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FOUR

EARTH FLOATS IN SPACE, SUSPENDED IN THE VOID

Many people today believe that in medieval Europe, the Earth was thought to be flat. According to this legend, when Christopher Columbus proposed to travel to China by sailing west, he was opposed by Spanish scholars who deemed his undertaking absurd because, in their view, he would fall off the edge of the Earth.

This legend is without substance. It is odd that it has endured in my country, Italy, where every schoolchild studies *The Divine Comedy*, a summa of medieval knowledge written two centuries before Columbus. In *The Divine Comedy*, Dante describes with great visual clarity an obviously spherical Earth. No one in medieval Europe believed the Earth to be flat. Saint Augustine, for example, argued that the existence of men living at the antipodes was impossible for reasons having to do with their relationship to Jesus Christ, but he did not challenge the idea that the Earth was spherical. At the very beginning of the *Summa Theologica*, Saint Thomas

Aquinas refers clearly to the Earth's spherical form.[1] There are almost no medieval texts that refer to a flat earth.*

In contrast, the objections raised by the scholars at the Spanish court to Columbus's plans were anything but unfounded. In the year 1400, the precise size of the Earth was known, with a margin of error of a few percent. It had been known since the third century BCE, when Eratosthenes, the director of the Great Library of Alexandria, measured it using a brilliant theoretical and observational technique. The Earth was too big to be circumnavigated without stopovers using the naval technology available in Columbus's day. Columbus tried to convince the Spanish court that the Earth was smaller than it really is, and that it was therefore possible to sail to China taking a western route without depending on known ports for food and water. In simple words, Columbus was wrong. Columbus died believing that the Earth was small and he had arrived in Asia. Of course, the twists of fate are unforeseeable, and Columbus's error determined the course of history (including, for instance, the extermination by Europeans of some 20 percent of humanity over the course of the following decades).

The belief that the Earth is a sphere was already established in Greece in Aristotle's time. Aristotle's writings

*There are rare exceptions: Lactantius in the fourth century CE, and Cosmas Indicopleustes in the sixth century CE. They were Christian authors who, in their zeal to categorically reject pagan thought, sought without success to return to the archaic idea of a flat Earth. According to Cosmas, the Earth is shaped like the Ark of the Covenant.

on the subject and the arguments he makes in support of the Earth's spherical form are correct and convincing to any person of good sense who takes the trouble to read and think through them. Should any doubts remain, the lucid first chapter of Ptolemy's *Almagest* offers complete and definitive clarity on the subject. Since shortly after Aristotle's time, no one in the West challenged the fact that the Earth is (more or less) spherical.

A generation earlier than Aristotle, the concept of a round Earth was already well known, but there was less clarity on the issue. Plato in the *Phaedo* has Socrates say that he maintains that the Earth is a sphere,[2] but he adds, "I myself should never be able to prove it." This passage in the *Phaedo* is the oldest direct evidence we have of the belief in a spherical Earth.

The conceptual clarity on this exquisitely scientific topic in the Greece of the fifth century BCE is impressive. Plato and Aristotle make a neat distinction between maintaining a point and possessing convincing scientific arguments in support of it. I think that the average educated European or American of today knows that the Earth is round, but is probably not able to offer direct and convincing proof of this belief. His level of scientific understanding, at least as far as this topic is concerned, lies somewhere between Plato's generation and Aristotle's.

There is another consideration that is perhaps interesting in this regard. The *Phaedo* is one of the most read, taught, and discussed texts in philosophy. But almost anyone who comments on it focuses solely on the soul's immortality and fails to notice that it contains this jewel of the history of science: the first written evidence we have of the new worldview, with a spherical Earth. This is glaring evidence of the abyss between the sciences and humanities in our time, each stupidly blind to the other.

Plato mentions that the Earth is round as if it was already a well-known idea. Where did the idea come from? It is sometimes attributed to Parmenides, but more often considered of Pythagorean origin, possibly going back to Pythagoras himself. Anaximander did not imagine the Earth to be round; instead, he refers to a more or less cylindrical shape, like that of a shallow drum or thick disk: "[Anaximander says that] the Earth is suspended in the void, supported by nothing, but stable because of its equal distance from everything. Its shape is rounded, like a column in stone. It has two surfaces, one made of the ground beneath us, and another opposite this."[3]

This cylindrical, disklike form may seem strange. I believe that one plausible explanation for it is as follows. Thales had taught that water was the origin of all things and imagined an immense ocean from which everything is born and upon which the Earth floats. Thales's Earth is a floating disk; its round shape follows the ancient idea that the emerged land forms a circle surrounded by sea. Anaximander's insight is that the ocean supporting the Earth isn't needed. Without the ocean, he is left with a disk floating in space.

Now, the point generally overlooked but of main importance for understanding Anaximander's achievement is the following. From a scientific perspective, the key step forward is not establishing whether the Earth is cylindrical or spherical; it is understanding that the Earth is a finite body that floats free in space. I examine this point in detail, because its significance can easily escape those who do not have direct experience in scientific research.

The Earth, in reality, is neither a cylinder nor a sphere. It is an ellipsoid slightly flattened at the poles. In truth, it isn't even an ellipsoid but rather a kind of pear, since the South Pole is more flattened than the North Pole. In fact, it is not pear-shaped either, because today we can detect additional irregularities. These progressive refinements in our understanding of the Earth's exact form are of interest to some, but in and of themselves they add nothing essential to our understanding of the world. The passage from Anaximander's cylinder to the sphere, ellipsoid, pear, and finally irregular form of today represents a progressive refinement in our knowledge of our planet's form, but it is not a conceptual revolution.

By contrast, understanding that the Earth is a stone that floats unsupported in space, with the same heaven underneath it as the one we see above—*this* is a huge step forward conceptually. And this is Anaximander's contribution.

Anaximander's cosmological model, with a cylindrical Earth, is often presented by scholars who lack a developed scientific training as primitive and uninteresting,[4] while the Pythagorean/Aristotelian model, with the spherical Earth, is presented as "scientifically correct." Both of these judgments reflect scientific illiteracy, for opposite reasons. First, as noted, the conceptual leap from a flat Earth to a finite Earth floating in space is immense and arduous. The fact that the Chinese Imperial Institute of Astronomy in two thousand years of existence failed to make this leap proves its difficulty. No other civilization made it either. By contrast, the conceptual leap from a cylindrical Earth to a round Earth is easy. The proof? It happened in only one generation. Second, as noted, the spherical model is by no means the "true" answer to the question of the Earth's shape. It is somewhat more precise than the cylindrical model and somewhat less precise than the ellipsoid model.

To Anaximander, then, without the slightest doubt, goes the full merit of the first great cosmological revolution.

But how was Anaximander able to understand that there is sky beneath the Earth?

A moment of reflection shows that there is plenty of evidence for this idea. Every evening, the Sun sets in the west; the next morning, it reappears in the east. How does it go from west to east during the night? Consider the North Star. On a clear summer night, we see all the other stars revolving slowly and majestically in the sky, while the North Star stays still, as a pivot. The stars closest to the North Star—the stars of the Little Bear, for example—revolve around it slowly and complete the circle in (approximately) twenty-four hours. They are always visible in the heavens (when we are not blinded by sunlight, that is). The stars a bit farther from the North Star complete a larger orbit in twenty-four hours, and the size of the orbit increases along with their distance from the North Star, until they seem to brush against the horizon to the north.

At times, a star seems to disappear behind a mountain and reappear slightly to the east a short time later (figure 12). Manifestly, it passes behind the mountain. And those farther from the North Star? They, too, seem to disappear behind something and then reappear. For them to be able to trace this route, there must be space *down there*. What of the stars on the celestial equator, far from the North Star, that are near the Sun's path in the sky? Doesn't one think immediately that they, too, disappear

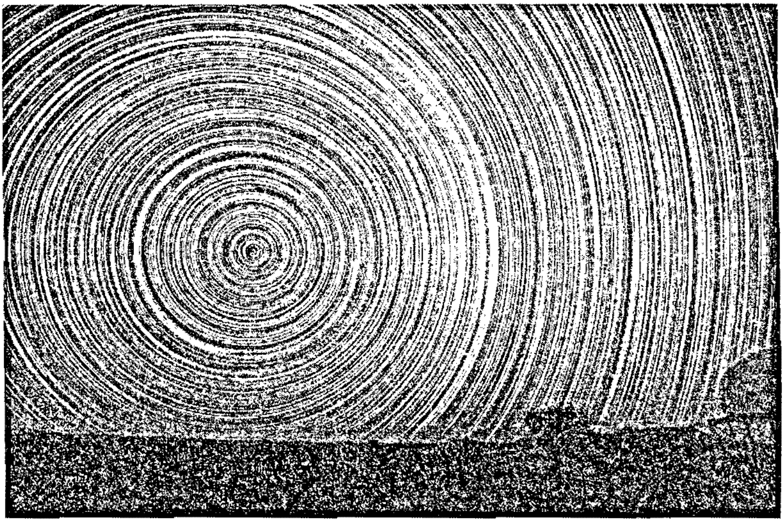

Figure 12. An extremely long-exposure photo of the night sky showing the movement of the stars over the course of the night around the North Star. The photo shows clearly that, beneath the horizon, there must be empty space in which the stars can complete their orbit.

behind the Earth and pass beneath it? And if they pass beneath the Earth, there must be empty space beneath the Earth!

Notice how the structure of this discovery resembles the discovery that rainwater comes from evaporation. In one case, water disappears from a bowl left out in the sunshine and appears falling from the sky. Intelligence connects disappearance with reappearance and identifies rainwater with evaporated water. In the other case, the Sun disappears in the west and reappears in the east; intelligence connects disappearance with reappearance and seeks the route connecting them: the empty space beneath the Earth. It is nothing more than the combination of curiosity with clarity of intelligence.

In grasping that there is a void beneath the Earth, indeed, Anaximander uses nothing more than the simple inference we make when we see a man disappear behind a house and reappear on the other side. How could that happen? There must be an open passage behind the house. Easy.

Easy? If it were really that easy, then why did generation after generation of human beings not come to the same conclusion? Why did so many civilizations go on believing that beneath the Earth there had to be more earth? Why did the Chinese, despite the splendor of their ancient civilization, not grasp this fact until the Jesuits arrived in the seventeenth century? Was the world outside of Miletus full of idiots? Certainly not. Why, then, was this point so difficult to grasp?

The difficulty derives from the fact that the idea that the Earth floats in space contradicts our fundamental experience of the world. In light of our experience, the notion is obviously absurd—unheard of—unbelievable.

First, we must accept that the world may not conform to our direct experience and to our long-held image of it, that things may be other than they seem and from the way everybody has always thought they are. We must let go of an image of the world that is familiar to us. What is needed to take this step is a civilization in which human beings are ready to call into question what everyone has always believed to be true.

Second, we must construct a credible and consistent alternative to the old image of the world. The fact that the Earth floats contradicts the rules that we know regulate the world: objects fall. If nothing were holding it up, the Earth would fall. If the Earth isn't supported by anything, why does it not fall?

Marking deductions from available evidence and supposing that there is nothing beneath the Earth was not the hard part. This idea may have come up in the history of Chinese astronomy and, very possibly, elsewhere. But in science it is not difficult to come up with ideas; it is difficult to come up with workable ideas, to find a way to compose and articulate new ideas as part of a whole that is consistent with the rest of our knowledge, and to convince others that the entire process is reasonable. What is difficult is to have the courage and intelligence to conceive and articulate a new, coherent, overarching image of the world.* It was difficult to reconcile the idea of the Earth suspended in the sky, which accounts neatly for the daily movement of the stars, with the obvious, experiential fact that any heavy object falls.

The genius of Anaximander is that he takes on the question, Why, then, does the Earth not fall? Aristotle relays his answer in *De Caelo* (*On the Heavens*). In my

*Like many scientists, I have drawers and files filled with mail from people who write to me with new scientific ideas, original and daring, but useless. Ideas can come and go many times, but an idea on its own is useless. In the third century BCE, Aristarchus considered the possibility that the Earth rotated on its own axis and around the Sun. In light of the Copernican revolution, his idea was correct. Still, Copernicus and not Aristarchus deserves the credit for this revolution, because it was Copernicus who showed how this idea might work and how it could be integrated with the rest of our knowledge; he set in motion the process that eventually persuaded the rest of the world. It is easy to have ideas; it is difficult to pick out good ideas and find the arguments to show that they are "better" than current notions. Who knows how many human beings had imagined that the Sun passed beneath the Earth without, however, being able to change humanity's worldview.

opinion, this is one of the most beautiful moments in the history of scientific thinking: the Earth does not fall because there is no particular reason for it to fall. In the words of Aristotle:

> There are some, Anaximander, for instance, among the ancients, who say that the earth keeps its place because of its indifference. Motion upward and downward and sideways were all, they thought, equally inappropriate to that which is set at the centre and indifferently related to every extreme point; and to move in contrary directions at the same time was impossible: so it must needs remain still. This view is ingenious.[5]

The argument is extraordinary and perfectly correct. Aristotle sees this: he does not credit many to be "ingenious." What, precisely, is the argument? It consists in overturning the question, Why doesn't the Earth fall?, transforming it into, "Why should the Earth fall?" The genius of Anaximander, in modern words, is to question the extrapolation from the objects of our experience to the Earth itself, of the observed universality of falling. More precisely, to take the observational evidence from the motion of the Heavens as an argument against the legitimacy of this extrapolation. This is science at its best. The point is even clearer if we read Hippolytus, whom we can translate as, "The Earth is aloft, not dominated by anything; it remains in place because of the similar distance from all points."[6]

In our everyday life, heavy objects fall, but they are in the vicinity of an immense body—the Earth—that "dominates" them and determines a preferred direction: toward the Earth. But Earth does not have any particular direction in which to fall because nothing "dominates" it. Objects do not fall in the direction of an absolute "down," a single direction that is the same

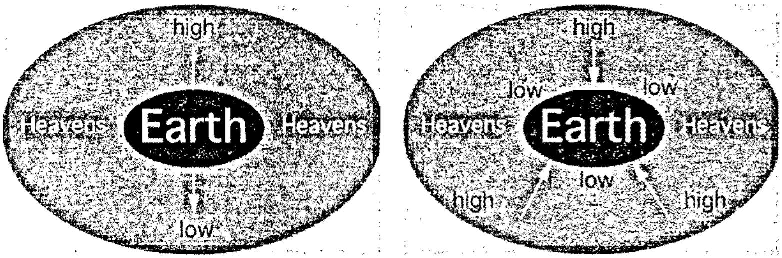

Figure 13: Anaximander's basic insight: the universe does not resemble the image on the left, and there is no privileged direction (here called "high-low") that determines how things fall. The figure on the right is a hypothetical illustration of the idea that an object's fall is determined by the presence of something that "dominates" it (the Earth), which determines a privileged direction (toward the Earth). We do not know if Anaximander could have drawn a figure like this, and the shape of the Earth in these drawings does not necessarily reflect that imagined by Anaximander.

throughout the universe; objects fall toward the Earth if they are on the Earth's surface.[7]

Notice, then, that the very meanings of "up" and "down" become ambiguous. We can continue to say that objects fall "down," however "down" no longer indicates an absolute direction in the cosmos (see figure 13).[8] Another text by Hippolytus is explicit on the matter: "For those standing on their own two feet down below (at the antipodes), high things are low, while low things are high . . . and so it is all over the Earth."[9]

The concepts of "high" and "low," or "up" and "down," structure our direct experience of the world and form the basis of our mental organization of the physical world. In the new world posited by Anaximander, the meaning of these concepts changes in depth. In bringing about his revolution, Anaximander has to understand that the notions of "up" and "down" required to make sense of the universe and to determine the direction of falling differ from those of our everyday experience. "Up" and "down," as commonly understood, do not constitute an absolute and universal structure of the physical world or a preexisting structure of space. "Up" and "down" are not absolute: they do not apply to the Earth itself.*

The deep change in perspective on the cosmos engineered by Anaximander has much in common with other great scientific revolutions. The step forward he took is similar to the one Galileo took that led to the triumph of the Copernican revolution. Does the Earth move? How could it move, when it seems evident that it stands still? No—Galileo understands, completing the Copernican revolution—absolute motion and stasis do not exist. Objects resting on the Earth are immobile with respect to one another, but this does not mean that, as a group, they cannot be in motion within the solar system. The concepts of "stasis" and "motion" are much more complex than our everyday experience indicates. Similarly, with his theory of special relativity, Einstein understands that the idea of simultaneity—of "now"—is not absolute either, but instead relative to the observer's state of motion.

The difficulty in understanding the complexity of the notion of simultaneity in Einstein's theory is very much

*This does not imply that Anaximander believed that the Earth is the cause of the fall (as in Newton), nor that the position of the Earth is caused by the radial direction of the fall of heavy objects (as in Aristotle). Anaximander, like Copernicus, might have had no dynamical theory of falling at all.[10] Aristotle, indeed, criticizes Anaximander precisely for this: for failing to see what Aristotle considers his own great insight into the problem, which is not the older idea that things fall toward the Earth, but the beautiful idea that the Earth is at the center of the universe because of the natural tendency of heavy objects to fall toward the center—a natural tendency introduced by Aristotle.

analogous to the difficulty in understanding the notions of "up" and "down" in Anaximander's new cosmological theory. If the relativity of "up" and "down" nowadays seems fairly easy to understand, while the relativity of simultaneity is still harder to grasp for those who are not professionals physicists, this is only because Anaximander's theory and its developments have been digested for twenty-six hundred years, while Einstein's is not yet widely assimilated. But we are dealing with the same conceptual path. The difference is that Einstein based his work on observations already fully codified in Maxwell's theories and the mechanics of Galileo and Newton, while Anaximander based his only on the observation of the rising and setting of the stars.

Anaximander's greatness lies in the fact that on the basis of so little, in order to better account for his observations, he redesigns the universe. He changes the very grammar of our understanding of the universe. He modifies the very structure of our conception of space.

For centuries, human beings had understood space as intrinsically structured in the direction toward which objects fell. No, says Anaximander: the world is not as it seems to us. The world is different from how it appears. Our perspective on the world is limited by the smallness of our experience. Reason and observation allow us to understand that our prejudices about the world's functioning are mistaken. Space does not have a privileged direction toward which objects fall. For the Earth itself, there is no "down" toward which it might fall.

This is a dizzying conceptual tour de force—and it is correct. Once a coherent conception of the world has been formulated in which objects fall not toward an absolute "down" but toward the Earth, there is no longer any reason for the Earth itself to fall. The focal point of Anaximander's argument, conveyed by the texts that have come down to us, is that the expectation that the Earth must fall is based on an unjustified extrapolation.*

Intelligence, used well and in conjunction with observation, frees us from an illusion, from a limited and partial view of the world. It remakes our understanding of the world in a new form. This form is more effective. To be sure, it can be improved: going forward, humans will have to learn that the Earth is not a drum but a sphere; that it is not really a sphere; that it is not at rest but in perpetual motion; that the Earth attracts other bodies; that all bodies, in fact, attract each other; that this attraction is the very curvature of space-time, etc. Each of these steps will take centuries, but the process has begun. It has been set in motion by a first great step, one that overturns a conception of the world common to all civilizations and brings forth the conception of a spherical world, surrounded by the sky, the distinctive mark of Greek civilization and of all civilizations, like our own, who are heirs to the Greeks.

There is another important novelty in Anaximander's cosmology, emphasized by Dirk Couprie. The heavenly vault had always been seen as the upper enclosure of the world. Humanity had seen Sun, Moon, and stars as enti-

*This exquisitely scientific argument can be hard for philosophers and historians to grasp. One reads, for example, that "we must wait for Newton to have the correct answer to the question of why the Earth does not fall." This is utter silliness. Why is Newton's answer the right one? Simply because it is the one that we learned at school, given that Kepler was no longer in fashion and Einstein was not yet taught at our school? There is no sense in which the problem of why the Earth does not fall was solved better by Newton than by Anaximander, Aristotle, Copernicus, or Einstein. Each one of these names represents a step toward a more powerful conceptualization of the world.

ties that traveled along the celestial vault itself—the ceiling of the world—all at the same distance from us. Anaximander, observing the heavens, for the first time did not see a vault, but instead an open space in which heavenly bodies were at various distances from us. The numbers that he proposes for the spokes of the wheels of Sun, Moon, and stars matter less for their specific values than for suggesting the possibility that these numbers may mean something. The step is from the world seen as the inside of a box to the world immersed in an open, external space.* As Couprie says, Anaximander in some way invents the open space of the cosmos.[11] The ramifications of this conceptual innovation are immense.

In the history of science, perhaps the only other example of a conceptual revolution comparable in greatness to Anaximander's is the Copernican revolution, opened by the publication of Copernicus's treatise in 1543.† Like Anaximander, Copernicus rethinks the map of the cosmos. In place of a cosmos made up of the Heavens above and the Earth below, Anaximander puts forth an open cosmos where the Earth floats, surrounded by the heav-

*Couprie asked me whether I, as a physicist, can understand the logic that led Anaximander to infer that the Sun, Moon, and stars were located at different distances from Earth. The only answer I can come up with is that if they were the same distance away, the wheels that carry the various celestial bodies (required to account for the fact that they don't fall) would pass one through the other, which does not make sense.

†The title of Copernicus's book is *De revolutionibus orbium cœlestium*, or "On the Revolutions of the Celestial Bodies," where "revolution" means the circular motion of the planets in the sky. Because Copernicus's book embodies the greatest scientific upheaval, it is hard to resist the idea that the word "revolution" acquired its meaning of "major upheaval" under the influence of the book itself, even if, according to some etymological dictionaries, the use of the word in the sense of "instance of great change in affairs" is recorded from the mid-fifteenth century, a bit before Copernicus's book.

ens. Copernicus moves this floating Earth from the center of the cosmos to an orbit around the Sun. As was the case with Anaximander, the Copernican revolution paved the way for immense scientific developments that would occur over the course of the following few centuries.

There were other similarities. Copernicus studied in Italy—a land of political disunity, trade, and openness to the rest of the world. He was nourished by the rich, vibrant cultural ferment of the early Renaissance. Anaximander emerged from the new cultural climate of young Greek civilization, similar in many respects to the Italian Renaissance.

But again, Copernicus based his theories on the vast technical and conceptual work accomplished by the Alexandrian and Arab astronomers. Anaximander's work was based on nothing more than the first questions and the first imprecise speculations of Thales, and on what he had observed with his own eyes—nothing more. On this slight basis, Anaximander achieved what I think must be deemed the first and greatest of all scientific revolutions: the discovery that the Earth floats in an open space.

I close this chapter with two quotations; the first is from Charles Kahn: "Even if we knew nothing else concerning its author, [Anaximander's theory on the Earth's position] alone would guarantee him a place among the creators of a rational science of the natural world."[12] The second is from Karl Popper, among the greatest philosophers of science of the twentieth century: "In my opinion this idea of Anaximander's [that the Earth is suspended in space] is one of the boldest, most revolutionary, and most portentous ideas in the whole history of human thinking."[13]