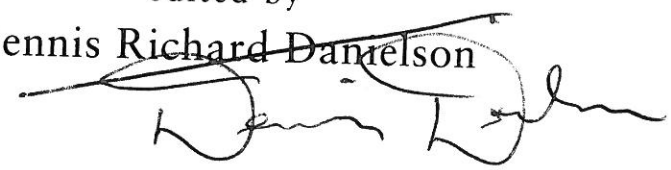
the Book of the Cosmos

Imagining the Universe from Heraclitus to Hawking

A Helix Anthology

edited by

Dennis Richard Danielson



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He Supposes the Earth to Revolve

Aristarchus and Archimedes

Not everyone before Copernicus believed that the planets and the sun revolved around the earth. The first astronomer known to have proposed a heliocentric rather than a geocentric model was Aristarchus of Samos (c. 310–c. 230 B.C.). Heliocentrism appears nowhere in his extant works, but we have authoritative attributions of the idea to him in other ancient sources. For example, Plutarch mentions Aristarchus's "attempt to save the phenomena by supposing the heaven to remain at rest, and the earth to revolve in an oblique circle, while it rotates, at the same time, about its own axis."

The most detailed reference, however, appears in the writings of Aristarchus's younger contemporary Archimedes (287–212 B.C.). The work in which Archimedes mentions Aristarchus's ideas is interesting for two further reasons. In it Archimedes is applying his development of an exponential system to express very large numbers—numbers which we quite naturally refer to as "astronomical" and which, without an exponential system, we would be at a loss to express. Archimedes asks, in what modern scientists would call a "thought experiment," how many grains of sand the universe itself might hold. The discussion also provides an occasion for worrying about the size and very definition of the term universe.

There are some . . . who think that the number of the sand is infinite in multitude; and I mean by the sand not only that which exists about Syracuse and the rest of Sicily, but also that which is found in every region, whether inhabited or uninhabited. Again, there are some who, without regarding it as infi-

nite, yet think that no number has been named which is great enough to exceed its multitude. And it is clear that they who hold this view, if they imagined a mass made up of sand as large in size as the mass of the earth, including in it all the seas and the hollows of the earth filled up to a height equal to that of the highest mountain, would be many times further still from recognizing that any number could be expressed which exceeded the multitude of the sand so taken.

But I will try to show you, by means of geometrical proofs, which you will be able to follow, that of the numbers named by me . . . some exceed not only the number of the mass of sand equal in size to the earth filled up in the way described, but also that of a mass equal in size to the universe.

Now you are aware that "universe" is the name given by most astronomers to the sphere the center of which is equal to the straight line between the center of the sun and the center of the earth. This you have seen in the treatises written by astronomers.

But Aristarchus of Samos brought out a book consisting of certain hypotheses, in which the premises lead to the conclusion that the universe is many times greater than that now so called. His hypotheses are that the fixed stars and the sun remain motionless, that the earth revolves about the sun in the circumference of a circle, the sun lying in the middle of the orbit, and that the sphere of the fixed stars, situated about the same center as the sun, is so great that the circle in which he supposes the earth to revolve bears such a proportion to the distance of the fixed stars as the center of the sphere bears to its surface.

Archimedes rightly objects that the ratio of a point to a circumference is no ratio at all, for a point has no dimension whatsoever. Therefore he adjusts the parallel thus: Aristarchus must mean that the ratio of the size of the earth to the size of the universe *as Archimedes has defined it must be equal to* the ratio of the size of the sphere of earth's orbit to the size of the universe *as Aristarchus defines it. In short, the Aristarchan theory entails an increase in the size of the universe by many orders of magnitude.*

Now it is easy to see that this is impossible; for since the center of the sphere has no magnitude, we cannot conceive it to bear any ratio whatever to the surface of the sphere. We must, however, take Aristarchus to mean this: since we conceive the earth to be, as it were, the center of the universe, the ratio which the earth bears to what we describe as the "universe" is the same as the ratio which the sphere containing the circle in which he supposes the earth to revolve bears to the sphere of the fixed stars. For he adapts the proofs of the phenomena to a hypothesis of this kind, and in particular he

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I say then, that, even if a sphere were made up of sand to a size as great as Aristarchus supposes the sphere of the fixed stars to be, I shall still be able to prove that . . . some [numbers] exceed in multitude the number of the sand which is equal in size to the sphere referred to.

As T. L. Heath comments in Greek Astonomy *(p. 108), after much "sheer calculation" Archimedes finds "that the number of grains of sand that would be contained in a sphere of the size attributed to the universe is less than the number which we should express as* 10^{63}*."*

SOURCE: Thomas L. Heath, *Greek Astronomy,* London: J. M. Dent, 1932.

8

A Geometrical Argument

Eratosthenes

A strangely persistent modern myth is that before about 1492, people thought the earth was flat. On the contrary, the ancient Greeks and others knew the earth to be spherical. Visual evidence could be found in lunar eclipses and in the fact that, as one travels southward, the pole star and others appear lower in the sky while new stars on the southern horizon come into view. But given that the earth is a sphere, and that the ancients had no opportunity to circumnavigate the globe, how large did they imagine this sphere to be?

Eratosthenes (c. 275 – c. 195 B.C.) became famous for an achievement that is geo-metrical *in the most literal sense of the term: He measured the earth. The second-century B.C. astronomer Cleomedes wrote the principal extant account of what he calls Eratosthenes' "geometrical argument," but the version of the story as recounted by Robert Osserman (b. 1926) is unsurpassed for clarity.*

How could one measure the whole earth, when the immense expanses of the oceans formed impenetrable barriers to travel? A most ingenious answer was provided by Eratosthenes of Alexandria.

Alexandria was founded at the delta of the Nile in northern Egypt, where the river empties into the Mediterranean Sea, by Alexander the Great, who wanted a city to match the grandeur of his own ambitions. He succeeded to an astonishing degree. Ancient Alexandria attracted the most outstanding literary, scholarly, and scientific talent of the day, in part because of its library—the most comprehensive in the world. The head of the library in the latter half of the third century B.C. was Eratosthenes, one of the greatest sci-

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entific talents in Alexandria as well as the author of books of poetry and literary criticism.

Eratosthenes' method for determining the size of the earth rested on three elements. The first was a bit of elementary geometry which will be explained in a moment. The second involved a serendipitous geographic fact regarding a city on the Nile River in southern Egypt called Syene in those days, now known as Aswan. The third was an absurdly simple apparatus called a *gnomon.*

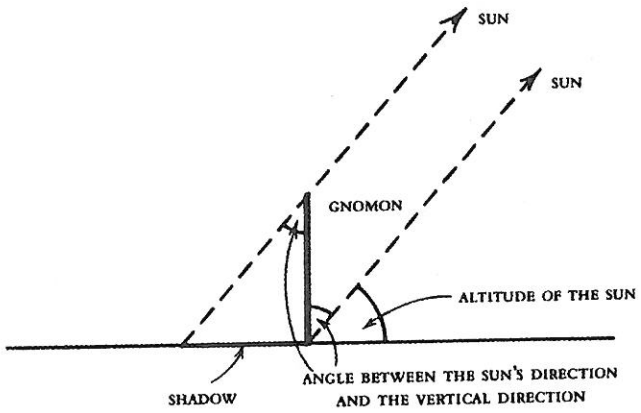
The gnomon had been in use for a very long time. It consisted of a vertical stick placed on a level piece of ground. The gnomon was a device that allowed one to follow the sun's shadow as the sun moves across the sky. Although the gnomon cannot be used to tell time in the manner of its more advanced cousin, the sundial, it does provide a surprising amount of useful information.

First, the gnomon gives the exact time once a day, at the moment that the sun is highest in the sky and the shadow of the gnomon is the shortest—at noon. In addition, it acts as a compass, since [in the northern hemisphere] the shadow at noon points due north. . . .

The gnomon also serves as a primitive calendar, determining two key days of each year: the summer and winter solstices. If one places a mark where the shadow ends at noon on each day of the year, one finds that in winter, when the sun is low in the sky, the shadows are longer, while in the summer, with the sun high in the sky, the shadows are shorter. The shadow at noon goes through a yearlong cycle, from the shortest noon shadow in summer, gradually reaching its greatest length six months later, and then shortening again over the succeeding six months. The day on which the noon shadow is shortest, and the sun is highest, is called the *summer solstice.* The day six months later when the sun is lowest and the noon shadow is longest is known as the *winter solstice.* Counting the number of days from solstice to solstice also provided one of the earliest accurate measurements of the length of the year.

Finally, the gnomon could be used to determine the altitude of the sun—that is, the angular distance of the sun above the horizon at any given moment (at least on sunny days). All one had to do was measure the length of the shadow and the length of the stick. By drawing a right triangle to scale with those measurements, one can measure the angle opposite, and that angle will indicate how far off the sun's direction is from an overhead, vertical direction. (See page 48.)

These uses of the gnomon were well known to Eratosthenes and his contemporaries. But it was the fortuitous geographical properties of Aswan that gave Eratosthenes his inspiration for determining the size of the earth. Aswan is almost due south of Alexandria. It also enjoys the special privilege of having



Gnomon and shadow.

the sun pass directly overhead at one moment of each year: at noon on the summer solstice. At that one moment each year, a gnomon in Aswan casts no shadow at all. (Aswan lies almost exactly on the Tropic of Cancer. . . .)

By combining these facts with some simple but clever geometric reasoning, Eratosthenes was able to produce his remarkable pièce de résistance: the circumference of the earth. At noon on the summer solstice, he simply used his gnomon to determine the angle between the sun and the vertical direction at Alexandria. Since the sun at that moment is directly overhead in Aswan, he thereby knew the angle between the vertical direction at Alexandria and at Aswan. He found the angle to be 1/50 of the circumference of a circle. That meant that the entire circumference of the earth is 50 times the distance between Alexandria and Aswan. Since the distance from Aswan to Alexandria is roughly 500 miles, by today's measurements, the earth must be approximately 25,000 miles around.

The brilliant simplicity of Eratosthenes' method is not diminished by the fact that his estimate involves several inaccuracies and uncertainties: first, measuring the angle between the direction of the sun and the vertical direction could be done only approximately; second, Aswan is not exactly due south of Alexandria, but only roughly so; third, it would have been difficult or impossible to obtain an accurate measure of the distance between the two cities; and finally, there is considerable uncertainty about how to interpret ancient units of measurement in modern terms. Large distances were given in terms of *stades*—the length of a stadium. According to Eratosthenes, the circumference of the earth was 250,000 stades. The length of a "stade" was standardized at 600 "feet," but the length of a foot was not standard, and varied by 10 percent or more. The figure of 25,000 miles for the earth's cir-

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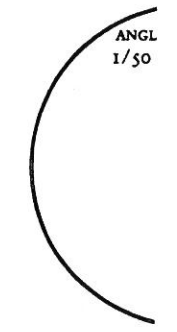

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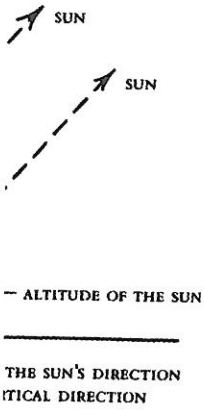

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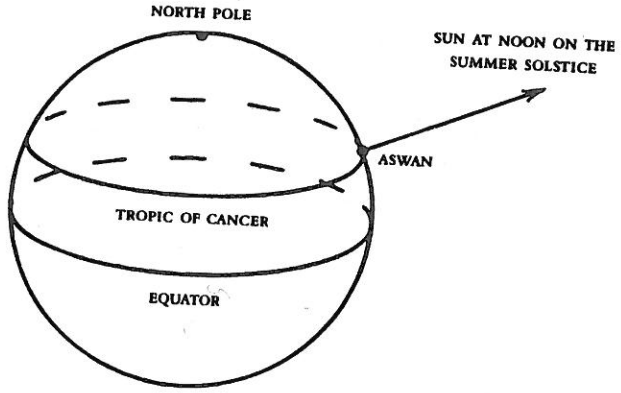
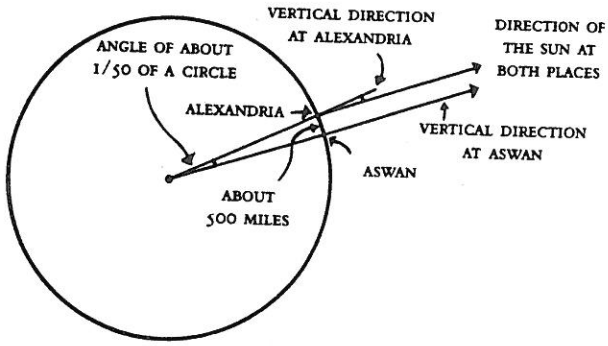


Tropic of Cancer is the name of a circle of latitude about 23.5 degrees above the equator.



Eratosthenes' method for measuring the earth: when the sun is directly overhead at Aswan, measure the angle between the sun and the vertical direction at Alexandria using the shadow of a vertical pole.

cumference results from choosing a value at the low end of the scale for the length of a stade. The net effect was that Eratosthenes' calculation might on several counts be termed a "ballpark estimate" rather than a scientifically precise measurement. Nevertheless, it provides dramatic testimony to the ability of simple but ingenious geometric reasoning to succeed where a direct approach—involving traversals of two polar regions and an ocean—was well beyond the realm of possibility.

SOURCE: Robert Osserman, *Poetry of the Universe: A Mathematical Exploration of the Cosmos*, New York: Anchor Books, 1995.

9

No Erratic or Pointless Movement

Cicero

Cicero (106–43 B.C.) stands as a kind of one-man summation of Roman political, literary, and philosophical life. Although Cicero's interests were not mainly cosmological, his dialogue On the Nature of the Gods *gives us a snapshot of the debate concerning the physical nature and purpose of the universe in first century B.C. Rome. Its dialogue form allows us to hear proponents setting forth their positions in their own voices, be they Epicurean, Stoic, or Academic. Velleius, who represents the Epicurean position, which if it posits gods at all sees them as distant and uncaring, begins by mocking both the Academic "craftsman-god" and the Stoic pantheistic god.*

"What you are going to hear are no airy-fairy, fanciful opinions, like the craftsman-god in Plato's *Timaeus* who constructs the world, or the prophetic old lady whom the Stoics call Pronoia, and whom in Latin we can term *Providentia*. I am not going to speak of the universe itself as a round, blazing, revolving deity endowed with mind and feelings. These are the prodigies and wonders of philosophers who prefer dreaming to reasoning. I ask you, what sort of mental vision enabled your teacher Plato to envisage the construction of so massive a work, the assembling and building of the universe by the god in the way which he describes? What was his technique of building? What were his tools and levers and scaffolding? Who were his helpers in so vast an enterprise? How could the elements of air and fire, water and earth knuckle under and obey the will of the architect? . . .

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"The question . . . is this: why did these world-builders [the Platonic Demiurge and the Stoic Providence] suddenly emerge after lying asleep for countless generations? For the non-existence of the universe does not necessarily imply absence of periods of time. . . . So what I am asking, Balbus [the Stoic], is this: why did your Pronoia remain idle throughout that boundless length of time? Was she avoiding hard work? But hard work does not impinge upon a god, and in any case there was no such labor, for all the elements of sky, stars, lands, and seas obeyed the divine will. . . .

"As for those who have maintained that the world itself possesses life and wisdom, they have totally failed to see into what shape the nature of intelligent mind could be installed. . . . I shall merely express surprise at the slow-wittedness of those who would have it that a living creature endowed with both immortality and blessedness is spherical in shape, merely because Plato maintains that no shape is more beautiful than the sphere. In my view, the cylinder, the cube, the cone, the pyramid are more beautiful. And what sort of life is assigned to this rotund god? Why, to be spun at speed the like of which cannot even be imagined; I cannot envisage mental stability or a life of happiness resident in that!"

Having set up straw deities, Velleius appeals—as materialists still do—to the "natural" production of the world that has no recourse to divine explanation.

"But we Epicureans define the life of blessedness as residing in the possession of untroubled minds and relaxation from all duties. Our mentor who has schooled us in all else has also taught us that the world was created naturally, without the need for a craftsman's role, and the process which in your view cannot be put in train without the skillful touches of a god is so straightforward that nature has created, is now creating, and will continue to create innumerable worlds. Because you Stoics do not see how nature can achieve this without being endowed with mind, you behave like poets of tragedy, unable to draw the plot to its close, and having recourse to a *deus ex machina*.

"You would surely have no need of the activity of such a figure if you would only observe how unlimited, unbounded tracts of space extend in all directions. When the mind strains and stretches itself to observe these distances, it journeys abroad so far that it can observe no ultimate limit at which to halt. It is in this boundless extent of breadth, length, and height, then, that innumerable atoms in infinite quantity flit around. There is space between them, yet they latch on to each other. In gripping each other they form a chain, as a result of which are fashioned the shapes and forms of things which you Stoics believe cannot be created without bellows and

anvils. So you have implanted in our heads the notion of an external lord whom we are to fear day and night; for who would not stand in awe of a god who is a prying busybody, who foresees and reflects upon and observes all things, believing that everything is his business?"

In The Nature of the Gods, *however, Cicero gives pride of place to the Stoic position. Balbus, the Stoic speaker, sketches an "argument from design" to support belief in the existence of deity.*

"What can be so obvious and clear, as we gaze up at the sky and observe the heavenly bodies, as that there is some divine power of surpassing intelligence by which they are ordered? If this were not the case, how could Ennius have won general assent with the words

> Behold this dazzling vault on high, which all
> Invoke as Jupiter!

and not merely as Jupiter, but also as the lord of creation, governing all things by his nod, and (to exploit Ennius's words again) as "father of gods and men," an attentive and supremely powerful God? I completely fail to understand how anyone who doubts this can avoid also doubting whether the sun exists or not—for in what way is the sun's existence more obvious than God's? If this realization was not firmly implanted in our minds, such steadfast belief would not have endured nor been strengthened in the course of time, nor could it have become securely lodged in succeeding generations and ages of mankind."

Although some of Balbus's reasoning may sound like that of St. Paul in the epistle to the Romans, the pantheism of the Stoical position is unmistakable: the universe itself is divine. Balbus then goes on to make the observation, one reemphasized in our own day by supporters of the "anthropic principle," that if rational, self-aware beings are produced by and part of the universe, then the universe itself must in some sense be seen as rational and self-aware.

"It can be established that the universe is wise, and blessed, and eternal, for all embodiments of these attributes are superior to those without them, and nothing is superior to the universe. This will lead to the conclusion that the universe is God.

"Zeno [the Stoic] also produced this argument: 'Nothing which is devoid of sensation can contain anything which possesses sensation. Now some parts of the universe possess sensation; therefore the universe is not devoid of

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sensation.' He goes further, pressing the argument more closely: 'Nothing which lacks a vital spirit and reason can bring forth from itself a being endowed with both life and reason. Therefore the universe is endowed with life and reason.' He also pressed home his argument with his favorite technique of the simile, like this: 'If flutes playing tunefully were sprouting on an olive-tree, you would surely have no doubt that the olive-tree had some knowledge of flute-playing; again, if plane-trees bore lutes playing in tune, you would likewise, I suppose, judge that plane-trees were masters of the art of music. Why then is the universe not accounted animate and wise, when it brings forth from itself creatures which are animate and wise?'"

Many of the features of the universe as Balbus describes them in Cicero's dialogue persisted as cosmological stock-in-trade for many centuries to come, including a preoccupation with circles and spheres. In chiding Velleius for his earlier flip comments about geometrical solids, Balbus betrays how deeply aesthetic one's choice of world view may be.

"Velleius, please do not parade the utter ignorance of learning of your school. You say that you regard the cone and cylinder and pyramid as shapes more beautiful than the sphere. In this you betray the same curious judgement in aesthetics which you show in all else. Let us suppose, however, that these shapes are more beautiful in appearance. This is not a view that I share; for what can be more beautiful than the shape which alone embraces and gathers in all other shapes, which can exhibit no rough surface, no jagged projection, no angular indentations or bends, no protuberances or yawning gaps? There are two shapes which excel all others: in solid bodies, the globe (*globus* is the word I use to render the Greek *sphaera*), and in planes the circle or orb, the Greek word for which is *kuklos*. These two shapes alone are closely similar in all their parts, with the circumference equidistant from the center at all points. Nothing can be better ordered than that. Still, if you Epicureans do not realize this because you have never traced diagrams in the dust of the schools, could you natural philosophers not have grasped even this, that the uniform movement and regular positions of the stars could not have been preserved in any other shape? So nothing could be more ignorant than the usual assertion of your school; for you claim that it is not certain that this universe of ours is round, since it has possibly another shape, and you maintain that there are countless other worlds of varying shapes. . . .

"Now there are two types of heavenly bodies. The first type travels from east to west over the same unchanging regions, never at any time making the slightest alteration to their course. The second type covers the same expanse and the same route in two revolutions without a break between them. The

two types reveal to us both the rotatory movement of the universe, achievable only because it is spherical in shape, and the circling revolutions of the stars.

"Take the sun first, which has pride of place among the heavenly bodies. In its course it first fills the lands with abundant light, and then shrouds them successively in shade, for night results when the earth's shadow blocks the sunlight. Its journeys in darkness have the same regularity as those in daylight. The sun also regulates the limits of cold and heat by drawing slightly nearer and retiring slightly further. The round of the year is complete by some 365 1/4 daily circuits by the sun; and by adjusting its course now northward, now southward, the sun creates summer and winter, and the two seasons which follow the tail-ends of winter and summer. The transformation of the four seasons ensures the birth and the rationale of all things which are begotten on land and sea.

"Next, the moon in her monthly circuit traverses the course over which the sun takes a year. When she draws nearest to the sun, her light becomes dimmest, and her orb is fullest when she is most distant. Not merely do her appearance and shape change, as she waxes and then by gradual diminution returns to her original form, but she alters her position in the sky. Her position in north or south creates in her course the equivalent of the winter and summer solstices; she is the source of the many effluences which result in the nurture and growth of living creatures, and which cause the plants which sprout from the earth to swell and ripen."

Balbus's survey of the heavens makes explicit two important astronomical definitions. He is critical of the term used for the planets, for the Greek planetes *means "wanderer," which to the Stoic ear in any case wrongly suggests "error" or "going astray." The dialogue also provides the first extant reference to the concept of the Great Year (the enormous period of time required for* all *heavenly bodies to return to a given initial position—like all three hands of a clock returning to a vertical position at the stroke of midnight).*

"Most remarkable, too, are the movements of the five planets, mistakenly labelled 'those which stray'; mistakenly, because nothing can be said to 'go astray' which through all eternity maintains in a steady, predetermined pattern its various movements forward, backward, and in other directions. What is all the more remarkable in these bodies under discussion is that at one moment they disappear, and at another reappear; now they draw close, and now retire; at one time they draw ahead, and at another lag behind; they alternatively accelerate and decelerate; on occasion, they cease to move at all, and remain still for some time. Mathematicians have exploited the varying

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movements of the planets to calculate the length of the Great Year, which is accomplished once the sun, moon, and five planets have completed all their revolutionary courses, and have returned to the same relative positions.

"The actual length of the Great Year is a difficult question, but it is undoubtedly a fixed and delineated period. The planet bearing the name of Saturn, which the Greeks call *Phaenon* ('shining') is furthest from the earth. It takes about thirty years for it to complete its journey, in the course of which it does many remarkable things. It goes ahead, and then falls back; it disappears during the hours of evening and shows itself again in the matutinal hours; and yet in age after age throughout eternity it never varies, but behaves identically at the identical times. Below Saturn and closer to the earth the planet Jupiter speeds on its way; men call it *Phaethon* ('blazing'). Jupiter completes the same circuit through the twelve signs of the zodiac every twelve years, and in its course it indulges in the same variations as Saturn does. The nearest circuit below this is covered by *Pyroeis* ('fiery'), which is called the star of Mars; this planet completes in, I think, some six days short of twenty-four months the same round as the other two. Below Mars lies the star of Mercury, called *Stilbon* ('gleaming') by the Greeks, which takes about a year to circle through the zodiac; it never distances itself from the sun more than one sign's length, sometimes leading ahead and sometimes falling behind. Lowest of the five planets and nearest to the earth is the star of Venus, in Greek called *Phosphoros* ('light-bringing'), and in Latin when it precedes the sun, Lucifer, but *Hesperus* ('at evening') when it follows behind. Venus completes its course in a year; it traverses the breadth as well as the length of the zodiac as also do the planets above it, and it never departs more than two signs' distance from the sun, sometimes lying ahead, and sometimes behind.

"This is why I cannot envisage such regular behavior in the stars, and such remarkable coincidence of timing in their varied paths throughout eternity, as existing without intelligence, reason, and planning; and since we observe these qualities in heavenly bodies, it is impossible for us not to number them among the gods.

"It is the same with the so-called fixed stars: they too evince the same intelligence and foresight. Every day they revolve with due and dependable regularity. It is not that they merely revolve with the aether, or that they cling close to the firmament, as is assumed by many who are ignorant of the laws of physics; for the composition of the aether is not such that it grips the stars and twists them round by its force, since it is rarefied and diaphanous and endowed with uniform heat. Thus it seems unsuited to be a receptacle for the stars. Accordingly the fixed stars have their own spheres, separated from and free of attachment to the aether. Their perennial and unceasing journey, traversed with a wondrous regularity beyond belief, makes manifest the divine

force and intelligence which resides within them. Hence anyone who fails to realize that they possess the power of gods seems incapable of any kind of observation.

In Balbus's Stoic picture of the universe we find also the notion, a commonplace of literature and cosmology for the better part of two millennia, that change and irregularity are confined to the sub-lunary sphere (for the moon, with its changing phases, marks the boundary between the earthly realm, where things are conspicuously unstable, and the heavenly realm, where regularlity and even "fixity" prevail).

"So the heavens contain no chance or random element, no erratic or pointless movement; on the contrary, all is due order and integrity, reason, and regularity. All that lacks these qualities, and misleads with falsehood and abounds in error, belongs to the vicinity of earth below the moon, the lowest of the heavenly bodies, and to earth itself. Therefore, any person who imagines that the heavens are mindless, when their remarkable order and regularity beyond belief ensure the total preservation and well-being of everything in the universe, must himself be regarded as out of his mind."

Although physically confined to this mutable realm beneath the moon, human beings nevertheless have a special ability to contemplate the universe beyond. And this ability in turn argues a special place for human beings in any analysis of cosmic purpose—of "teleology"—an issue that remains actively discussed among cosmologists to this day.

"Has not our human reason advanced to the skies? Alone of living creatures we know the risings, settings, and courses of the stars. The human race has laid down the limits of the day, the month, the year; they have come to recognize eclipses of the sun and moon, and have foretold the extent and the date of each occurrence of them for all the days to come. Such observation of the heavens allows the mind to attain knowledge of the gods, and thus gives rise to religious devotion, with which justice and the other virtues are closely linked. These virtues are the basis of the blessed life which is equivalent and analogous to that enjoyed by the gods. . . .

"It remains finally for me to show . . . that all things in this universe of ours have been created and prepared for us humans to enjoy. So first, the universe itself was made for the benefit of gods and men. All that is in it has been provided and devised for us to enjoy; for the universe is, so to say, the shared dwelling of gods and men, or a city which houses both, for they alone enjoy the use of reason, and live according to justice and law. So just as we

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must believe that Athens and Sparta were founded for the Athenians and Spartans, and that everything in those cities is rightly claimed to belong to those peoples, so all that exists in the entire universe must be regarded as the possession of gods and men.

"Again, the revolutions of sun, moon, and other heavenly bodies admittedly form part of the organic structure of the universe, but they also offer a spectacle to the human race. This is supremely the sight of which we never tire; it is more beautiful and reflects greater reason and intelligence than all others, for by measuring their courses, we become aware of the due arrival of the seasons, and of variations and changes in them. Since only humans have this awareness, we must infer that this is a dispensation made for their sake."

SOURCE: Marcus Tullius Cicero, *The Nature of the Gods*, trans. P. G. Walsh, Oxford: Clarendon Press, 1997.

10

Turning the Universe Upside Down

Plutarch

Since the beginning of human history and probably before, people have wondered about the moon. What is it made of? How does it shine? How does it affect us?

Plutarch (A.D. *46?–c. 120), the great first-century biographer of Greeks and Romans, gives us in his dialogue on* The Face Which Appears on the Orb of the Moon *an intriguing taste of some of the issues debated in the Roman Empire of his time. This dialogue also set the agenda for investigations by Galileo and Kepler in the seventeenth century. In particular it raised the question of what causes the mottled appearance of the moon's face. One view discussed is that of the Stoics, "that the moon is a mere mixture of air and mild fire, that the air grows dark on its surface, as a ripple courses over a calm sea, and so the appearance of a face is produced." The response of Lamprias, who also narrates the dialogue, combines a desire to explain the matter scientifically with an effort to speak of the moon respectfully.*

I said, ". . . It is a slap in the face to the moon when [the Stoics] fill her with spots and black patches, addressing her in one breath as Artemis and Athena, and in the very same describing a congealed compound of murky air and charcoal fire, with no kindling or light of its own, a nondescript body smoking and charred like those thunderbolts which poets address as 'lightless' and 'sooty.' . . . But if the moon is fire, where does all this air inside it come from? For this upper region, always in circular motion, is com-

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posed not of air but of some nobler substance, which has the property of refining and kindling all things. If air has been generated, how can it not have been vaporized by the fire and so changed into some other form, instead of being preserved near the fire all this time, like a nail fitted into the same place and wedged there for ever? If it is rare and diffused, it should not remain stable, but be displaced. On the other hand, it cannot subsist in a solidified form, because it is mingled with fire, and has no moisture with it, and no earth, the only agents by which air can be compacted. . . . The Stoics are displeased with Empedocles when he describes the moon as a mass of air frozen like hail and enclosed within her globe of fire. Yet they themselves hold that the moon is a globe of fire which encloses air variously distributed, even though they do not allow that she has clefts in herself, or depths and hollows, for which those who make her an earth-like body find room. Instead they clearly suppose that the air lies upon her convex surface, an absurd idea given the problem of its stability, and impossible given what we see at full moon. For if they were right, we ought not to be able to distinguish black parts and shadow. Either everything there should be dull and shrouded, or else everything should radiate equally when the moon is caught by the sun. . . ."

Here Pharnaces [the Stoic] interrupted me: "There it is again, the old trick of the Academy brought out against us! They amuse themselves with arguing against others but never offer their own views to be examined. . . . You won't draw me on today to answer your charges against the Stoics unless we first hear an account of your behavior in turning the universe upside down."

Lucius smiled: "Yes, my friend," he said, "only do not threaten us with the writ of heresy that Cleanthes used to think the Greeks should have served upon Aristarchus of Samos for shifting the hearth of the universe. For that great man attempted 'to save the phenomena' with his hypothesis that the heavens are stationary, while our earth moves round in an oblique orbit, at the same time whirling about her own axis. It's true we Academics have no views of our own, but tell me: How do those who assume that the moon is an earth turn things upside down any more than you do when you fix the earth where she is, suspended in mid air, a body considerably larger than the moon? At least mathematicians tell us so, calculating the magnitude of the obscuring body from what takes place in eclipses, and from the passages of the moon through the shadow. . . . Yet you have fears for the moon lest she should tumble, while as for our earth, Aeschylus [525–456 B.C.] has perhaps satisfied you that Atlas

> 'Stands, and the pillar which parts Heaven and Earth
> His shoulders prop, no load for arms t'embrace!'

Then you think that under the moon there circulates light air, quite inadequate to support a solid mass, while the earth, in Pindar's words, 'is compassed by pillars set on adamant.' And this is why for his part Pharnaces has no fear of the earth's falling. . . . Yet the moon does have something to prevent her from falling, the very speed and swing of her passage round, just as objects placed in slings are kept from falling by the whirl of their rotation. For everything is borne on in its own natural direction unless this is changed by some other force. Therefore, the moon is not drawn down by her weight, since that downward tendency is counteracted by her circular movement. There would perhaps be greater grounds for wonder if she were entirely at rest as the earth is. But as things are, the moon has a powerful cause that prevents her from being borne down upon us. The earth, by contrast, not having any movement, might naturally be moved by its own weight. It is heavier than the moon not merely in proportion to its greater bulk, but because the moon has been rarefied by heat and fire. It would actually seem that the moon, if she is a fire, needs earth all the more, as a solid substance to move about and to cling to, so feeding and sustaining the force of her flame. For it is impossible to conceive fire unless it is maintained with fuel. But you Stoics say that our earth stands firm without foundation or root."

"Of course," said Pharnaces, "it keeps its proper and natural place, as being the essential middle point, that place around which all weights press and bear, converging towards it from all sides. But all the upper region, even if it does receive an earth-like body thrown up with force, immediately thrusts it out hitherward, or rather lets it go, to be borne down by its own momentum."

In spite of both sides' accusations that their opponents are trying to turn the world upside down, all the participants in this dialogue hold a geocentric view. However, the Academics such as Lucius see the moon as essentially earth-like, and therefore solid and heavy. Their difficulty is thus how to account for the fact that the moon remains up *there. (Lucius invokes something that Huygens and Newton would later call centrifugal force.) By contrast, the Stoics see the moon as akin to the other planets and the stars, which are up there because they are composed of light material, air and especially fire. Their problem is accordingly to explain the evidence (such as eclipses and the new moon) that would indicate the moon has no light of its own.*

The other crucial physical disagreement to emerge from this discussion is about gravity. There is confusion as well as insight on both sides of the argument. The Stoics are Aristotelian in their explanation of gravity: Heavy things fall towards the center of the universe, and the earth lies at the center

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because it is the heaviest thing. The Academics display greater affinity with Newton or even Einstein: Bodies fall not towards a particular place but towards other bodies—and the greater the mass, the greater the gravity. Yet it is the Stoics' view that produces the most coherent description of how gravity actually behaves—for example how it would affect a body at, or passing through, the center of the earth. It is a description the Academics like Lamprias consider ridiculous:

I said, ". . . But philosophers must not be listened to, if they choose to meet paradoxes with paradoxes, and if, when contending against strange views, they invent views which are even more strange and wonderful. Here are these Stoics with their 'tendency towards the middle!' Is there any paradox which is not implicit there? That our earth, with all its depths and heights and inequalities, is a sphere? That there are people at our antipodes who live like timber-worms or lizards, their lower limbs turned uppermost as they plant them on earth? That we ourselves do not keep perpendicular as we move, but remain on the slant, swerving like drunkards? That masses of a thousand talents weight, borne through the depth of the earth, stop when they reach the middle point, though nothing meets or resists them; or, if mere momentum carry them down beyond the middle point, they wheel round and turn back of themselves? . . . This is to make

'Up down, down up, where Topsy-Turvy reigns,'

all from us to the center down, and all below the center becoming up in its turn! So that if someone, out of 'sympathy' with earth, were to stand with the central point of his own body touching the center, he would have his head up and his feet up too! . . .

"Such are the monstrous paradoxes which they bear on their backs and trail along behind them . . . nothing but a conjuror's stock-in-trade and show-booth. And then they call others triflers for placing the moon, which is an earth, up above, and not where the middle point is. Yet if every weighty body converges to the same point with all its parts, then the earth will claim the heavy objects not so much because she is middle of the whole, as because they are parts of herself. And the inclination of falling bodies provides evidence not of any property of earth as middle of the universe, but rather of a community and fellowship between earth and her own parts, once ejected but now drawn back to her. For as the sun draws into himself the parts of which he has been composed, so earth receives the stone as belonging to her, and draws it towards herself. . . . It is not proved that earth is the middle of the universe. Moreover, the way in which bodies here are collected and

drawn together towards the earth suggests how bodies which have fallen together onto the moon may reasonably be supposed to keep their place with respect to her."

The rejection of place *as explanation for gravity is part of an effort to replace an Aristotelian finite universe with one that is infinite. Yet this somehow remains a universe in which "up" and "down" are fundamental categories.*

"Look at the question broadly. In what sense is the earth 'middle,' and middle of what? For The Whole is infinite. Now the infinite has neither beginning nor limit, so it ought not to have a middle, for a middle is in a sense itself a limit, whereas infinity is a negation of limits. It is amusing to hear someone labor to prove that the earth is the middle of the universe, not of The Whole, forgetting that the universe itself is subject to the same difficulties; for The Whole, in its turn, left no middle for the universe. 'Hearthless and homeless' it is borne across an infinite void towards nothing which it can call its own. Or, if it finds some other cause for remaining, it stands still, but not because of the nature of the place. Much the same can be speculated concerning the earth and the moon: if the one stands here unshaken while the other moves, it is because of a difference of soul and of nature rather than of place. And in addition to all this, hasn't one other important point escaped them? If anything, however great, which is outside the center of the earth is 'up,' then no part of the universe is 'down.' Earth is 'up,' and so are the things on the earth. Absolutely all bodies lying or standing about the earth become 'up' and one thing only is 'down,' namely, that incorporeal point which of necessity must resist the pressure of the whole universe, if 'down' is naturally opposed to 'up.' Nor is this the only absurdity. [At the center] weights lose the cause of their downward tendency and motion, since there is no body below towards which they move. That the incorporeal should have so great a force as to direct all things towards itself, or hold them together about itself, is not probable."

The Academics, in keeping with their general Platonism, mistrust merely physical explanation and do not accept nature alone as a sufficient reason why things should be as they are. For them, order in the world is attributable not to nature but to the Good. Nature alone, as Hobbes pointed out in the seventeenth century in regard to political and social affairs, may produce nothing more than a war of each against all. Lamprias continues:

"Consider well, my friend, whether, when you shift all things about and remove each to its 'natural' place, you are not framing a system that will dissolve the universe, and introducing Empedoclean strife, or rather stirring up

the old Titans against Nature, in your eagerness to see once more the dreadful disorder and discord presented by the myth. All that is heavy in a place by itself, and all that is light in another,

> 'Where neither sun's bright face is separate seen,
> Nor Earth's rough brood, nor Ocean any more,'

as Empedocles says! Earth had nothing to do with heat, nor water with wind; nothing heavy was found above, nothing light below; without commixture, without affection were the elements of all things, mere units, each desiring no intercourse with each or partnership, performing their separate scornful motions in mutual flight and aversion, a state of things which must always be, as Plato teaches, where God is absent, the state of bodies deserted by intelligence and soul. So it was until the day when Providence brought Desire into Nature, and Friendship was engendered there, and Aphrodite and Eros, as Empedocles tells us and Parmenides too and Hesiod, so that things might change their places, and receive faculties from one another in turn, and, from being bound under stress, and forced, some to be in motion, some to rest, might all begin to give in to the Better, instead of the Natural, and shift their places and so produce harmony and communion of The Whole."

The picture of nature without government, especially without providential government, is akin to the pictures of chaos presented earlier not only by Plato but also by the Atomists, and centuries later by Milton:

> [a] wild Abyss,
> The womb of nature, and perhaps her grave,
> Of neither sea, nor shore, nor air, nor fire,
> But all these in their pregnant causes mixed
> Confusedly, and which thus must ever fight,
> Unless the Almighty Maker them ordain
> His dark materials to create more worlds.

Returning to the specific issue of the moon, including the question of how best to honor her, Lucius the Academic argues that to treat the moon as earth-like actually saves her from the embarrassment of being a rather shabby star. A millennium and a half before its confirmation by Galileo, Lucius thus presents a picture of an earth-like moon reflecting the sun's borrowed rays.

"Regarding the other stars, and the heavens in general, when you [Aristotelians] assert that they have a nature which is pure and transparent, and

removed from all changes caused by passion, and when you introduce a circle of eternal and never ending revolution, perhaps no one would want to contradict you, at least for the present, although there are countless difficulties. But when the theory comes down and touches the moon, the moon no longer retains the freedom from passion and the beauty of form the others possess. Quite apart from her other irregularities and points of difference, this very face which appears upon her must have been caused either by some passion peculiar to the moon herself or by admixture of some other substance. Indeed, mixture implies passion, since a body loses its own transparency when it is forcibly filled with something inferior to itself. Consider her own torpor and dullness of speed, and her faint ineffectual heat . . . : to what are we to attribute this except weakness in herself and affection, if affection can ever reside in an eternal and Olympian body?

"It comes down to this . . . : Look on her as earth, and she appears a very beautiful object, venerable and highly adorned. But as a star, or light, or any divine or heavenly body, I'm afraid she may be judged lacking in form and grace, and do no credit to her beautiful name, if out of all the multitude in heaven she alone goes round begging light of others, as Parmenides says,

'For ever peering toward the Sun's bright rays.'

Now when our friend, in his exposition, had explained the claim of Anaxagoras, that 'the sun places the brightness in the moon,' he was highly applauded. But . . . I will gladly pass on to the remaining points. It is probable, therefore, that the moon is illuminated not as glass or crystal by the sunlight shining in and through her, nor by way of accumulation of light and rays, as torches multiply their light. For then we should have full moon at the beginning of the month just as much as at the middle, if she does not conceal or block the sun but lets him pass through because of her rarity, or if he intermingles his rays with the light around her and helps to kindle it with his own. For we cannot say she bends or swerves aside, as when she is at half moon or when she is gibbous or crescent. Being then, as Democritus puts it, 'plumb opposite' to the body illuminating her, she receives and admits the sun, so that we should expect to see her shining herself and also allowing him to shine through her. But she is very far from doing this. At those times she is herself invisible, and she often hides him out of our sight. As Empedocles says,

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Wide as the compass of the glancing moon.'

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been caused either by some
ixture of some other sub-
body loses its own trans-
inferior to itself. Consider
int ineffectual heat . . . : to
herself and affection, if af-
body?
th, and she appears a very
it as a star, or light, or any
dged lacking in form and
out of all the multitude in
rs, as Parmenides says,

right rays.'

ned the claim of Anaxago-
' he was highly applauded.
s. It is probable, therefore,
by the sunlight shining in
light and rays, as torches
on at the beginning of the
t conceal or block the sun
if he intermingles his rays
h his own. For we cannot
half moon or when she is
it, 'plumb opposite' to the
un, so that we should ex-
to shine through her. But
herself invisible, and she
s,

ve for men
lice of earth
on.'

These words would suggest that the sun's light had fallen not upon another star but upon night and darkness. Empedocles also implies that the illumination which we get from the moon arises in some way from the reflection of the sun falling upon her. Hence her light reaches us without heat or lustre, whereas we should expect both heat and lustre if there were a kindling of the moon by the sun or an intermingling of lights. But as voices return an echo weaker than the original sound, and missiles which glance off strike with weaker impact,

'E'en so the ray which smote the moon's white orb'

reaches us in a feeble and exhausted stream, because the force is dissipated by reflection."

SOURCE: Adapted from Plutarch, *The Face Which Appears on the Orb of the Moon*, trans. A. O. Prickard, Winchester: Warren and Son, 1911.