor. Before the end of the century, the cycloidal pendulum clock vanished even in observatories, since the anchor escapement made very small oscillations practical. The longitude at sea problem was far more difficult than he or Hooke or anyone else had guessed; it was only solved by George Harrison, almost a hundred years after the first pendulum clock, not from more theorems in mechanics, but through advances in metallurgy and precision machining, and a temperature-compensation device. To follow Huygens' thought and mechanisms step by step, see Mahoney, *Christiaan Huygens: The measurement of time and longitude at sea*, *STCH*, 234; and *The Longitude Timekeepers of Christiaan Huygens*, J.H. Leopold, in Andrewes (1996). The South Kensington Science Museum exhibits working models of the Galileo clock, the Huygens 1657 and 1673 clocks (without and with cycloidal cheeks respectively), and of a 1669 Hooke experiment in which the amplitude of a 12 ft. pendulum had been reduced to about 10 arc minutes; thus, cycloidal correction was no longer needed.

Neither can his work in optics be described here apart from basic principles. Again, the starting point is Cartesian: light can only be understood as some motion propagating through a *plenum* thanks to collisions, and the Huygens attitude is already clear from his 1672 reaction when first learning of Newton's experiments on the "Phænomena of Colors." He is less than enthusiastic, because Newton does not go to the bottom of the problem:

> Even if it was true that some light rays should be red and others blue from their origin etc… there would remain the difficulty of explaining what this diversity of colors is made of…

A little later, he stresses again that only a full explanation is worthwhile:

> Until he has found that hypothesis, he will not have taught us the nature and the difference of colors, but merely that accident (admittedly a considerable one) of their different refrangibilities. (*Letters to Oldenburg*, Sept 27 1672 and Jan 14 1673, *OCCH*, VII, p. 228, 242).

Here, his attitude is strictly Cartesian, and his Master would have behaved in the same way: remember Descartes' reaction to the Galileo free-fall laws.

To these objections Newton answered:

> How Colors may be explained hypothetically is besides my purpose. I never intended to shew, wherein consists the Nature and Difference of colors, but only to shew that de facto they are Original and Immutable qualities of the Rays which exhibit them; and to leave it to others to explicate by Mechanical Hypotheses the Nature and Difference of those qualities; which I take to be no difficult matter. (quoted by Bell 1947, 72, without exact reference).

The modern verdict on this complex case is mixed: on the one hand, the Newton refusal of half-baked hypotheses was wise, and his experiment on colors has ever remained a capital contribution to optics just as it stood. But contrary to his breezy dismissal, the explanation proved a very difficult matter, indeed an impossible one within his own emission theory. On the other hand, Huygens contributed nothing to the immediate understanding of colors, even in his 1690 *Traîté de la Lumière*; but the explanation when it finally came more than a century later, was constructed by adding to his own pulse-and-wave theory the hypothesis of periodic vibrations, and this happy combination has proved definitive.

The two contrasting attitudes are clear: Newton describes a fact for which the explanation can wait; but Huygens wants it right away, and it must be complete and fully mechanical. And they will behave in exactly the same way in the case of gravitation; from these two exemplar cases of light propagation and celestial mechanics, one may even predict their respective positions concerning other planetary systems and their habitability: Newton feels no need to formulate that sort of additional hypothesis, unnecessary for explaining all known facts, while Huygens rejoices in a notion that fits perfectly within his Cartesian world model. However, in the 1713 edition of his *Principia*, p. 544, Newton added a guarded allusion to possible other planetary systems:

> This most beautiful system of the Sun, planets and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being. And if the fixed stars are the centres of other like systems, these, being formed by the like wise counsel, must all be subject to the same dominion of One…

At the time, it must have become impossible to ignore the contributions of Fontenelle and Huygens altogether. Concerning Plurality, in 2019, the majority mood is triumphantly Hugenian.

As already seen, the Huygens refusal of all explanations based on "qualities, substantial forms, intentional species…" is radical, and fully Cartesian. This guiding principle he will follow throughout his life, and it will lead him, in a perfectly logical manner, to his worst mistake: a categorical rejection of Newtonian gravitation, similar to that of the Newtonian colors, and for the same reasons. This major failure has to be discussed if we insist nevertheless on upholding him as the father of Plurality in modern garb.

Truly, can we blame Huygens? In the whole history of science, there is possibly no more ironical twist anywhere than in the devious way chosen by Fate to unveil universal gravitation. The time-worn Peripatetic qualities had just been unmasked and revealed for what they had always been: pale inconsistent shadows, cloaks for ignoramuses, scarecrows flourished by pedants, mere hollow words which had never once led to the prediction of any novel effect nor to the quantitative analysis of a single phenomenon. Half a century after Descartes' *Discours de la Méthode*, all were at long last dead and buried, and the Cartesian universe was (or tried to be) fully mechanical. And then! out of a clear blue sky, one new occult quality fell down to Earth, and presented natural philosophers with an explanation of the Cosmos more universal, more strictly mathematical and more exquisitely accurate than any of them had ever dreamed about. Einstein's famous one-liner notwithstanding, God has been in the case of gravitation not merely subtle but also malicious; and worse.

In 1669, long before Newton's *Principia* appeared on the scene, Huygens had already presented his own thoughts on gravity, when the still-young French Academy devoted a few sessions to that venerable conundrum (see Costabel in *HFR*, 139). Here are the key-points of his fully-Cartesian argument:

> In order to search an intelligible cause for gravity, one had to suppose only bodies made of the same matter, within which one considers no quality nor inclination to approach each other, but merely different magnitudes, shapes and motions… We see two kinds of motions in the world, the straight and the circular…

But the first is quite well known, together with the collision laws, and whenever closely studied "nothing is found which determines a center. Thus, one must necessarily resort to properties of circular motion." The resulting hypothesis is Cartesian: subtle matter rapidly whirling around the Earth (or other celestial bodies) pushes down heavy matter toward a centre. The advantage is that we can visualise the model, and that it obeys the Descartes golden rule: any motion is solely caused by other motions through collisions. Huygens stresses

> an experiment, rather easy but quite worthy of notice because it shows to the eye some sort of image of gravity, by rotating water in a flat-bottomed vessel after adding small particles of some matter a little heavier than water…as soon as they reach the bottom they will gather close to the center… (Huygens, *Mémoire,* Aug. 28 1669, *OCCH* XIX, 631, 633).

Actually, a similar experiment had already been at least proposed by Descartes (see the preceeding chapter), but it is here better described, since Huygens knows all about centrifugal force; still, it remains qualitative, and (to our modern eyes) completely irrelevant to gravity. The experimental tests for which Huygens is remembered as a pioneer of modern mechanics fall into an altogether different class.

When he takes up the subject of gravity again, in his 1690 *Discours de la Pesanteur,* Huygens faces a changed situation. He has received his copy of the Newton *Principia* three years before, and he is one of the few scientists able to follow its mathematics fully. On his side, Newton was fully aware of Huygens stature as a mathematician: an early biographer writes "He thought him the most elegant of any mathematical writer of modern times" (quoted by Yoder 1988*,* p. 145). Thus, the strength of the Newtonian argumentation is not lost on Huygens, and he will readily acknowledge "… the high esteem in which this work is held, and rightfully so, as one could not find anything more clever in these matters, nor that shows a greater acuteness of mind." The hard fact of accurate predictions of planetary motions, totally unexpected by himself, was inescapable:

> Thus I have nothing against the Vis Centripeta, as Mr. Newton calls it… by supposing such a gravity toward the Sun, and decreasing with the said proportion, it counterbalances so well the centrifugal forces of the Planets, and produces so precisely the Elliptical motion effect that Kepler had guessed and verified from observations, that I cannot doubt those Hypotheses about gravity being true, nor that the System of Mr. Newton, insofar as based on the same, is similarly true… There is found the solution of several problems that caused much pain with the supposed vortices of Des Cartes… One sees how the Comets are able to cross our System… it was difficult to conceive how they could move against the Vortex that was strong enough to carry the Planets. (*Discours de la Cause de la Pesanteur*, *OCCH* XXI, 475, 473).

However, acknowledging both convenience and accuracy of the Newtonian $1/r^2$ law did not mean for Huygens granting it the exalted status of true physical explanation; he found himself in the situation of those astronomers who had been ready to use the Copernican model as mathematical tool while refusing it all semblance of reality. For himself and all Cartesians, any sort of force at a distance remained unthinkable; the full horror of the concept has been best expressed by Leibniz: if it "is a law of God who brings about this effect without using any intelligible means, then it is a senseless occult property which is so very occult that it can never be cleared up." (*Leibniz letter to Hartsoeker*, quoted and translated by Bell 1947, p. 86). Moreover, even for those who (unlike Descartes himself) insisted on fully mathematical mechanics, the assumption of an inverse-square variation smacked of the arbitrary. Within optics, the Kepler law of illumination decreasing as the inverse-square distance from the source had been a straightforward deduction from Euclidean geometry, hence was readily granted by all without any soul-searching. But when gravitation was concerned, Newton had explicitly given up any such demonstration: *"Hypotheses non fingo…"*; and none of his followers proved able to do any better, a situation that was to persist during two very-full centuries. Thus it is hard to blame Huygens too much when he writes:

> I am not in agreement with a Principle… which is that all the small parts that may be fancied within two or more different bodies, attract each other or tend to get closer. That much

> I am unable to admit, because I believe I can clearly see that the cause of such an attraction is not explainable from any principle of Mechanics…

And the true underlying cause of gravity remained for him what it had always been: a vortex of subtle matter, invisible but easy to visualise from the mind's eye:

> to these bodies which we call weighty, gravity may be impressed by the centrifugal force of a matter which has no weight toward the centre of the Earth because of its very fast circular motion, but tends to get away. (*Discours de la Cause de la Pesanteur*, *OCCH* XXI, 474).

Conclusion: Huygens remained a vortex devotee up to the end of his life, and never realised that such pleasing tools had grown just as obsolete as the Peripatetic qualities. He failed to anticipate the revolution brought to physics by the universal gravitation concept, and the deep wisdom hidden behind the Newtonian refusal to search for a further cause. Unlike any Newton disciple, he would have been unable even to suggest the experiment (performed by Cavendish one hundred years later) which was to demonstrate and measure attraction in the laboratory. Nevertheless, the only obnoxious consequence for his world picture was that he could not provide celestial bodies with a computed mass; but Newton himself was still unable to do it, even for the Earth. Altogether, at the time when Huygens was writing *Cosmotheoros*, every part of his personal Cosmos was ruled by a universal inverse-square-distance centripetal force law; ruled, but definitely not explained. However, when everything is said, neither is ours; thus, despite his rejection of attraction and reliance on vestigial vortices, the Huygens brand of Plurality rested on physics not so distant from our own.

## Cosmology From Observations

However, the Hugenian cosmos was not simply elaborated from his physics, much unlike the *a priori* construct of his master Descartes: it was based on recent observations carried out with the help of the latest and fanciest telescopes, in particular his own. Apart from mathematical problems, the very first efforts of Huygens had been devoted to optics; these ripened during most of his life, and led to his wave theory of light, which was to be presented in the 1690 *Traité de la Lumière*. There is no need to follow this line here: whether light operates through waves or particles makes no difference to the information it carries about planets or stars, and we will be only concerned with Huygens' practical achievements.

He had made an early start, long before coming to Paris, and while he published rather little about his techniques, they were closely involved in his astronomical discoveries, and helped to make him while still very young one of the best observers of the time. In his *Letters*, the earliest ones mentioning lenses and telescopes appear in 1652, when he was twenty-three. A large number of his own papers have been preserved; he had soon become interested simultaneously in lens theory and lens polishing. His numerous diagrams of optical systems, while crudely scribbled, look almost modern. Like Descartes, he was much concerned about spherical aberration and vainly looked for solutions from aspheric surfaces polished by elaborate machines. Like him (and everybody else before Newton) he did not understand chromatic aberration; still, he knew that in practice the obnoxious effects would be reduced by increasing telescope length. Unfortunately, he waited until 1690 to publish as *Dioptrica* the bulk of his studies on geometrical optics and by then much of their novelty had been lost.

Of immediate relevance to astronomy were two novel optical devices: the micrometer, and the so-called Huygens eyepiece. His very primitive micrometer was already usable at the time of his Saturn discoveries in 1655–6, and is described in his *Systema Saturnium*. The starting point had been the discovery of an unrealised advantage of the convergent Kepler eyepiece compared to the divergent Galileo type:

> There is a certain place, located about twice as far from the eye as the convex eyepiece, such that if an object as fine and small as one wants is placed there, it is seen distinctly, with an extremely sharp contour… Thus one should prepare some rod of copper or some other substance of gradually decreasing width…

Unfortunately, no drawing nor more precise description survives; King (1955, fig. 4 p. 97), gives a partly imaginative reconstruction. This tapered "rod" (more likely some sort of thin strip?) was used to occult a planet, or a pair of stars, and the corresponding width measured later. Unfortunately, such a procedure always gives an overestimate of the wanted angle: as lens aberrations invariably widen the image, trying to occult it fully is misleading, and Huygens planetary diameters all turn out to be too large, for which he was to be rebuked by Newton. Later, he proceeded to a less-clumsy form of micrometer that became better known "a small grid divided in a certain number of equal squares formed by very-fine silk or metal threads." (*Histoire de l'Académie Royale des Sciences*, I, p. 10). Ironically, the definitive mobile-wire type had been invented years before by William Gascoigne in England, but never published, and remained unknown while Huygens performed most of his work. As to the invention of the compound eyepiece, it arose from the desire of a further increase of the field of view, beyond that given by the single-lens Kepler type. Huygens arrived at his elegant combination of two plano-convex lenses partly by trial-and-error, but also from his exact computation of spherical aberration; as his solution involved only spherical surfaces, it proved easy to build. His peculiar Archimedes-like ability to solve problems involving both theory and experiment, already expressed in the cycloidal pendulum case, is found again in the Huygens eyepiece. The device was not yet available at the time of the Saturn ring observations, but remains in use today (see Acloque, *HFR*, 177).

The place of Huygens within astronomy would nevertheless remain a minor one had he not built with his own hands several remarkable telescopes; actually, four hands were involved since his brother Constantijn Jr. performed at least half of the work, and their collaboration was long and intimate, as shown by many *Letters*. They built together two telescopes, which were immediately put to excellent use, being responsible for the discoveries of the Saturn ring and satellite Titan. As early as 1656 the brothers became convinced that even longer ones would prove better: "if one could reach a hundred or 2 hundred feet, doubtless one could see the planets revolving around their axis." (*Letter from Ch. Huygens to Chapelai*, July 165, *OCCH*, I, 472). They were not alone in pursuing that goal, and fantastically long telescopes began to appear throughout Europe; today, this craze looks absurd, since we know that both resolving power and luminosity depend only on objective-lens diameter; however, as seen above, chromatic aberration was mitigated by an increase of focal length. As to Newton's much shorter mirror telescope (also built with his own hands), it remained hardly more than an interesting toy for astronomers, and never produced a single astronomical discovery before William Herschel radically increased its size one hundred years later. In Huygens' days, the most spectacular undertaking was that of Johannes Hevelius in Danzig, who managed to operate a 45 m-long telescope hanging from a vertical mast! This would be hard to believe, if it were not for the magnificent engravings. A formidable team of assistants was required; even so, pointing was extremely difficult and wind and vibrations remained a constant hindrance.

Such a brute-force approach could go no farther and a different type of mount was needed; at which point sheer instrumental ingenuity was required, and here nobody could beat Huygens. His own solution was not described before 1684, in a small brochure published in Den Haag entitled *Astroscopia Compendiaria Tubi Optici Molimine Liberata* (Abridged method for observing celestial bodies, freed from the encumbrance of the optical tube); it involved a tubeless mount. This highly-elegant device is shown and briefly explained in figure 12.1. Huygens discusses at length construction details and operating mode, ending by speculations of which at least the spirit appears wholly modern: how far is it feasible to go in the same direction? do ultimate limits exist? His own mast is merely 50 feet high, and permits the use of lenses with a 70 ft. focal length (not too close to zenith); however, by interconnecting several masts with a trestle of oblique beams "we shall easily reach a height of 100 ft… truly, I cannot impose precise limits to the art." Even so, his speculations remain far more prudent than those of Descartes writing to Ferrier, since there is no hope "to perceive with our own eyes if [moon and planets] are inhabited by living creatures." (*OCCH*, XV, 228).

However, after such a promising start, no actual results were reported; most further discoveries were to be reaped at the Paris Observatory by Cassini, whose observing assiduity Christiaan never matched. Also, brother Constantijn abandoned lens polishing and reverted to the family calling of diplomacy.

The two great Huygens astronomical discoveries are well known, and will only be mentioned here. The first one is Saturn's satellite Titan. The second is the ring around Saturn, which was seen by many before, beginning with Galileo, but not understood as such. This shows the future author of *Cosmotheoros* to have been at the frontier of astronomical research, and far more intimately acquainted with celestial observing than Fontenelle. Not merely did he build with his own hands and use with his own eyes some of the best available tools for looking at these other Worlds, but he proved himself a master at interpreting imperfect telescope images, from then on a key part of the game. His ramblings about Planetarians etc.… will of course be pure speculation, but at least based on the latest scientific data, and from the pen of a true expert. What else are we hoping for today?

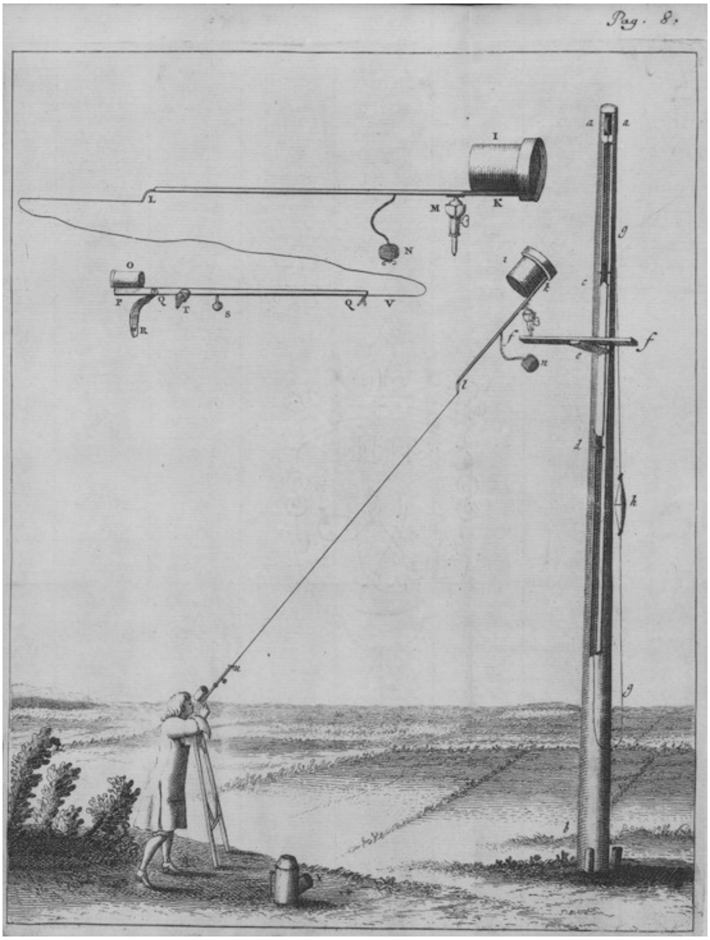


**Figure 12.1** Huygens' Astroscope. The objective lens *k* (upper right) is supported by the mast; its height may be adjusted by use of a slide. The pull from the wire keeps the lens perpendicular to the light beam. The eyepiece *o* is carried on a separate stand; the complete mechanism is detailed on top. The lantern (standing on the ground) may be used for checking objective alignment through the reflected light. This astute and elegant solution, praised by Newton, had no future: Cassini was to gather better results from his own standard mounts, or absence of. www.e-rara.ch

In order to understand Huygens' development of the Plurality theme, one still has to account for his views about the size of our own planetary system, and on stellar distances. To the first subject, he contributed nothing, but used (somewhat by luck) a nearly exact figure, which provided him with roughly correct sizes for all planets, an essential parameter for proper comparison with Earth. On the second question, Huygens was first to estimate the distance of stars from a measurement of their brightness; even if his result was still very crude (and soon superseded by a better one from Newton), it provided him with adequate room to install his other planetary systems.

To start with, the solar-system picture of Huygens had by no means been free of Pythagorean-or Keplerian-like postulates. For instance, after discovering Titan, he did not hesitate to write that his new find "completes the collection of wandering stars and their number of twelve. I would almost affirm that no more will be found"[5]; alas! Cassini was to prove him wrong within a few years. On the question of solar and/or planetary distance, he had better luck, and a fundamental belief in celestial harmony led him by pure chance to an almost correct result. One remembers that Galileo, Kepler and Descartes had still relied on the old and much too small Ptolemaic solar distance estimate, which made the Earth a remarkably large planet. Huygens is free from such delusions, and stresses in *Systema Saturnium* that "no reasonable method for measuring that distance has yet been found. Whether they try to derive it from the Eclipses or from the Moon's dichotomy, it is easy to show that such efforts must be in vain" (*Systema Saturnium*, *OCCH*, XV, 347–348); in which he is fully right. Next, the only other procedure he can think of is

> to observe with the telescope the apparent diameter of planets… then to adopt for size of the Earth relative to the others that which best agrees with the order and the good disposition of the whole system [*totius systematis ordini aptæque dispositioni*]." (*Systema Saturnium*, *OCCH*, XV, 344).

Here, he drifts out of luck, neither Plato's *Demiourgos* nor the Biblical Creator having shown loving concern with *apta dispositio* in the case: the first four planets happen to be rather small, the next two are quite large, and that's that. Poor Huygens feels disappointed; where is he going to find order? There remains a saving grace:

> Nevertheless, in order to preserve as much as feasible the harmony of the entire system, it seems after all more reasonable to admit that, as the Earth is placed between Mars and Venus as to distance, it also occupies an intermediate position in size.

Now, he has a possible base for his calculation; starting from the Mars and Venus apparent diameters, and after some juggling with fractions, he is able to conclude that "the [linear] diameter of Earth is 1/12 543 of its distance to the Sun". Q.E.D! At which point, it is the modern reader who is tempted to invoke divine intervention, as the actual figure happens to be 1/11 728, a 5% error and all from an utterly fanciful argument. Admittedly, Huygens is ready to grant that "this computation relies on a shaky basis" but even so he insists that he has found the correct order of magnitude, and "there is no other method in which a ten-times larger error should not be feared"; in which he had been, so far, perfectly right.

However, within a few years, the solar-distance problem was solved, not through unearthing any further hints from Plato, but by trigonometry with decisive help from those micrometers to which Huygens had so much contributed; it is best followed through the invaluable *Measuring the Universe* of Albert Van Helden (1985). The estimate of the solar-system size relying at long last on a correct technique (a key

[5] Dedication of *Systema Saturnium* to Prince Leopold of Etruria, *OCCH*, XV, 214. This figure of 12 comes from 6 planets, 4 Jupiter satellites, one for the Earth and one for Saturn.

step in the history of astronomy) resulted from the determination of the Mars parallax. The first step was a 1672 *Académie des Sciences* expedition to Guyana, where Jean Richer was entrusted with the observations of the planet, while Giovanni-Domenico Cassini stayed in Paris to make similar ones; next the program was pursued solely from the Paris Observatory. The positions of Mars relative to distant stars were simultaneously observed from two very distant places on Earth by two observers, hence the distance of the planet knowing the distance between the two observing sites; the subsequent Paris data used the rotation of the Earth to change the viewing-point of a single observer. The full solar-parallax story is actually more complex (and interesting!) than as summarised here: see Van Helden (1985). The young Flamsteed independently performed valuable work from Greenwich. In the short term, results seem to have appeared less decisive to contemporaries than commonly believed today; thus Huygens may be excused to some extent for paying scant attention, and sticking to his own estimate, which we have seen to differ little anyway.

Next, the angular diameter of each planet was needed; here Huygens could rely on his own figures. However, as already seen, with his primitive micrometer all such angles were over-valued; so, when Huygens plotted planetary diameters relative to the Sun (figure 12.2) they were all too large. The result is deeply ironical: the mistake does not arise from any error in distance estimates, where he had been right by sheer luck, but from optical measurements which he believed fully objective. Even so, the correct order of magnitude of all planetary sizes was now known, and the Earth at long last took its proper place among the lesser planets of our own Solar system: a thoroughly unremarkable one.

For a conception of multiple planetary systems approaching the modern one, at least rough estimates of stellar distances are needed. Previous treatments of the subject had been completely misleading, from either wrong optical arguments (Kepler), or fanciful physics (Descartes). In the first case, there had been no room at all for other systems; in the second, they were all crowded together without vacant spaces, since Descartes had simply ignored the distance problem. As to Fontenelle, we have already seen him starting from frankly confused notions about those distances, and correcting them from Huygens. From the time of Copernicus the principle of stellar parallax measurements had been well understood, and in the waning seventeenth century several attempts were made using those newfangled micrometers, which gave wild and contradictory results. Huygens was first to show that a totally different optical technique could at least give hints about stellar distance: his tool was not trigonometry, but photometry, for which no name yet existed. The question is not tackled before the final pages of *Cosmotheoros*, and may be some of the last he ever wrote.

Huygens starts from a thorough demolition of Kepler, who had wildly overestimated stellar angular diameters, and deduced all stars to be at similar distances from Earth. This is

> a thing that we need go no farther than the Lamps set along the Streets to prove. For although they are a hundred foot from one another, yet you may count twenty of them in a continued row with your eyes, and yet the twentieth of them scarce makes an Angle of six Seconds.

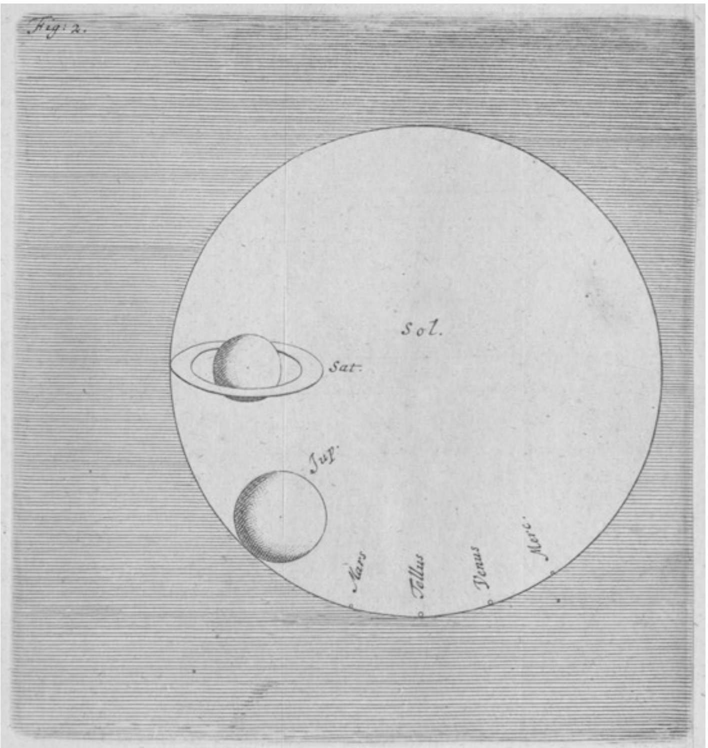



**Figure 12.2** Sizes of the planets relative to the Sun. They are mostly too large, due to Huygens' primitive micrometer. www.e-rara.ch

As a consequence, he had granted the Sun a unique role and position, but his true and barely hidden reasons had not been physical:

> *Kepler* had a private design in making the Sun thus superior to all other Stars and planting it in the middle of the World attended with the Planets, a favour that he did not desire to grant to the rest. For his aim was by it to strengthen his Cosmographical Mystery… but that whole Mystery is nothing but an idle Dream taken from *Pythagoras* or *Plato*'s philosophy. (*Cosmotheoros*, 145-6).

More recent attempts by colleagues to measure stellar parallax had proved unreliable "by reason of the extreme niceness and almost impossibility of the Observations requisite for their purpose."

Now Huygens proposes a new technique, which relies on the assumption "that the Stars are so many Suns"; then, the brightest are simply the closest. He will attenuate the light from the Sun until it looks equal to Sirius in brightness: "To this purpose I clos'd one end of my twelve-foot Tube with a very thin Plate, in the middle of which I made a hole not exceeding the twelfth part of a Line [i.e. 0.17 mm]." Looking at the Sun, he concluded that such a "little piece of him was brighter much than the Dog-Star in the clearest night"; hence, much greater attenuation was still required. A longer tube was impractical and a smaller hole difficult, thus "against it I plac'd a little round Glass that I had made use of in my Microscopes. According to the rules of Dioptricks I found his Diameter now was but 1/152 part…" Finally, the Sun-hole-lens system "will send us just the same Light as the Dog-Star now doth; and his Distance then from us will be…undoubtedly as 27 664 is to 1." At which point the author breaks into dithyrambs, strangely forgetting that his *Cosmotheoros,* unlike the *Entretiens*, is written for professionals:

> And what an incredible distance that is… for if 25 years are required for a Bullet out of a Cannon to travel from the Sun to us…. [it] would spend almost seven hundred thousand years in its Journey between us and the nearest of the fix'd Stars… And what a prodigious number must there be besides of those which are placed so deep in the vast spaces of Heaven, as to be as remote from these as these are from the Sun!

The spectacle is so dramatic indeed that Huygens makes a very rare call to "consider the infinite power of God." (*Cosmotheoros*, 152–154).

Unlike him, we feel moved to admire more the power of the human mind, which had at long last measured rather than fancied the distance of the stars. Even so, the Huygens technique is still primitive, and his Sirius distance proves twenty times too small. One reason is Nature's perversity, as Sirius happens to be intrinsically much brighter than the Sun; the other, that the human eye acts as a passable photometer only when two illuminated patches are presented side-by-side; in the Sun-Sirius case, human memory (a disastrously subjective tool) had been involved. However, this defect was soon corrected by Isaac Newton, who described a safer procedure, and obtained a larger distance which has been better remembered, and proved more influential. This is found only in his posthumous *System of the World* (Newton 1728, p. 92); he does not say that he took any hint from this rather hidden passage of *Cosmotheoros*, a work that must have held little appeal for him. While Newton's understanding of photometry does not surpass Huygens', he starts from a more practical idea: comparing our Sun-illuminated planets with some bright stars; these are simultaneously visible, which provides a key advantage. He builds his case from Saturn "which receives but about 1/2100000000 of the Sun's light." Then, he knows from common observations that "Saturn… without its ring is somewhat more lucid than a fixed Star of the first magnitude." Lastly he has to make (like Huygens) an arbitrary assumption since he needs to know the fraction of the incident sunlight reflected by Saturn; he settles on ¼ without argument (the actual value is 0.75), and the conclusion is that "the distance from which the Sun would shine as a fixed Star exceeds that of Saturn by about 10 000 times," which means a 0.42 pc distance and a 2.3 arc sec parallax.

Crude as they were, the Huygens star distances had proved adequate to explain the lack of any measurable parallax and at the same time to provide enough room for multiple planetary systems. Moreover, physics acted in the same way: thanks to his acceptance of vacuum, he was freed from the necessity of filling space to the brim, and his own vortices became far less naïve than those inherited from the Master:

> For Des Cartes makes his so large, as every one of them to touch all the others round them in a flat Surface, just as you have seen the Bladders that Boys blow in Soap-suds do; and

> would have the whole Vortex to move round in the same way. But the Angles of every Vortex will be no small hindrance to such a Motion." (*Cosmotheoros,* 157).

Altogether, while still built of a fanciful subtle matter, these updated vortices generated a Newtonian-type inverse square distance centripetal force, revolved according to Kepler's Laws, and (even more important) kept decently aloof from each other.

At this point, we hold all the tools necessary to understand Huygens' adoption of Plurality, and we may tackle *Cosmotheoros*, so far barely sampled.

## *Cosmotheros and Plurality*

Barely ten years separate *Entretiens* and *Cosmotheoros*, and no major astronomical discoveries had taken place in between; hence the two books cannot help having much in common, and superficial analyses are prone to dismiss the second as bringing in no essential novelty. However, the frivolous device of an after dinner conversation with some Marquise in a pleasant park is not used, and the few astronomical diagrams look austere when compared with the appealing theatre scenery relished by Fontenelle. The text is in Latin, apart from the title which mixes in some Greek*: Christiani Hugenii ΚΟΣΜΟΘΕΩΡΟΣ Sive De Terris Coelestibus, earum ornata CONJECTURAE,* which is freely rendered by the 1698 English translator as *The Celestial Worlds discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets.* The word *Cosmotheoros* itself is a fabrication meaning *Cosmic Observer*, thus clearly reminiscent of *Sidereus Nuncius.*(Figure 12.3)

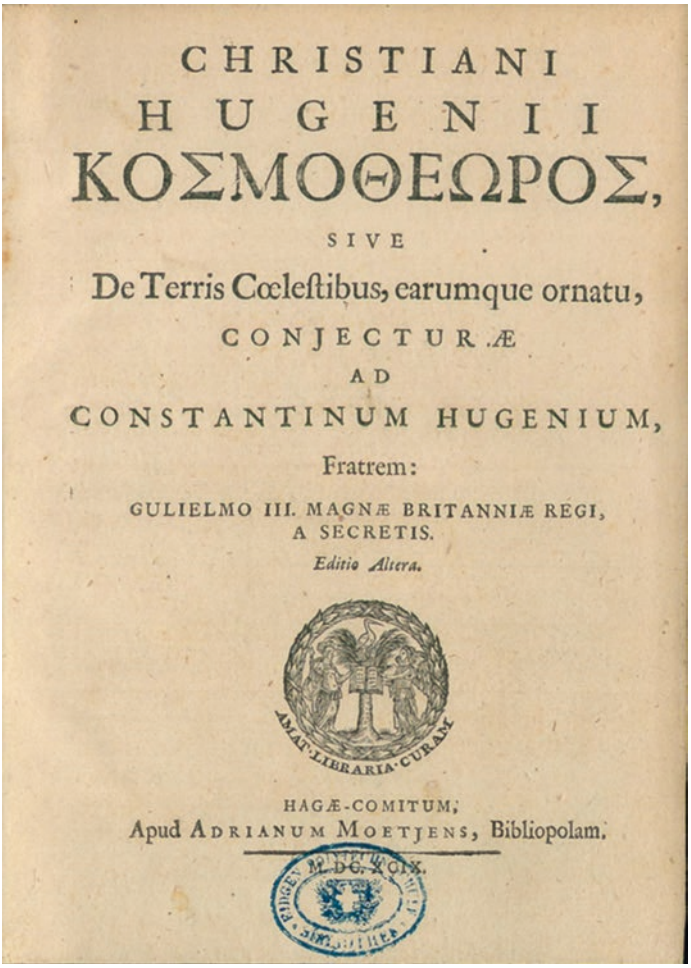
The book is dedicated to *Constantinum Hugenium Fratrem*, and makes pretence to be written for him, or at least for "Men like you, not ignorant in Astronomy and true Philosophy": unlearned readers will not follow the technical arguments, while those who know too much risk misconstruing the purpose of the author. To the first, it is "mere Conjuration to talk of measuring the Distance or Magnitude of the Stars", indeed the one important technical novelty to be found in the book. The second are dangerous; when they learn about

> new Lands and Animals endued with as much Reason as themselves [they] will be ready to fly out into religious Exclamations that we broach Opinions directly opposite the Holy Writ. For we do not there read one word about the Production of such Creatures, nor not so much about their Existence.

For Huygens, such controversies are old hat:

> They have been answer'd so often that I am almost ashamed to repeat it: That it is evident God had no design to make a particular Enumeration in the Holy Scriptures of all the Works of his Creation. (*Cosmotheoros,* 4-8).

Moreover, telescopes have definitively killed the belief that everything in the Universe has been created for the sight or use of Man; but they have forced him to pose a new question: are all these newfangled celestial bodies intended for other


CHRISTIANI
HUGENII
ΚΟΣΜΟΘΕΩΡΟΣ,
SIVE
De Terris Cœleſtibus, earumque ornatu,
CONJECTURÆ
AD
CONSTANTINUM HUGENIUM,
Fratrem:
GULIELMO III. MAGNÆ BRITANNIÆ REGI,
A SECRETIS.
*Editio Altera.*
AMAT·LIBRARIA·CURAM
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Apud ADRIANUM MOETJENS, Bibliopolam.
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**Figure 12.3** The title page of Cosmotheoros. www.e-rara.ch

creatures? Such will be the basically teleological argument throughout *Cosmotheoros*; no other was conceivable at the time.

Huygens enters the subject through a detailed description of the Solar system, a modernised Copernic-Kepler one from which we have already extracted all the important elements; in particular, the distances and sizes which make the Earth a mediocre planet. Needless to say, Fontenelle's Marquise would never have survived such a preamble. The book begins to drift away from standard handbooks of astronomy when the author stresses this mediocrity, in order to hypothesise unobservable features. For instance, "the other Planets are round like [the Earth], and like it receive all the Light they have from the Sun." Jupiter and Saturn also revolve around their axis, and also have satellites, hence

> since in so many things they thus agree, what can be more probable that in others they agree too; and that the other Planets are as beautiful and as well stock'd with Inhabitants as the Earth? or what shadow of Reason can there be why they should not?.... to reason from what we see and are sure of, to what we cannot, is no false Logick. This must be our Method in this Treatise wherein from the Nature and Circumstances of that Planet which we see before our eyes, we may guess at those that are farther distant from us. (*Cosmotheoros,* 18-19).

The program is that of the entire book and will be carried to the full, step by step.

First, other planets must have a solid surface, and "they don't want what we call Gravity, that virtue which like a loadstone attracts whatsoever is near the Body to its Center." The proof is not new, being simply borrowed from Aristotle, but even today, it looks as fresh as ever: "their Roundness proceeds from an equal pressure of all their parts tending to the same Center." The next step, the introduction of Life is the most hazardous one, and Huygens is ready to confess as much:

> There's somewhat more of a Contrivance, somewhat more of a Miracle in the production of Plants and Animals than in lifeless heaps of inanimate Bodies… the finger of God, and the wisdom of Divine Providence, is in them much more clearly manifest than in the other.

Calling in the Creator was of course unavoidable at this stage; even Descartes, who had held all animals to operate as mere machines, had not attempted to account for their manufacturing process.

> Everything in [animals] is so exactly adapted to some design that they manifest an infinite Wisdom, an exquisite Knowledge in the laws of Nature and Geometry…[it is] an absurdity even to think of their being thus haply jumbled together by a chance Motion of I don't know what little Particles. (*Cosmotheoros,* 20-21).

Indeed, neither Democritus nor Lucretius had ever solved the case, and Huygens cannot be blamed for arguing as a standard seventeenth-century Creationist.

Having made this point, Huygens is convinced to have shown that Reason itself requires planetary life:

> Should we allow the Planets nothing but vast Deserts, lifeless and inanimate Stocks and Stones, and deprive them of all those Creatures that more plainly speak of their Divine Architect, we should sink them below the Earth in Beauty and Dignity; a thing that no Reason will permit. (*Cosmotheoros,* 21).

Alas! At this very instant, he is forgetting the lessons of his master Des Cartes, whose own reason had never taken him along such a dangerous path. The naive disciple is not merely ordering the Creator to behave according to his own wishful thinking, but reintroducing abolished Qualities, and final causes to boot. Descartes had needed a Creator all right, but left Him wholly free to behave as He had seen fit; here we remember

> One should not examine what the aim of God has been when he created any thing, but solely through which means He has wanted it to be produced…We shall totally exclude from our Philosophy the search for final causes, since we should not presume so much about ourselves as to believe that God was bound to make us privy to His councils… (Descartes *Principes,* I, 37; already quoted in our Chapter 11 ).

This departure from Cartesian orthodoxy is noteworthy; if Descartes had refrained from writing a single line about extraterrestrial life, it was in part because that pleasing appendage could not be inserted within the cosmos without presuming about God's goals. For Huygens, as indeed for Fontenelle and most of their eighteenth-century followers, the restriction vanishes and the so-called Principle of Plenitude will take its place.

Once these premises are granted, the path is clear: planets must have animals, and also the plants required for their food. Even so, efficient causes are not forgotten about: "for their Growth and Nourishment, 'tis no doubt the same with ours, seeing they have the same Sun to warm and enliven them as ours have." However, a considerable question remains "Must they be of the same nature with ours? Nature seems to court Variety in her Works… she may have made them such as neither our Understanding nor Imagination can conceive." A helpful analogy is brought in: "Who doubts but that God, if he had pleased, might have made the Animals in America and other distant Countries nothing like ours… yet we see that he has not done it… their Animals have Feet and Wings like ours." The author's sensible conclusion is that Nature has not exhibited as much variety as she could, consequently we should not suppose "everything in the Planets quite different from what it is here." The actual differences are even predictable since they should "spring from the greater or less distance and influence from that Fountain of Heat and Life the Sun"; in which line he clearly upholds Fontenelle.

In the development and propagation of living creatures, water plays the key role:

> Their Growth and Nourishment proceeds from some liquid Principle…all Philosophers agree that there can be no other way of Nutrition,

and the technical arguments still seem perfectly sound today:

> The parts of a Liquid being in continual motion one with another, and insinuating and twisting themselves into the smallest Places, are thereby very proper and apt to add not themselves only, but whatsoever else they may bring along with them to the increase and growth of Bodies.

Twenty-first century biochemists are using somewhat fancier language, but are they really saying anything else? And the first rule of the present planetary study programs seems to be: Search for Water. Huygens' only tool is his own telescope:

> That the Planets are not without Water is made not improbable by the late Observations: For about Jupiter are observed some spots of a darker hue than the rest of his Body, which by their continual change show themselves to be Clouds.

Bright spots have also been observed, which "Monsieur Cassini thinks are only the reflection from the Snow that covers the tops of the Hills", but here Huygens takes the liberty of disagreeing: "it is only the colour of the Earth [i.e., solid ground], which chances to be free from those Clouds…" Mars has dark spots too, which have pinpointed the rotation period at 24 h 40 m, still he is not confident that clouds have been truly observed. In any case, different conditions apply:

> Every Planet must have its Waters of such a temper as to be proportion'd to its heat: Jupiter's and Saturn's must… not be liable to frost, Venus' and Mercury's… not easily evaporated by the Sun. (*Cosmotheoros,* 24-28).

However, the case of our Moon is quite different:

> The Moon has no air or Atmosphere surrounding it as we have… [which] hinders all probable Conjectures about it. If we could but once be sure that it had Water… we might, with Xenophanes, furnish it with Inhabitants, Cities and Mountains.[6]

Here, Huygens confesses embarrassment:

> What! And must all those Moons round Jupiter and Saturn be condemned to the same Uselessness?… I know of nothing like them to found a Conjecture upon… Perhaps the moisture of the Earth there is just sufficient to cause a Mist or Dew, which may be very suitable to the growth of their Herbs. Which I remember is Plutarch's opinion, in his Dialogue upon this subject. (*Cosmotheoros,* 131-133).

He has not forgotten Kepler's *Somnium* either, and develops the celestial scenery observed from the surface of the Moon, but far less thoroughly than Kepler: the Copernican system no longer requires a demonstration.

Far more than Fontenelle, Huygens is concerned with presenting a likely picture of the growth and propagation of animals on planets, however not venturing into any form of evolution. He does it from a conservative viewpoint, consistently rejecting the fancy of too exotic mechanisms, either on our own Earth or abroad: "Since all Generation is performed by the impregnating of the Eggs, and the Copulation of Male and Female: Why may not the same rule be observ'd in the Planetary Words?" He refuses to have "new ones made everyday out of some such fruitful Mud as that of the Nile" and stresses that "'tis much more agreeable to the Wisdom of God once for all to create all sorts of Animals… than to be continually obliged to new Productions out of the Earth." As to the forms plants and animals may take, those which are displayed on Earth are plentiful enough, and "they must have as great a variety of both as we have." Down here, all walk "upon two feet or four, or like Insects, upon six, nay sometimes hundreds…" Others fly, or swim or "creep upon the ground without feet… I don't believe, nor can I conceive, that there should be any other way than these mentioned." However, differing physical conditions may be responsible for differences:

> The Air I confess may be much thicker and heavier than ours, and so, without any disadvantage to its Transparency, be fitter for the volatile Animals… The Sea perhaps may have such a fluid lying on it, which tho ten times lighter than Water, may be a hundred times heavier than Air.

Prudence is required:

> I think it is beyond the force of Imagination to arrive at any knowledge in the matter, or reach probability concerning the figures of these Planetary Animals. (*Cosmotheoros,* 30-34).

The next step is the introduction of "Inhabitants, not Men perhaps like ours, but some Creatures or other endued with Reason." The argumentation is both

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[6] Huygens may have been first to write down explicitly that the Moon has no atmosphere *(Avertissement du Cosmotheoros*, *OCCH,* XXI, 659), but it is difficult to believe he had been first to formulate the hypothesis. As we have seen, Fontenelle was still putting air around the Moon (*Entretiens,* 63).

teleological and theological: all this "Furniture and Beauty of the Planets [would be] without any design or end unless there were some in them that might at the same time enjoy the Fruits and adore the wise Creator of them." However, Huygens stresses again and again that the principle of Earth mediocrity is just as important for him; were planets devoid of intelligent creatures

> our Earth would have too much the advantage of them…. If we should allow Jupiter a greater variety of other Creatures, more Trees, Herbs and Metals, all these would not advantage and dignify that Planet so much as that one Animal does ours by the admirable Productions of his penetrating Wit. (*Cosmotheoros,* 37-38).

After performing this leap of imagination, the wildest of them all, Huygens asks himself two sets of questions: What about their bodies and what about their minds? In both cases he will remain a conservative at heart, convinced that terrestrial samples provide an adequate glimpse of the universal blueprint.

Bodies first. Planetarians must enjoy appendages very much like hands and feet, stand erect and nevertheless may show up as extremely different from men: "T' is a very ridiculous opinion that the common people have got that it is impossible a rational Soul should dwell in any other shape than ours". The conceptual difficulty is admittedly large: "Yet me thinks this fancy has such a rule upon my mind that I cannot without horror and impatience suffer any other figure for the habitation of a rational Soul." (*Cosmotheoros*, 71–77). Still, very small sizes are ruled out, for which the argument is teleological, and seems rather weak: "our Bodies are made in such proportion to our Earth as to render us capable of travelling about it and making Observations upon it's bulk and figure." (*Cosmotheoros,* 77). Those about the senses of Planetarians (here, intelligent or not) are easier to follow: "Their Animals are like ours in all that relates to the Senses: without the power of Seeing we should find it impossible for Animals to provide Food for themselves." Hence they must have eyes, and even two of them, "otherwise they would not perceive some things close to them, and so could not avoid Mischiefs that take them on the blind side." They must possess a sense of hearing, which "when Seeing is no use it supplys its place and gives us seasonable warning of any imminent danger"; later on, being endowed with ears will take them quite far, indeed to language and society. Next, there is an "inevitable necessity for all creatures that live by feeding to have both Taste and Smell… as for Feeling all Creatures [should be] covered with a fine and sensible Skin." Actually, speculations along those lines must have been rampant, since "it hath been a question with many, whether there might not have been more Senses than those five"; a fancy which Huygens rejects as superfluous, the standard five having proved fully adequate for him. And as a further step on the way to full humanisation of Planetarians: "the senses were not wholly designed for use: Men from them… reap Pleasure as well as Profit", thus the said Pleasure must be universal, as Providence cannot possibly have designed "the Earth, the smallest part almost of the Universe, to monopolize so great a Blessing." (*Cosmotheoros,* 43–53). Altogether, these senses must have led them to "maintain a Society and Fellowship, and afford mutual Assistance and Helps to one another", from which arises the appealing picture of a wholly virtuous Cosmos. Alas! It is at once sadly dismissed:

"Perhaps they may be so just and good as to be at perpetual Peace… But still it's more likely they have such a medley as we, such a mixture of good and bad, of wise with fools, of war with peace." (*Cosmotheoros,* 79–80).

The minds of these exotic intelligent creatures should not be unfathomable either:

> Allowing these Planetarians some sort of Reason, must it needs be the same with ours? Why truly I think 't is, and must be so; whether we consider it as applied to Justice and Morality, or exercized in the Principles and Foundations of Science.

Good and Bad are truly cosmic values: "can what we call just and generous, in *Jupiter* and *Mars* be thought unjust Villany?" This is impossible, because the same Creator has been at work everywhere, and his sole design has been "the preservation and safety of his Creatures." One should allow that "Morality and Passions with those Gentlemen [may be] somewhat different from ours", but at least Science is bound to be truly universal: "in reasoning [about] Magnitude and Quantity… their Reason must be exactly the same, and go the same way to work with ours, and what's true in one part will hold true over the whole Universe." Whatever difference exists "must lie in the degrees of Knowledge, which will be proportional to the Genius and Capacity of the Inhabitants." (*Cosmotheoros,* 41–43). Which is as close to the modern viewpoint as Huygens will ever get; while not making any explicit mention of Biblical chronology, he remains constrained by its time frame, thus none of his alien civilisations ever gets a chance to grow older and wiser than our own.

Even so, an essential question remains: "Whether they have made as great advances in Arts and Knowledge as we in our Planet." (*Cosmotheoros,* 58). Astronomy must have played the central role, because Planetarians cannot help watching those same phenomena that are available to us. Some of them are even luckier: on Earth "Amazement and Fear at the Eclipses of the Moon and the Sun gave the first occasion to the study of Astronomy", but such providential accidents are far more frequent on Jupiter and Saturn, thanks to their swarms of satellites. Wherever astronomy develops, it is bound to require tools, material or mental: observations cannot be made "without Instruments, nor can these be made without Metal, Wood…. Carpenter's Tools, the Saw, the Ax…. these Instruments can't be without a Circle divided into equal Parts… Here's a necessity for introducing Geometry and Arithmetick." Marking and transmitting the observations will require "the Art of Writing; I won't say the same with ours, but I dare affirm not more ingenious or easy", and Huygens mentions disparagingly those unwieldy Chinese characters, and the "Knots tied in Cords or Pictures in use among the barbarous People of *Mexico* and *Peru*." (*Cosmotheoros,* 64). Today, we feel less contemptuous about the *khipu*, and we still have not managed to unravel completely its meaning.

Nevertheless, for reasons which are never cleared up, Huygens is not willing to grant Planetarian astronomy equal status with our own: "But for all our large and liberal allowances to these Gentlemen, they will still be behind-hand with us… we have so an admirable an Invention of Telescopes… we must necessarily be far their Masters in that Knowledge." That Planetarians cannot have telescopes of their own is an unexpected deduction, and the attitude proves quite surprising, since in other places Huygens is willing to grant that "there's no reason to think the Planetarians less ingenious than our selves… It is probable that they are as skilful Astronomers as we can pretend to be." (*Cosmotheoros,* 70). In the same vein "they are as good Architects, have as noble Houses and stately Palaces…. have the use of all those Arts subservient to it and whatsoever else is necessary for it, as Iron, Lead and Glass." (*Cosmotheoros,* 82). More fundamentally, they are just as good mathematicians, and have managed to acquire all the latest tricks:

> They have our Inventions of the Tables of Sines and Logarithms and Algebra." As to geometry, Nature itself "presents us with Geometrical figures… [which] makes it not improbable that there are in the Planets some who partake with us in these delightful and pleasant Studies… It's the same with Musick as with Geometry. (*Cosmotheoros,* 84-86).

Altogether, within all fields Planetarians prove equal, but not better.

Why are telescopes, and more specifically better telescopes, excluded from such pleasant achievements? Was Huygens feeling jealous about all colleagues, either human or planetarian, or simply allergic to science-fiction? On Jupiter he might have erected futuristic versions of his beloved aerial telescope, growing to "one hundred or two hundred feet… [showing] planets revolving around their axis"; he held all the technical data for discussing both possibilities and difficulties, e.g. local winds and gravity. In any case, something prevented him from any steps along this obvious path, and even from asking whether aboard planets anybody was interested in that "delightful Study" of detecting Life on Earth. Fontenelle had proceeded farther, since his Jupiterians might have been embroiled in "some lawsuit against philosophers who have asserted that we exist." Likewise, he had considered at least cases of cosmological changes, and we remember his fable of the rose garden with attendant gardener. Within Hugenian Plurality is found no hint of a past nor any prospect of a future.

In Book II of *Cosmotheoros*, Huygens is mostly concerned with providing the serious astronomical data he needs to erect his fancies; for instance, here are found the planetary sizes and the stellar distances we have quoted before, together with some *Somnium*-like descriptions of the celestial show as observed from the surface of the planets. He provides no further speculations about the nature or life style of Planetarians; for us, the new point of interest lies solely in the extension of his visions to other planetary systems.

Huygens enters the fray by deriding the *Iter Extaticum* of the Jesuit Athanasius Kircher, who (amongst others) had been rejecting all motion of the Earth as late as 1656 through adoption of the Tychonic system. His cosmic-exploration device had been equally orthodox: an angel-powered journey through the Heavens, on which way he had incidentally observed numerous planets circling around each star. However, Kircher had failed to notice his own absurdity: "When he supposes all the fix'd Stars to be Suns and round each of them places their Planets… he has unawaredly made an infinite number of *Copernican* Systems." (*Cosmotheoros,* 102). A more serious criticism is that of Kepler's Sun-centred star distribution, which had solely proceeded from his "idle Dream taken from Pythagoras or Plato." Huygens' own pet dream arises from the opposite conviction: our Sun is a wholly-common star. His fancy of solar-system Planetarians had been based on a Principle of Earth Mediocrity; his extrasolar planetary systems rested on an unexpressed Principle of Sun Mediocrity. Up to a very recent date, we had no more solid ground for erecting our own fancies.

Admittedly, Cusanus and Bruno had fancied as much. The difference is that Huygens is an expert optician and a consummate astronomer, with all the resources of the waning seventeenth century at his disposal. He is still unable to see with his own eyes those hypothetical planetary systems, just like Cusanus and Bruno; but he understands the precise optical reasons for this failure, and presents the problem in terms so modern that hardly any word has to be changed today:

> Why may not every one of these Stars or Suns have as great a Retinue as our Sun, of Planets, with their Moons to wait upon them? Nay, there's a manifest reason why they should. For let us fancy our selves placed at an equal distance from the Sun and the fix'd Stars; we should then perceive no difference between them. For, as for all the Planets that we now see attend the Sun, we should not have the least glimpse of them, either that their Light would be too weak to affect us, or that all the Orbs in which they move would make up one lucid point with the Sun. (*Cosmotheoros,* 149).

Cusanus and Bruno had never posed the problem in terms of material facts fitting or not their metaphysical notions; Kepler had missed it altogether by operating from Pythagorean dreams; Descartes had filled his own Universe with multiple and analogous Vortices, but side-stepped the final question of their content because of theological fears and intellectual restraint; Fontenelle had provided a pleasing, but hazy and qualitative picture for *les gens du monde*. Huygens is a professional astronomer who means precisely what he says. When he sees himself "placed at an equal distance from the Sun and the fix'd Stars", he has measured these distances; when stressing that "Their Light would be too weak to affect us", he means that the light flux collected by the aperture of the largest telescopes is just too faint. Last, "The Orbs… would make up one lucid point with the Sun" means that, given (1) distance of star and radius of planetary orbit, (2) intrinsic luminosities of planet and star, and (3) resolving power of telescope, the proposed observation is not feasible; Q.E.D. While no summary of all those technical points is given within *Cosmotheoros* (except for star distances), the educated reader knows that every single one has been handled in other works of the same author.

Nevertheless, there is still a great deficiency in the Huygens account: the complete absence of all speculations about future technical possibilities. In the above summary, the astronomical parameters are permanent; the distances and angles involved in any attempted search have not become more favorable for the twentieth-century planetary seeker. But the optical devices have grown far more complex and their performance immensely better. During his lifetime, Huygens did witness spectacular improvements of telescopes, many of them his own. His finding of Titan, the biggest satellite of Saturn, had been a great achievement, but at the end of his career, the last Saturn satellite discovered by Cassini showed up as ten times fainter. He had unveiled the Ring, but some years later Cassini proved it to be double, with a very faint gap between the two parts. Thus some modest conjectures about the feats that would hopefully become achievable in the future would not have been out of place *in fine*; and the Saturnians might have been granted right away larger and better telescopes, leading (why not?) to the discovery of cities on Earth; however, Huygens does not proceed beyond Fontenelle. Such speculations, through which any similar modern text would unavoidably conclude, are not attempted. We are left with the feeling that *Cosmotheoros* is, on that count, frankly incomplete.

Last act: the long-awaited introduction of more Planetarians around those other Suns presents no difficulty. We must

> conclude that our Star has no better attendance than the others…those Planets… must have their Plants and Animals, nay and their rational ones too, and those as great Admirers and as diligent Observers of the Heavens as our selves.

And the closing encomium is not unexpected:

> What a wonderful and amazing Scheme have we here of the magnificent Vastness of the Universe! So many Suns, so many Earths, and everyone of them stock'd with so many Herbs, Trees and Animals… (*Cosmotheoros,* 150).

Indeed, the news trumpeted by that *Cosmic Observer* were even more startling than all those from the *Starry Messenger.* Alas, unlike them, they were to prove premature, the Creator having grievously failed to oblige; unlike Huygens, He had been a philosopher, and not one from any deviant Cartesian school. That "wonderful and amazing scheme" lacked all substance, and *Cosmotheoros* would have shown himself wiser had he remembered the advice of his earthly Master "One should not examine what the aim of God has been when he created anything, but solely through which means He has wanted it to be produced."