the Book of the Cosmos

Imagining the Universe from Heraclitus to Hawking

A Helix Anthology

edited by
Dennis Richard Danielson

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Neither Known Nor Observed by Anyone Before

Galileo Galilei

In 1898 Agnes Clerke wrote:

No one could at first have divined the momentous character of the accident by which Hans Lippershey, a spectacle-maker at Middleburg in Holland, hit upon an arrangement of lenses serving virtually to abridge distance. It happened in 1608; and Galileo Galilei (1564–1642), hearing of it shortly afterwards at Venice, prepared on the hint a "glazed optic tube," and viewed with it, early in 1610, the satellites of Jupiter, the mountains of the moon, the star-streams of the Milky Way, and in 1611, the phases of Venus, the spots on the sun, and the strange appendages of Saturn. Thus, amid a tumult of applause, the telescopic revelation of the heavens began.

It does not diminish Galileo's accomplishment—though perhaps it enhances our sense of his humanity—that he in fact openly invited the applause, especially from the box seat occupied by the Grand-Duke of Tuscany, Cosimo de' Medici II, to whom he dedicated his 1610 pamphlet, Sidereus Nuncius (The Starry Messenger), *and after whom he christened the four moons of Jupiter "the Medicean Stars." Galileo begins the text of his potent little work with a blurb summarizing, excitedly but truly without exaggeration, the astonishing list of discoveries he is about to unfold.*

In the present small treatise I set forth some matters of great interest for all observers of Nature to look at and consider. They are of great interest, I think, first, from their intrinsic excellence; secondly, from their utter novelty;

and lastly, also on account of the instrument by whose aid they have been presented to my sight.

To this day the fixed stars which observers have been able to view without artificial powers of sight can be counted. Therefore it is certainly a great thing to add to their number and to expose to our view myriads of other stars never seen before and outnumbering the old, previously known stars more than ten to one.

Again, it is a most beautiful and delightful thing to behold the body of the moon—which is actually distant from us nearly sixty semidiameters of the earth—as if it were only two such semidiameters distant from us; so that the diameter of the same moon appears about thirty times larger, its surface about nine hundred times, and its solid mass nearly 27,000 times larger than when it is viewed only with the naked eye. Consequently, anyone may know with palpable certainty that the surface of the moon really is not smooth and polished but instead rough, uneven and, just like the face of the earth itself, everywhere full of vast protuberances, deep chasms, and sinuosities.

Then to have got rid of disputes about the galaxy or Milky Way, and to have made its nature clear to the very senses, not to say to the understanding—this too would seem a matter of no small importance. In addition to this, to trace out with one's finger the nature of those stars which all astronomers until now have called *nebulous*, and to demonstrate that it is very different from what has hitherto been believed—this also will be thrilling and beautiful. But what is most exciting and astonishing by far, and what particularly moved me to address myself to all astronomers and philosophers, is this: I have discovered four planets, neither known nor observed by anyone before my time.

Maintaining his almost conversational narrative style, Galileo recounts his construction of a telescope, as Clerke says, from a hint; and he carries on to describe, step by step, his observations of the surface of the moon. What he sees, amazingly, is phenomena that are conspicuously earth-like.

About ten months ago a rumor reached my ears that a certain Dutchman had constructed a telescope, by means of which visible objects, although at a great distance from the eye of the observer, were seen distinctly as if nearby. Testimonies concerning its amazing powers were reported, but some believed these and others denied them. A few days later I received confirmation of the report in a letter written from Paris by a noble Frenchman, Jacques Badovere. This finally caused me to devote myself first to working out the principle of the telescope, and then to considering how I might achieve the invention of a similar instrument, which in a short while I succeeded in doing

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through a study of the theory of refraction. At first I prepared a tube of lead into whose ends I fitted two glass lenses, both plane on one side, but on the other side one spherically convex, and the other concave. Then bringing my eye to the concave lens I saw objects gratifyingly large and near. In fact they appeared one-third as distant and nine times as large as when seen with the natural eye alone. I shortly afterwards constructed another, superior telescope, which magnified objects more than sixty times. Finally, by sparing neither labor nor expense, I succeeded in constructing for myself such an excellent instrument that it rendered objects seen through it nearly a thousand times larger and more than thirty times nearer than they appeared when viewed by unaided natural powers of sight.

It would be a complete waste of time to list here the many great advantages this instrument will afford when used by land or sea. But leaving earthly things behind, I devoted myself to observing the heavens. First of all, I viewed the moon as if it were distant scarcely two semidiameters of the earth. And afterwards I frequently observed other heavenly bodies, both fixed stars and planets, with incredible delight. . . .

Now let me review my observations during the two months just past, again calling upon all who love true philosophy to undertake the contemplation of truly great things.

Let me speak first of the surface of the moon turned towards us, which for the sake of clarity I divide into two parts, the brighter and the darker. The brighter part seems to surround and pervade the whole hemisphere; but the darker part, like a sort of cloud, discolors the moon's surface and makes it appear covered with spots. Now these spots, as they are somewhat dark and fairly large, are plain to everyone, and every age has seen them. Accordingly I shall call them *great* or *ancient* spots, to distinguish them from other spots, smaller in size, but so thickly scattered that they sprinkle the whole surface of the moon, especially the brighter portion of it. These spots have never been observed by anyone before me; and from my repeated observations I have arrived at the following conclusion: that we undoubtedly do not perceive the surface of the moon to be perfectly smooth, free from inequalities and exactly spherical (as a large school of philosophers believes concerning both the moon and other heavenly bodies), but on the contrary to be full of inequalities, uneven, full of hollows and protuberances. It is like the surface of the earth itself, which is everywhere varied with lofty mountains and deep valleys. The appearances from which we may derive these conclusions are as follows.

On the fourth or fifth day after new moon, when the moon presents herself to us with bright horns, the boundary which divides the part in shadow from the enlightened part does not appear as a consistent curve, as it would on a perfectly spherical body, but traces an irregular, uneven, and very wavy line. . . . Several bright excrescences, so to speak, extend beyond the boundary of light and shadow into the dark part, and on the other hand bits of shadow encroach upon the light. Indeed, quite a lot of small blackish spots, quite separated from the dark part, are sprinkled across almost the entire area now otherwise flooded with sunlight, except only for the region of those great and ancient spots. I noticed that the small spots just mentioned consistently display this characteristic: they always have the dark part towards the sun, while on the side away from the sun they have brighter boundaries like shining ridges. Indeed on earth about sunrise we have a very similar phenomenon: we behold the valleys not yet flooded with light while the mountains surrounding them on the side opposite to the sun are already ablaze with the splendor of his beams. And just as the shadows in the hollows of the earth diminish in size as the sun rises higher, so also these spots on the moon lose their blackness as the illuminated part grows larger and larger. Again, not only are the boundaries of light and shadow in the moon seen to be uneven and sinuous, but—even more astoundingly—there appear many bright points within the darkened portion of the moon quite divided and broken off from the illuminated region and located no small distance away. Gradually, as time passes, these grow larger and brighter, and after an hour or two are joined on to the rest of the bright part, which is now somewhat larger. In the meantime others within the shaded part, one here and another there, sprout up and are ignited, increase in size, and at last are joined up with the rest of the luminous surface, which has now spread even further. . . .

And is it not the case on earth before sunrise, that while the level plain is still in shadow, the peaks of the most lofty mountains are illuminated by the sun's rays? Then, a little later, does not the light spread further, while the middle and larger parts of those mountains are gradually illuminated; and finally, when the sun has risen, do not the illuminated parts of the plains and hills join together? The grandeur, however, of such prominences and depressions in the moon seems to surpass both in magnitude and extent the ruggedness of the earth's surface, as I hope to demonstrate later. However, let me mention here what a remarkable spectacle I observed while the moon was rapidly approaching her first quarter. . . . A large bulge of the shadow protruded into the illuminated part near the lower horn of the crescent. As I studied this indentation longer, I observed that it was dark throughout. Finally, after about two hours, a bright peak began to arise a little below the middle of the depression. This gradually increased and formed a triangular shape but was still quite detached and separate from the illuminated surface. Soon, three other small bright points emerged round about it, until, when the moon was just about to set, that triangular shape, having now extended and

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Galileo's observations of the play of light upon the surface of the moon reveal not only a great deal about the nature of that surface but also something of the reciprocal relationship between moon and earth. The importance of this finding can hardly be overstated for a world previously thought to be qualitatively set apart—virtually quarantined—within the "sublunary sphere." As expounded by Thomas Edgerton in the next chapter, Galileo's demonstration of "earthshine" established that heavenly influence could be a two-way street. Galileo states explicitly that he introduces the discussion of earthshine "chiefly in order that the connection and resemblance between the moon and the earth may appear more plainly." Poetically and tellingly, he describes the phenomenon as constituting a kind of commerce.

The earth, with fair and grateful exchange, pays back to the moon an illumination like that which it receives from the moon nearly the whole time during the darkest gloom of night. Let me explain the matter more clearly. At new moon, when the moon occupies a position between the sun and the earth, the moon is illuminated by the sun's rays on the hemisphere facing the sun but turned away from the earth. The other hemisphere, which faces the earth, is covered with darkness and thus in no way illumines the earth's surface. As the moon slightly recedes from the sun, she is at once partly illumined on the half facing us. She turns towards us a slender silvery crescent, and slightly illumines the earth. The sun's illumination increases upon the moon as she approaches her first quarter, and the reflection of that light increases on the earth. The brightness in the moon then extends beyond the semicircle, and our nights grow brighter. Finally, the entire surface of the moon facing the earth is irradiated with the most intense brightness by the sun. This happens when the sun and moon are on opposite sides of the earth, and far and wide the surface of the earth shines with the flood of moonlight. Afterward, when the moon is waning, it sends out less powerful beams and so the earth is illumined less powerfully. Finally, the moon draws near her first position of conjunction with the sun and again black night invades the earth.

Thus in its cycle each month, the moon gives us alternations of brighter and fainter illumination. But the benefit of her light to the earth is balanced and repaid by the benefit of the light of the earth to her. For while the moon approaches the sun about the time of the new moon, she has in front of her the entire surface of that hemisphere of the earth which is exposed to the sun and vividly illumined with his beams, and so receives light reflected from the earth. Because of this reflection, the hemisphere of the moon nearer to us, though deprived of sunlight, appears of considerable brightness. When the moon is removed from the sun through a quadrant, she sees only one half of the earth's hemisphere illuminated, namely, the western half, for the other, the eastern, is covered with the shades of night. The moon is therefore less brightly enlightened by the earth, and accordingly that secondary light appears fainter to us. But if you imagine the moon to be positioned on the opposite side of the earth to the sun, she will see the hemisphere of the earth, now between the moon and the sun, quite dark, and steeped in the gloom of night. If, therefore, while the moon is in this position an eclipse should occur, she will receive no light at all, being altogether deprived of the illumination of the sun or earth. In any other position with respect to the earth and the sun, the moon receives more or less light by reflection from the earth in proportion to how much or how little of the earthly hemisphere illuminated by the sun she beholds. This is the law observed between these two orbs: whenever the earth is most brightly enlightened by the moon, that is when the moon is least enlightened by the earth, and vice versa.

That is all I need say for now on this subject, which I will consider more fully in my *System of the Universe*, where many arguments and experimental proofs will be provided to demonstrate a very strong reflection of the sun's light from the earth—this for the benefit of those who assert, principally on the grounds that it has neither motion nor light, that the earth must be excluded from the dance of the stars. For I will prove that the earth does have motion, that it surpasses the moon in brightness, and that it is not the sump where the universe's filth and ephemera collect.

This last paragraph is highly instructive in view of the persistent myth that ancient and medieval geocentrism placed the earth and humankind in a position of supreme importance in the universe. Galileo's comment indicates exactly the contrary: that the center, as a place where heavy, gross things settle, was seen as a place of disrepute. There is much evidence in the writings of Galileo and of Kepler (see Chapter 26) that their version of heliocentrism was in fact motivated by a desire to reconstruct the place of humankind as a position of prominence within the universe.

Galileo next moves from the moon to the stars; indeed, at a stroke he lays stellar astronomy's observational foundation and takes the first steps towards answers to some of its central questions: the nature and number of the stars, the nature of the Milky Way, and the composition of nebulae.

In what follows it is useful to remember that stellar magnitude, though often used loosely as a unit of apparent stellar size, is technically a measure of *brightness, and that the smaller the number, the brighter the star. Thus first magnitude is brightest, down to sixth magnitude, which is the dimmest degree of brightness visible to the naked eye. Galileo extends this scale further downwards.*

Now I will briefly announce the phenomena which I have observed so far concerning fixed stars. First, it is worth noting the following: the stars, fixed as well as erratic [i.e., the planets], when seen through a telescope, do not appear enlarged in the same proportion as are other objects, including the moon. On the contrary, the stars appear much less magnified. Accordingly, if for example a telescope magnifies other objects a hundred times, you will find it magnifies the stars scarcely four or five times. But the reason for this is that, when stars are viewed with natural sight they do not, as regards their size, present themselves to us so to speak naked and unadorned but radiant with a certain splendor and fringed with a sparkling aura, especially as night wears on. Thus they seem much larger than they would if stripped of these inessential fringes, for apparent size within one's field of vision is determined not by the actual body of a star but by the luster with which it is circumfused.

Perhaps you will grasp this most readily from a well-known phenomenon: stars emerging at sunset in the first coming on of twilight, even stars of the first magnitude, appear very small. Indeed, even Venus, whenever she is visible in broad daylight, seems so small as scarcely to equal a little star of the least magnitude. It is different for other objects, including the moon, which always appears the same size whether viewed in noonday brightness or in darkest night. Thus stars seen at midnight in uncurtailed glory can be shorn of their fringes by the light of day—indeed not only by the light but also by any little cloud which comes between a star and the eye of an observer. A dark veil or colored glass has the same effect: placed between eye and object, these banish from the stars their radiant halos. And a telescope does the same thing, removing from the stars their inessential and extraneous splendors but then enlarging their actual spheres (if this is truly their shape). The result is that the stars seem proportionately less magnified than other objects, with one of the fifth or sixth magnitude appearing through a telescope merely like one of first magnitude. . . .

But below stars of the sixth magnitude you will see through the telescope a host of other stars that escape natural sight—so many that it is almost unbelievable—more than six other degrees of magnitude, and the largest of them, which we can call seventh magnitude stars, or first magnitude invisible stars, appearing through the telescope larger and brighter than second magnitude stars seen with the naked eye. . . .

The next thing I observed is the essence, or substance, of the Milky Way. With a telescope this can be perceived so palpably that all the disputes that have tormented philosophers for so many centuries are quashed by sheer ocular proof, and we are released from all those wordy arguments. For the galaxy is nothing else but a mass of innumerable stars planted together in clusters. Point your telescope in any direction within the galaxy and at once a great mass of stars comes into view. Of these, many are fairly large and robustly conspicuous, but the number of small ones is utterly unfathomable.

Now this milky brightness, like that of whitish clouds, is seen not only in the Milky Way; several disks of a similar color shine faintly here and there throughout the ether. Turn your telescope upon any one of them and what you will discover is a cluster of stars packed close together. Furthermore—and even more amazingly—the stars which absolutely all astronomers until now have called *nebulous* are swarms of small stars astonishingly packed together. Although on account of smallness or immense distance from us each such star eludes our sight, nevertheless from the commingling of their rays there arises that brightness which until now was thought to be the denser part of the heavens capable of reflecting rays from the stars or the sun.

Although at a stroke Galileo had changed forever how human beings would view the moon, the stars, and the galaxy, he had still to serve up what he regarded his pièce de résistance: the discovery of the moons of Jupiter, "the Medicean Stars."

I have yet to present what I consider most important in this undertaking, namely the announcement and exposition of my discovery and observation of four *planets* never seen from the beginning of the world to the present age, together with their positions and the notes I have made on them over the past two months. . . .

On January 7th of this year, 1610, in the first hour after midnight, while I was viewing the celestial constellations through a telescope, Jupiter appeared before my sight. Because I had made for myself an exceptional instrument, I noticed . . . that three little stars, small but very bright, were near the planet. Although I believed them to belong to the number of the fixed stars, they did make me wonder, for they seemed arranged exactly in a straight line parallel to the ecliptic. They were brighter than other stars of the same size. And their positions relative to one another and to Jupiter was as follows:

On the east side there were two stars, and a single one towards the west. The star which was furthest towards the east, and the western star, appeared rather larger than the third.

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I was not at all bothered about the distance between them and Jupiter, for as already mentioned I started out thinking they were fixed stars. However, when on January 8th I returned to the same observation, led by I know not what fate, I discovered a very different state of affairs: three little stars all of them west of Jupiter, nearer together than on the previous night, and spaced at equal intervals. . . .

At this point, although I had not given any thought to the mutual configuration of these stars, yet it piqued my curiosity how Jupiter could one day appear to the east of all those fixed stars when the day before it had been to the west of two of them. And I started to worry that perhaps the planet, violating the predictions of astronomers, passed those stars by means of its own motion. Therefore I waited for the next night with intense longing, but my hopes were frustrated, for the sky was covered with clouds in every direction.

But on January 10th the stars appeared in the following position relative to Jupiter: there were only two, both of them on the east side of Jupiter, with the third, I thought, hidden behind. As before, they were exactly in the same straight line with Jupiter and along the Zodiac.

Given these observations, and knowing that such changes of position could not be explained by reference to Jupiter—and also recognizing that the stars I saw were consistently the same ones, for there were no others in Jupiter's path in front or behind for a great distance in the Zodiac—finally moving from doubt to amazement, I saw that the change of positions was attributable not to Jupiter but to those stars. And therefore I reckoned they had better be observed more accurately and attentively.

Thus on January 11th I saw an arrangement as follows: only two stars to the east of Jupiter, the nearer of which was three times as far from the planet as from the star that stood further to the east. And the star furthest to the east was nearly twice as large as the other one, whereas on the previous night they had appeared nearly the same size. I therefore concluded beyond doubt that there are three stars in the heavens circling about Jupiter as do Venus and Mercury around the sun. Afterwards, many subsequent observations showed the same thing as plain as day, and also that there are not only three, but four wandering stars performing revolutions around Jupiter.

Galileo's discovery, as he well knew, was no mere curiosity, and certainly more than just an opportunity for an ambitious but struggling academic approaching middle age to flatter the equivalent of his granting agency, the Medici family. Its greatest significance as far as cosmology is concerned was that it observationally confirmed what seemed one of the most incredible tenets of Copernicanism: in Copernicus's words, that "there is more than one center." In short, it demonstrated an orbit upon an orbit. In Galileo's words, *"No one can doubt that [the Medicean stars] make their revolutions about [Jupiter] while at the same time together completing twelve-year orbits about the center of the universe."*

Besides, we have a notable and splendid argument with which to remove the scruples of people who serenely tolerate the revolution of the planets round the sun in the Copernican system, yet are so perturbed by the motion of one moon about the earth while the two together accomplish an annual orbit about the sun that they think this theory of the universe's constitution must be rejected as impossible. For now we have not just one planet revolving about another while both traverse a vast orbit about the sun, but we actually see four satellites circling about Jupiter, like the moon about the earth, while the whole system makes a great orbital journey about the sun.

So long as it is not read as diminishing the immense beauty and wonder of Galileo's achievement, Agnes Clerke's comment remains a worthy if incomplete assessment: "The problem of the heavens, stripped . . . of metaphysical obscurities, was laid bare to the reason as one of pure mechanics: The planets came to be treated as ordinary projectiles, and distinct reasoning about the nature of their paths was rendered possible. Newton's great task was thus prepared and defined by Galileo."

SOURCES: Galileo Galilei, *Sidereus Nuncius*, Venice, 1610; translation adapted from *The Sidereal Messenger of Galileo Galilei*, trans. E. S. Carlos, London, 1880; Agnes M. Clerke et al., *The Concise Knowledge Astronomy*, London, 1898.

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Galileo and the Geometrization of Astronomical Space

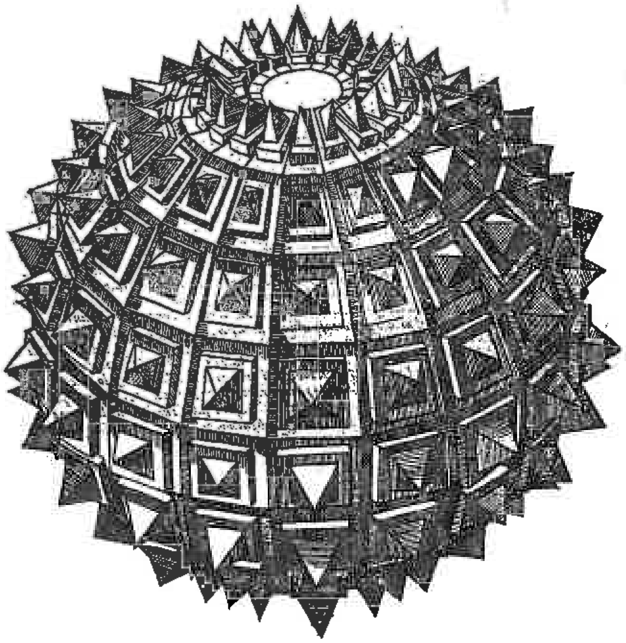
Samuel Edgerton

While no one doubts that science influences art, historian Samuel Edgerton (b. 1926) presents a complementary picture of Galileo and late Renaissance Italy in which influence flows the other way—in which a particular technique of painting provides the foundation for a monumental advance in astronomical knowledge.

Everyone knows about Galileo's extraordinary contributions to astronomy—his discoveries, for instance, of the earthlike topography of the moon, the moonlike phases of Venus, and the four satellites of Jupiter—but few historians, even modern Galileo scholars, have paid serious heed to the famous Florentine's interest in the fine arts. As his contemporaries often remarked, he knew something of painting and was particularly skilled in the specialized Florentine practice of *disegno*. This activity was much more than just a casual pastime for Galileo. It contributed crucially to at least one of his revolutionary astronomical discoveries: the true physical appearance of the surface of the moon. . . .

By the sixteenth century the study of linear perspective in general and of chiaroscuro in particular appealed not only to artists but even more to professional scholars, especially in Italy and Germany, who otherwise had no interest in the visual arts. Highly technical perspective books were published with this audience in mind.

Edgerton summarizes the published material on perspective available to Galileo and provides examples of drawings from, for example, Daniel



Barbaro's Pratica della perspettiva *(1568), which includes the illustration shown above.*

In sum, how could Galileo, lover of geometry and living in the most competitive art center of western Europe, have missed these chiaroscuro spheroid exercises that so challenged the mind's eye?

Let us for a moment take leave of Florence and look in on Jacobean London during the summer of 1609, where we find Galileo's scientific contemporary Thomas Harriot (1560–1621) turning his attention from mapping the Virginia colonies . . . to a study of the moon; in fact, observing it through a six-power telescope that he managed to procure from its Flemish inventors. Oddly, Harriot's primacy in this matter, preceding Galileo as he did by some six months, goes unmentioned in most modern astronomy textbooks. Harriot even made an extant drawing of the moon as seen through his "perspective tube" (as the English called the new device). Unfortunately, he added no explanation save the Julian date and time of his observation: "1609, July 26, hor. 9 p.m." . . . In any case—and this is why he is so seldom recorded in books on modern astronomy—Harriot's crude sketch reveals nothing new.

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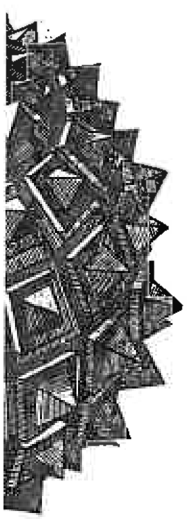

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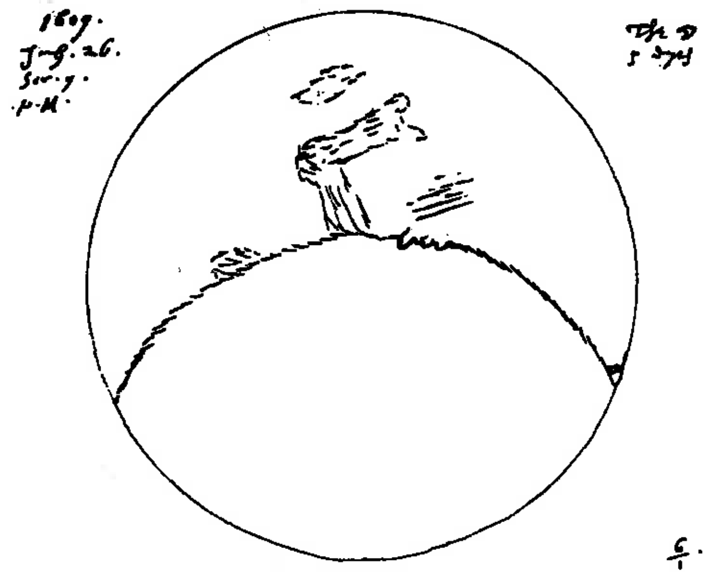

in the cosmos. Christian dogma added to this euphoric image by having the moon symbolize the Virgin's Immaculate Conception. "Pure as the moon" became a commonplace expression for Mary, implying that the universe, like herself, was incorruptible, that God would not have created the moon or any other heavenly body in another shape. Renaissance artists, especially those who served zealous Catholic patrons, frequently depicted the Virgin standing on such as moon, as did Bartolomé Esteban Murillo (1617–1682) as late as the mid-seventeenth century in Spain . . . —[a moon] marbled like translucent alabaster but with a highly polished, utterly smooth surface.

In Thomas Harriot's England, the anti-Aristotelian Francis Bacon had concluded that the lunar body was not solid at all, but rather composed of some unexplained "vapour." Harriot's own opinion about the moon's composition remains unrecorded. Nonetheless, he drew the terminator—that is, the demarcation line between the illuminated and shaded portions of the moon—with short, ragged strokes as if it fell over a roughened surface. On the upper half of the sphere Harriot indicated the configurations of what we now know as the great lunar "seas," the Maria Tranquilitatis, Crisium, and Serenitatis, which do seem to have appeared to him as surface markings rather than internal, vaporous discolorations. Nevertheless, he was unable to recognize the significance of these observations. The telescope only confirmed more or less what the ancients had always said he would see. The "strange spottednesse of the Moon," as Harriot called the phenomenon, remained as mysterious to him as ever.

Why did the Englishman miss what Galileo saw so precisely just a few months later? Was it only because his telescope was less powerful than Galileo's? No, because the moon through any telescope of the time could hardly have looked as sharp as it does in [a modern telescopic photograph]. Both Galileo's and Harriot's telescopes, mounted on rickety homemade stanchions, must have been difficult to focus, to say the least. Moreover, as Albert Van Helden has calculated, such primitive instruments had very narrow fields of view; only about a quarter of the moon could be observed at one time. In sum, neither the English nor the Tuscan scientist could have seen the moon so distinctly that its true surface topography would be instantly self-evident. Besides, as Van Helden also points out, quite a number of such telescopes were being produced in several centers of Europe by the end of 1609. Would not someone else also have thought to aim the instrument toward the sky? . . . If one knew nothing a priori about the moon's external topography, would its grayish blotches be seen immediately as shades and shadows of mountain ridges? Especially if the observer, like all people before 1610, was already certain that such blotches had something to do with the moon's translucent internal composition? . . .

[In Harriot's time] no serious study of geometric perspective . . . existed in England at all. Demand in Britain for perspective training was so slight that no indigenous book on the subject was published until 1635, when John Wells edited a crude manual titled *Sciographia, or The Art of Shadows*, too late of course to have been much use to Harriot.

In the meantime back in Padua, where Galileo was living and teaching, the Tuscan scientist heard nothing of Harriot's lunar observations. In fact, he learned of the recent Flemish invention of the telescope only in May 1609. Immediately he sent for instructions. With remarkable ingenuity, not to say alacrity, he applied his considerable perspective experience to the optical problems and managed by the end of the year to build a number of the instruments with magnification improved to twenty power and with the addition even of aperture stops. . . .

Galileo's recordings of the moon's phases date from November and December 1609. Since his observations during these two months could be affirmed only when the moon appeared in partial shadow, his viewing nights were limited to about twenty-four, not all of which would conveniently be free of clouds.

Perhaps Galileo made some illustrations from the beginning, right there on the spot as he stared at the moon from the San Giorgio Maggiore campanile. No such drawings have survived, but we are in possession of seven finished sepia studies, obviously done later but probably based on firsthand ad hoc sketches. These small wash drawings, four of the waxing and three of the

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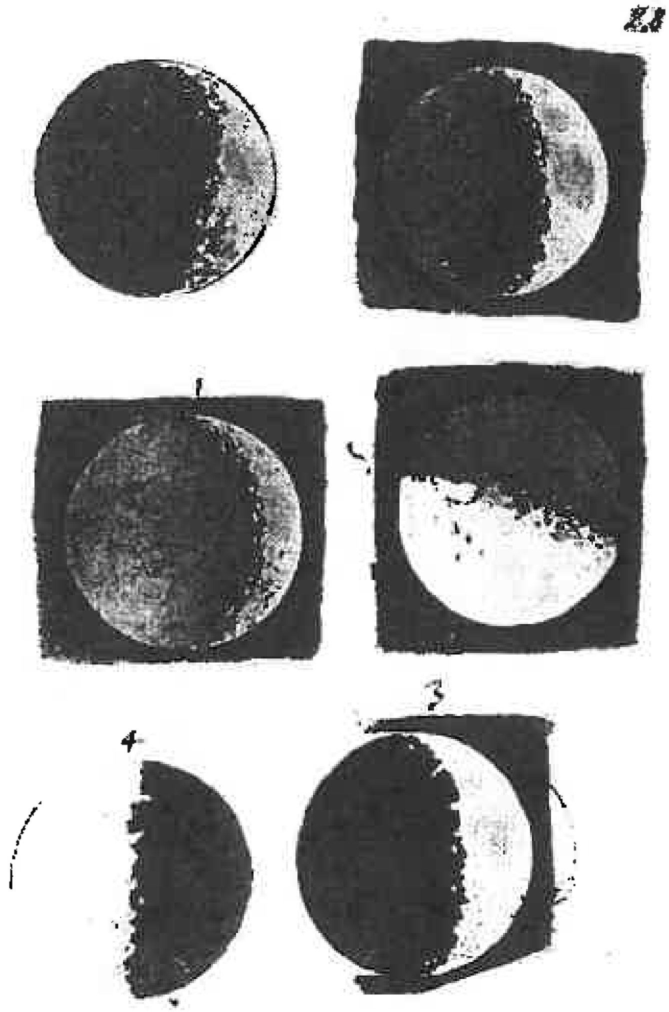

waning moon were certainly done by someone well practiced in the manipulation of ink washes, especially the rendering of chiaroscuro effects. They are by an experienced artist, and we have no reason to believe it was anyone other than Galileo himself. The astronomer no doubt prepared these washes as models for the engraver who would illustrate his book *Sidereus nuncius*, . . . which he rushed to publication in March 1610, barely five months after he began looking at the skies through his telescope.

Only five engravings of the moon's phases were printed in *Sidereus nuncius*, none exactly replicating the wash drawings. . . . Galileo's accompanying matter-of-fact description of these engravings belies both his own excitement and the stupendous impression they made on an unsuspecting world: "I have been led to the opinion and conviction that the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the Earth, relieved by chains of mountains and deep valleys." . . .

Is it preposterous to claim that these simple yet highly professional paintings belong as much to the history of art as to the history of science? Though no comparable artwork also attributable to Galileo exists, we do have much contemporary verbal testimony concerning his considerable skill as a draftsman. In the true spirit of the Florentine Academia, Galileo seems to have engaged in drawing not for the sake of self-expression but rather to discipline his eye and hand for science. And yet in these chiaroscuro washes he has anticipated the independent landscape in the history of art. His almost impressionistic technique for rendering fleeting light effects reminds us of Constable and Turner, and perhaps even Monet. One needs only to read on in *Sidereus nuncius* to appreciate his wonder, as well as his rational understanding, as he first gazed at the transient moonscape. . . .

Moreover, after [marvelling] at the picturesque lunar terrain, Galileo quickly reverted to his scientific self and made two other amazing perspective-related discoveries. The first came when he noticed that some of the lunar peaks were tipped with light within the shadow side even as the terminator boundary lay a long way off. At the same time, he was able to convert this phenomenon into a geometric diagram for solving a shadow-casting problem such as he may have recalled from Guidobaldo del Monte.

Edgerton describes the simple geometry that Galileo used to triangulate the heights of a mountain whose top peeks up out of the moon's shadow on the dark side of the terminator. It should be noted that the calculation is remarkable not only for Galileo's accuracy given the limitations of his equipment, but also for the very fact that geometry—literally "earth measurement"—was applied extraterrestrially. The implication—an anti-Aristotelian one—is that space is qualitatively the same up there as it is down here. Hence the geometrization of astronomical space.

Since the moon's diameter was known to be two-sevenths of the earth's diameter, or about 2,000 miles, Galileo . . . revealed by Pythagorean calculation that . . . the mountain's height on center from its base reached more than four miles into the lunar sky! By applying a problem well known to students of Renaissance perspective, Galileo added yet another fact to his already

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His next observation had to do with what is today referred to as "earthshine," described thus in *Sidereus nuncius*:

> When the Moon is not far from the Sun, just before or after a new Moon, its globe offers itself to view not only on the side where it is adorned with shining horns, but a certain faint light is also seen to mark out the periphery of the dark part which faces away from the Sun, separating this from the aether. Now if we examine the matter more closely, we shall see that not only does the extreme limb of the shaded side glow with this uncertain light, but the entire face of the Moon (including the side which does not receive the glare of the Sun) is whitened by a not inconsiderable gleam.... It is then found that this region of the Moon, though deprived of sunlight, also shines not a little. The effect is heightened if the gloom of night has already deepened through departure of the Sun, for in a darker field a given light appears brighter.... This remarkable gleam has afforded no small perplexity to philosophers.... Some would say it is an inherent and natural light of the Moon's own; others that it is imparted by Venus; others yet, by all the stars together; and still others derive it from the Sun, whose rays they would have permeate the thick solidity of the Moon. But statements of this sort are refuted and their falsity evinced with little difficulty. For if this kind of light were the Moon's own, or were contributed by the stars, the Moon would retain it particularly during eclipses.... Now since the secondary light does not inherently belong to the Moon, and is not received from any star or from the Sun, and since in the whole universe there is no other body left but the Earth, what must we conclude? What is to be proposed? Surely we must assert that the lunar body (or any other dark and sunless orb) is illuminated by the Earth. Yet what is so remarkable about this? The Earth, in fair and grateful exchange, pays back to the Moon an illumination similar to that which it receives from her throughout nearly all the darkest gloom of night.

How was Galileo able to make such a discovery? What led him to raise this issue in the first place? The fact is, as any seventeenth-century Florentine connoisseur of art would have known, the ability to depict reflected light was one of the outstanding achievements of Renaissance painting. . . . While growing up in Tuscany, the young scientist may have seen many unforgettable examples. . . . Moreover, Galileo, through association with Cigoli and the Florentine Accademia del Disegno, is likely to have known the relevant instructions in Leon Battista Alberti's treatise *On Painting*, available since 1568 in a popular Italian-language edition:

> A shadow is made when rays of light are intercepted. Rays that are intercepted are either reflected elsewhere or return upon themselves. They are reflected, for instance, when they rebound off the surface of water onto the ceiling; as mathematicians prove, reflection of rays always takes place at equal angles. . . . Reflected rays assume the color they find on the surface from which they are reflected. We see this happen when the faces of people walking about in the meadows appear to have a greenish tinge.

Any would-be artist since the quattrocento had to learn to draw this optical phenomenon just as Alberti described it—but of course only in relation to terrestrial experience. . . . By applying the same painterly logic to the moon, Galileo discovered what had eluded professional astronomers for centuries.

SOURCE: Samuel Y. Edgerton, Jr., *The Heritage of Giotto's Geometry: Art and Science on the Eve of the Scientific Revolution*, Ithaca: Cornell UP, 1991.

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This Boat Which Is Our Earth

Johannes Kepler

Kepler (1571–1630) and Galileo form a delightful diptych: the German and the Italian, the profound theorizer and the penetrating observer, the two greatest among second-generation Copernicans—and, inevitably, rivals. Moreover, we find Kepler at perhaps his most charming, exasperating, and revealing even as, in 1610, he confronts the stunning discoveries Galileo has just published in his little book Sidereus Nuncius. *Kepler asks himself, it seems, "Why didn't I think of that?"—and answers, in most cases, that he had thought of it.*

In 1609, Kepler had published his Astronomia Nova (The New Astronomy), *most famous for his first two laws of planetary motion. Entertaining an idea that even Copernicus had not considered, namely, that the orbits of the planets might be other than circular, Kepler explained those orbits as ellipses (his "first law") which nevertheless displayed regularity: The changing velocity of a planet within its elliptical orbit renders areas of an ellipse "swept out" in equal intervals of time equal. (Picture an elliptical pizza whose wedge-shaped slices are all actually equal in weight and calories, even though the width of each piece at the wide end varies; this is the "second law.") One of the assumptions of these laws is that the planets are physical earth-like objects—a claim Galileo in 1610 makes regarding the moon. One may perhaps be more patient in reading Kepler if one reflects on the fact that Kepler at least acknowledges Galileo's accomplishments even when Galileo does not return the favor. Kepler even salutes Galileo's writing ability.*

I may perhaps seem rash in accepting your claims so readily with no support from my own experience. But why should I not believe a most learned mathematician, whose very style attests the soundness of his judgment? He has no intention of practicing deception in a bid for vulgar publicity, nor does he pretend to have seen what he has not seen. Because he loves the truth, he does not hesitate to oppose even the most familiar opinions, and to bear the jeers of the crowd with equanimity. Does he not make his writings public, and could he possibly hide any villainy that might be perpetrated? Shall I disparage him, a gentleman of Florence, for the things he has seen? Shall I with my poor vision disparage him with his keen sight?

Kepler recognizes at once that the success of Galileo's observations has implications for the very nature of space or its contents. He explains that, though he had the theoretical knowledge of optics necessary for the invention of the telescope, he did not push ahead with the project because he assumed that the cumulative opacity of the "aether" would prevent accurate vision at enormous distances.

I believed that the air is dense and blue in color, so that the minute parts of visible things at a distance are obscured and distorted. Since this proposition is intrinsically certain, it was vain, I understood, to hope that a lens would remove this substance of the intervening air from visible things. Also with regard to the celestial essence, I surmised some such property as could prevent us, supposing that we enormously magnified the body of the moon to immense proportions, from being able to differentiate its tiny particles in their purity from the lowest celestial matter.

For these reasons, reinforced by other obstacles, I refrained from attempting to construct the device.

But now, most accomplished Galileo, you deserve my praise for your tireless energy. Putting aside all misgivings, you turned directly to visual experimentation. And indeed by your discoveries you caused the sun of truth to rise, you routed all the ghosts of perplexity together with their mother, the night, and by your achievement you showed what could be done.

Under your guidance I recognize that the celestial substance is incredibly tenuous. To be sure, this property is made known on page 127 of my "Optics." If the relative densities of air and water are compared with the relative densities of the aether and air, the latter ratio undoubtedly shows a much greater disparity. As a result, not even the tiniest particle of the sphere of the stars (still less of the body of the moon, which is the lowest of the heavenly bodies) escapes our eyes, when they are aided by your instrument. A single fragment of the lens interposes much more matter (or opacity) between the eye and the object viewed than does the entire vast region of the aether. For a slight indistinctness arises from the lens, but from the aether none at all. Hence we must virtually concede, it seems, that that whole immense space is a vacuum.

Like most scientists who make major breakthroughs, Galileo and Kepler are naturally best known as thinkers who are forward-looking and before their time. However, even aspects of their discussion that strike us as antiquated are engaging and imaginative, as in the following section in which Kepler acknowledges the role of Plutarch in the ongoing discussion on the nature of the moon, and divulges his belief that somehow nature had sought out both him and Galileo as conduits of astronomical revelation.

What shall I say now [Galileo] about your very acute analysis of the ancient spots on the moon? On page 251 of my book I cited the opinion of Plutarch, who regarded those ancient spots on the moon as lakes or seas, and the bright areas as continents. I did not hesitate to oppose him and to reverse his interpretation, by attributing the spots to continents, and the purity of the bright region to the effects of a liquid. Wackher used to give strong approval to my stand on this question. We were deeply engaged in these discussions last summer (I suppose, because nature was seeking the same results through us as it achieved a little later through Galileo). To please Wackher, I even founded a new astronomy for the inhabitants of the moon, as it were; in plain language, a sort of lunar geography. Among its basic propositions was this thesis, that the spots are continents, while the bright areas are seas. . . . Suppose that the moon, like the island of Crete, is composed of a white soil (as Lucian said that the moon is a cheese-like land). We shall have to admit that the soil shines by sunlight more vividly than the seas, however little they may be tinged with black.

My book, consequently, does not prevent me from agreeing with you, as you adduce mathematical arguments against me in favor of Plutarch with brilliant and irrefutable logic. Certainly the bright areas are broken up by many cavities; the bright areas are bounded by an irregular line; the bright areas contain great peaks, on account of which they light up sooner than the neighboring region. Where they face the sun, they are bright; where they face away from the sun, they are dark. All these characteristics suit a dry, solid, and high material, but not a fluid. On the other hand, the dark spots, known since antiquity, are flat. The dark spots light up later—a fact which proves their low elevation—when the surrounding peaks are already aglow far and wide. When the dark spots are illumined, a certain shadow-like black effect differentiates them from the peaks. The boundary of the illumination in the dark area is a straight line at half-moon. These characteristics, in turn, belong to a liquid, which seeks the lowest levels and on account of its weight settles in a horizontal position.

By these arguments, I say, you have proved your point completely. I admit that the spots are seas, I admit that the bright areas are land.

Kepler seems irresistibly drawn beyond observation to speculation—speculation that nurtured what later generations would call science fiction.

I cannot help wondering about the meaning of that large circular cavity in what I usually call the left corner of the mouth. Is it a work of nature, or of a trained hand? Suppose that there are living beings on the moon (following in the footsteps of Pythagoras and Plutarch, I enjoyed toying with this idea, long ago in a disputation written at Tübingen in the year 1593, later on in my "Optics" on page 250, and most recently in my aforementioned lunar geography). It surely stands to reason that the inhabitants express the character of their dwelling place, which has much bigger mountains and valleys than our earth has. Consequently, being endowed with very massive bodies, they also construct gigantic projects. Their day is as long as 15 of our days, and they feel insufferable heat. Perhaps they lack stone for erecting shelters against the sun. On the other hand, maybe they have a soil as sticky as clay. Their usual building plan, accordingly, is as follows. Digging up huge fields, they carry out the earth and heap it in a circle, perhaps for the purpose of drawing out the moisture down below. In this way they may hide deep in the shade behind their excavated mounds and, in keeping with the sun's motion, shift about inside, clinging to the shadow. They have, as it were, a sort of underground city. They make their homes in numerous caves hewn out of that circular embankment. They place their fields and pastures in the middle, to avoid being forced to go too far away from their farms in their flight from the sun.

But let us follow the thread of your discourse still further. You ask why the moon's outermost circle does not also appear irregular. I do not know how carefully you have thought about this subject, or whether your query, as is more likely, is based on the popular impression. For in my book . . . I stated that there was surely some imperfection in this outermost circle during full moon. Study the matter, and once again tell us how it looks to you, for I shall have confidence in your telescopes.

Assuming the fact to be established, you answer the question in two ways. The first way is not incompatible with my findings. For the multitude of peaks, crowded one behind another, presents the appearance of a perfect circle at the outermost limb of the visible hemisphere. This can happen only if

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the peaks have been smoothed and polished on a lathe so that any tiny crevices or bumps fail to show up. This situation would be consistent with my observations.

Your second way of answering the question is to wrap a sphere of air around the moon. Where this sphere curves back to the recesses of the lunar globe, it presents some depth to the rays from the sun and the earth, and thus to our eyes also. Hence the limb gleams pure and spotless, while the entire interior of the face, where this air does not obstruct our vision so deeply, abounds with numerous spots.

Pages 252 and 302 of my book could have told you about this air on the moon. These passages in my book are splendidly confirmed by your pertinent observations.

When he turns to Galileo's findings regarding the number of the stars and the telescopic appearance of their light, Kepler reveals how profoundly anthropocentric his Copernicanism is and how radically his conception of the sun differs from more modern (and in Bruno's case, earlier) views of the sun as one among countless stars.

Your second highly welcome observation concerns the sparkling appearance of the fixed stars, in contrast with the circular appearance of the planets. What other conclusion shall we draw from this difference, Galileo, than that the fixed stars generate their light from within, whereas the planets, being opaque, are illuminated from without; that is, to use Bruno's terms, the former are suns, the latter, moons or earths?

Nevertheless, let him not lead us on to his belief in infinite worlds, as numerous as the fixed stars and all similar to our own. Your third observation comes to our support: the countless host of fixed stars exceeds what was known in antiquity. You do not hesitate to declare that there are visible over 10,000 stars. The more there are, and the more crowded they are, the stronger becomes my argument against the infinity of the universe, as set forth in my book on the "New Star." . . . This argument proved that where we mortals dwell, in the company of the sun and the planets, is the primary bosom of the universe; from none of the fixed stars can such a view of the universe be obtained as is possible from our earth or even from the sun. For the sake of brevity, I forbear to summarize the passage. Whoever reads it in its entirety will be inclined to assent.

Let me add this consideration to buttress my case. To my weak eyes, any of the larger stars, such as Sirius, if I take its flashing rays into account, seems to be only a little smaller than the diameter of the moon. But persons with unimpaired vision, using astronomical instruments that are not deceived by these wavy crowns, as is the naked eye, ascertain the dimensions of the stars' diameters in terms of minutes and fractions of minutes. Suppose that we took only 1000 fixed stars, none of them larger than one minute. . . . If these were all merged in a single round surface, they would equal (and even surpass) the diameter of the sun. If the little disks of 10,000 stars are fused into one, how much more will their visible size exceed the apparent disk of the sun? If this is true, and if they are suns having the same nature as our sun, why do not these suns collectively outdistance our sun in brilliance? Why do they all together transmit so dim a light to the most accessible places? . . . Will my opponent tell me that the stars are very far away from us? This does not help his cause at all. For the greater their distance, the more does every single one of them outstrip the sun in diameter. But maybe the intervening aether obscures them? Not in the least. For we see them with their sparkling, with their various shapes and colors. This could not happen if the density of the aether offered any obstacle.

Hence it is quite clear that the body of our sun is brighter beyond measure than all the fixed stars together, and therefore this world of ours does not belong to an undifferentiated swarm of countless others.

Kepler goes on in his slightly deflating way to compliment Galileo on his resolution of the Milky Way, but from this discovery he draws an implication that betrays his still mystical and essentially medieval notion of the immutability of the fixed stars.

You have conferred a blessing on astronomers and physicists by revealing the true character of the Milky Way, the nebulae, and the nebulous spirals. You have upheld those writers who long ago reached the same conclusion as you: they are nothing but a mass of stars, whose luminosities blend on account of the dullness of our eyes.

Accordingly, scientists will henceforth cease to create comets and new stars out of the Milky Way, after the manner of Brahe, lest they irrationally assert the passing away of perfect and eternal celestial bodies.

When he turns to Galileo's visual discovery of the planets of Jupiter, Kepler gives himself credit for having predicted the same thing at the theoretical level. More interesting than this specific claim, however, is Kepler's engagement of the fact—and the ongoing mystery—that often, in science, human beings have indeed achieved a priori knowledge or conceptions of things that have only later been proven experimentally.

Finally, I move on with you to the new planets, the most wonderful topic in your little book. . . . I rejoice that I am to some extent restored to life by your

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Wackher of course had once more been seized by deep admiration of that dreadful philosophy [of Bruno's]. What Galileo recently saw with his own eyes, I had many years before not only proposed as a surmise, but thoroughly established by reasoning. It is doubtless with perfect justice that those men attain fame whose intellect anticipates the senses in closely related branches of philosophy. Theoretical astronomy, at a time when it had never set foot outside Greece, nevertheless disclosed the characteristics of the Arctic Zone. . . . Who does not honor Plato's myth of Atlantis, Plutarch's legend of the gold-colored islands beyond Thule, and Seneca's prophetic verses about the forthcoming discovery of a New World, now that the evidence for such a place has finally been furnished by that Argonaut from Florence [Vespucci]? Columbus himself keeps his readers uncertain whether to admire his intellect in divining the New World from the direction of the winds, more than his courage in facing unknown seas and the boundless ocean, and his good luck in gaining his objective. . . . Surely those thinkers who intellectually grasp the causes of phenomena, before these are revealed to the senses, resemble the Creator more closely than the others, who speculate about the causes after the phenomena have been seen.

In this way Kepler at once compliments Galileo and puts him in his place. And, as he did in connection with his discussion of the moon, Kepler unleashes his imagination with regard to extraterrestrial inhabitants. In so doing, he reveals much concerning his view of the teleology of the cosmos and of humans' unfolding role within it. He begins with what was to become the persistent analogy between voyages of discovery and colonization to America and those to other "new worlds" in space.

I cannot refrain from contributing this additional feature to the unorthodox aspects of your findings. It is not improbable, I must point out, that there are inhabitants not only on the moon but on Jupiter too or . . . that those areas are now being unveiled for the first time. But as soon as somebody demonstrates the art of flying, settlers from our species of man will not be lacking. Who would once have thought that the crossing of the wide ocean was calmer and safer than of the narrow Adriatic Sea, Baltic Sea, or English Channel? Given ships or sails adapted to the breezes of heaven, there will be those who will not shrink from even that vast expanse. Therefore, for the sake of those who, as it were, will presently be on hand to attempt this voyage, let us establish the astronomy, Galileo, you of Jupiter, and me of the moon.

Let the foregoing pleasantries be inserted on account of the miracle of human courage, which is evident in the men of the present age especially. For the revered mysteries of sacred history are not a laughing matter for me.

I have also thought it worth while, in passing, to tweak the ear of the higher philosophy. Let it ponder the questions whether the almighty and provident Guardian of the human race permits anything useless and why, like an experienced steward, he opens the inner chambers of his building to us at this particular time. Such was the opinion put forward by my good friend Thomas Seget, a man of wide learning. Or does God the creator, as I replied, lead mankind, like some growing youngster gradually approaching maturity, step by step from one stage of knowledge to another? (For example, there was a period when the distinction between the planets and the fixed stars was unknown; it was quite some time before Pythagoras or Parmenides perceived that the evening star and the morning star are the same body; the planets are not mentioned in Moses, Job, or the Psalms). Let the higher philosophy reflect, I repeat, and glance backward to some extent. How far has the knowledge of nature progressed, how much is left, and what may the men of the future expect?

But let us return to humbler thoughts, and finish what we began. There are in fact four planets revolving around Jupiter at different distances with unequal periods. For whose sake, the question arises, if there are no people on Jupiter to behold this wonderfully varied display with their own eyes? For, as far as we on the earth are concerned, I do not know by what arguments I may be persuaded to believe that these planets minister chiefly to us, who never see them. We should not anticipate that all of us, equipped with your telescopes, Galileo, will observe them hereafter as a matter of course. . . . It becomes evident that these four new planets were ordained not primarily for us who live on the earth but undoubtedly for the Jovian beings who dwell around Jupiter.

With this daring suggestion Kepler's imagination opens onto a still more arresting scene in which inhabitants of spaceship earth—"this boat, which is our earth"—exercise their planetary patriotism by asserting the superiority of their location within the universe.

Well, then, someone may say, if there are globes in the heaven similar to our earth, do we vie with them over who occupies the better portion of the universe? For if their globes are nobler, we are not the noblest of rational crea-

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tures. Then how can all things be for man's sake? How can we be the masters of God's handiwork?

It is difficult to unravel this knot, because we have not yet acquired all the relevant information. We shall hardly escape being labeled foolish if we expatiate at length on this subject.

Yet I shall not pass over in silence those philosophical arguments which, it seems to me, can be brought to bear. They will establish not merely in general . . . that this system of planets, on one of which we humans dwell, is located in the very bosom of the world, around the heart of the universe, that is, the sun. These arguments will also establish in particular that we humans live on the globe, which by right belongs to the primary rational creature, the noblest of the (corporeal) creatures.

In support of the former proposition concerning the inmost bosom of the world, . . . the evidence . . . was based, first, on the fixed stars, which by their vast numbers truly enclose this area like a wall and, secondly, on our sun, which is more splendid than the fixed stars. . . .

Let us now also indicate why the earth surpasses Jupiter and better deserves to be the abode of the predominant creature.

In the center of the world is the sun, heart of the universe, fountain of light, source of heat, origin of life and cosmic motion. But it seems that man ought quietly to shun that royal throne. Heaven was assigned to the lord of heaven, the sun of righteousness, but earth, to the children of man. God has no body, of course, and requires no dwelling place. Yet more of the force which rules the world is revealed in the sun . . . than in all the other globes. Because man's house is otherwise, therefore, let him recognize his own wretchedness and the opulence of God. Let him acknowledge that it is not the source and origin of the world's splendor, but that he is dependent on the true source and origin thereof. Moreover, as I said in the "Optics," in the interests of that contemplation for which man was created, and adorned and equipped with eyes, he could not remain at rest in the center. On the contrary, he must make an annual journey on this boat, which is our earth, to perform his observations. So surveyors, in measuring inaccessible objects, move from place to place for the purpose of obtaining from the distance between their positions an accurate base line for the triangulation.

After the sun, however, there is no globe nobler or more suitable for man than the earth. For, in the first place, it is exactly in the middle of the principal globes (if we exclude, as we should, Jupiter's satellites and the moon revolving around the earth). Above it are Mars, Jupiter, and Saturn. Within the embrace of its orbit run Venus and Mercury, while at the center the sun rotates, instigator of all the motions, truly an Apollo, the term frequently used by Bruno.

Thus Kepler redefines centrality itself in a most dynamic manner based on the idea that geometrical comprehension, triangulation, requires variation of place. Earlier Kepler had commented that "geometry . . . shines in the mind of God. The share of it which has been granted to man is one of the reasons why he is the image of God." To exercise or actualize this image properly, humans must be able to observe the universe from a "central" but changing point of view. On the other hand, Kepler generously theorizes that God—to mitigate interplanetary envy—has granted the Jovians a few extra moons by way of compensation.

We on the earth have difficulty in seeing Mercury, the last of the principal planets, on account of the nearby, overpowering brilliance of the sun. From Jupiter or Saturn, how much less distinct will Mercury be? Hence this globe seems assigned to man with the express intent of enabling him to view all the planets. Will anyone then deny that, to make up for the planets concealed from the Jovians but visible to us earth-dwellers, four others are allocated to Jupiter, to match the four inferior planets, Mars, Earth, Venus, and Mercury, which revolve around the sun within Jupiter's orbit?

Let the Jovian creatures, therefore, have something with which to console themselves. Let them . . . have their own planets [i.e., their moons]. We humans who inhabit the earth can with good reason (in my view) feel proud of the pre-eminent lodging place of our bodies, and we should be grateful to God the creator.

SOURCE: *Kepler's Conversation with Galileo's Sidereal Messenger*, trans. Edward Rosen, New York and London: Johnson Reprint Corporation, 1965.

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27

The Two Books of God Agree with Each Other

Tommaso Campanella

Tommaso Campanella (1568–1639) provides an example of one who was willing to mount a defense of the beleaguered Galileo from within Roman Catholicism. So much has been written about the warfare between science and theology, with Galileo as prime exhibit of victimization by the latter, that it is stimulating to hear arguments arising from scriptural hermeneutics and theology in defense of the scientist. As in most interpretation, the largest issue is the nature of truth itself. But close behind it is that of how the human subject, immersed in the world's contingencies, perceives *the truth. Such is the first point made by Tobias Adami, publisher of Campanella's* Apologia Pro Galileo.

GREETINGS TO THE BENEVOLENT READER
from the Publisher

For insignificant creatures like us, who live in this world surrounded on all sides like worms in a cheese, it is no small matter to engage in grave disputes about the structure of the world, such as whether our abode or house, which we call the earth, rotates on high around the sun together with the other globes similar to it, or whether the sun rotates around the earth. We are indeed such small creatures that we are very ignorant of such matters. We are like a mouse in a ship who, when asked by a fellow mouse about the ship being at rest on the sea, would never be able to say whether the ship, their common home, is in motion or whether it remains fixed in one and the same place.

As a result many judge these investigations to be more complex than is commonly thought, especially after so many new things have been detected in the celestial globes by means of the optical instrument which the Lycean philosophers in Rome call a telescope. On the other hand, although certain arrogant people, who wish to pass themselves off as philosophers, have seen most of these things, still their spontaneous amazement did not prevent them from turning others away from a more careful investigation of the truth. And indeed many theologians, both Catholic and Protestant, are especially eager to suppress this investigation by appealing to the unchanging authority of the Sacred Scriptures. But whoever loves the truth must give special consideration to what is right or wrong in this matter. Both in our day and in times past, many famous people who were well informed about both profane and sacred studies, beginning with the Pythagoreans, have defended and still defend this view; and they ought not to be accused rashly of either impiety or ignorance.

Campanella's defense of Galileo itself is really a principled theological defense of the kind of investigation Galileo has engaged in, rather than a defense of the rightness of the heliocentric system as such. The work has a quite medieval flavor, with a palpable concern for citation of biblical and patristic authorities even while arguing that truth itself supersedes authority.

I will never be sufficiently astonished at those potbellied theologians who locate the limits of human genius in the writings of Aristotle. The fact that not even Ptolemy reached the truth is shown by the new phenomena which his theory cannot explain, and thus he does not remove disorder from the heavens. I will also pass over the errors which Copernicus introduced into astronomy, for example, that there is a regular motion of a sphere around a center other than its own. . . . But Copernicus . . . has returned to the teachings of the ancient Pythagoreans, which provide a better account of the appearances. In addition to this, Galileo has discovered new planets and new worlds and previously unknown changes in the heavens.

Therefore, anyone is insane and most ignorant to think that an adequate knowledge of the heavens is to be found in Aristotle, who contributed nothing on his own and who encouraged others to investigate such matters. And those who came after him are uncertain and are still fighting with each other.

Galileo, in a letter to the Grand Duchess of Tuscany written a year before Campanella composed his defense, cites Tertullian on the "parallel texts" of Nature and Scripture: "God is known . . . by Nature in his works, and by doctrine in his revealed Word." Upon this foundation Galileo defends him-

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*self, arguing that the two "books" must be interpreted consistently with each other, so that "having arrived at any certainties in physics, we ought to utilize these as the most appropriate aids in the true interpretation of the Bible" (*Discoveries and Opinions of Galileo*, ed. Stillman Drake [1957], 183). Similarly, Campanella defends Galileo on the universal grounds that God is the author of both books—of Scripture and of Nature—and that "one truth does not contradict another truth."*

Hence human science does not contradict divine science, nor do the works of God contradict God. . . . Therefore, although theology in itself does not need proofs taken from the human sciences, nevertheless, for our sake theology does need to do this so that we can strengthen our convictions by understanding the supernatural in terms of the sensible and the natural. . . .

Now it is clear that the sciences exist in the human race as a whole, and not only in this or that individual person. For God made man to know God, and by knowing to love Him, and by loving to please Him; and for this man has senses and reason. But if the purpose of reason is to attain knowledge, then humans would act contrary to the divine natural order, just like a man who would not wish to use his feet to walk, unless one uses this gift of God according to the divine plan, as Chrysostom has regularly argued. As Aristotle has said, "All men by nature desire to know," and as Moses said in Genesis 1, "God put man in paradise to cultivate and take care of it." But this was not manual labor or the caring for animals. . . . Rather man's work was to know things, and to observe the heavens and the natural world out of curiosity, so that he would as a result investigate everything to meet his obligation to venerate God, which cannot be done without first having knowledge, for "The invisible things of God are known through what He has made," as the Apostle said [Rom. 1:20].

Even if it be granted that all the sciences were infused into Adam, still he lacked experiential knowledge. Further, this command to learn was given to him, not as an individual person but as the head of the human race, and hence it has been also given to us, his descendants, as the Fathers testify. . . .

As a result, from the beginning the world has been called the "Wisdom of God" (as was revealed to St. Brigid) and a "Book" in which we can read about all things. Hence . . . St. Leo says, "We understand the meaning of God's will from these very elements of the world, as from the pages of an open book." . . .

Since the more wonderful and more extraordinary things in the world are better images of God, their author, they should be investigated for this reason with greater care. And by this study divinity is shown to the human soul. Such are the heavens and the stars and the great system of the world. Thus

Anaxagoras has said that man was made to contemplate the heavens. And Ovid was much praised by all the theologians, and especially by Lactantius, for having said of God, "While the other animals look down towards the earth, he created man to face upwards, and he ordered him to see the heavens and to stand erect, turning his gaze to the stars."

David reveals the reason for this when he sings in Psalm 18, "The heavens proclaim the glory of God, and the firmament speaks of the work of his hands," and in Psalm 8, "For I will look at your heavens, the work of your fingers, and at the moon and the stars, which you have made." Moreover Plato . . . proves the dignity and the deification of man and the immortality of his soul from his knowledge of the heavens. . . . Ovid also confirms this when he says to the astronomers, "Yours is a happy lot because your primary role is to know about these matters and to rise up to the celestial houses; you bring the distant stars closer to our eyes, and you subject the heavens to your genius."

These praises belong to Galileo more than to anyone else.

Campanella engages in a balancing act: praising Galileo, but refusing to idolize him or to see him—or anyone else either—as the epitome of knowledge.

The wisdom of God is exceedingly vast and cannot be confined to the genius of any one human. The more it is sought, the more it is found to contain, and we then realize that we know nothing in comparison to the numerous and marvelous things of which we are ignorant. This is the knowledge which Solomon envisioned in Ecclesiastes, and which the Apostle praises, and which Socrates found in himself. Those who think that they know because they know Aristotle or because, like Galileo, they know something new about the world, the book of God, do not know the method required for knowledge. They are not truly wise unless they know that there are many more things of which they are ignorant, and that they should not stop their investigations as if they already knew everything. . . . For what we know is only a glimmer.

Therefore, wisdom is to be read in the immense book of God, which is the world, and there is always more to be discovered. Hence the sacred writers refer us to that book and not to the small books of humans.

Campanella's defense of Galileo from within the faith is motivated not only by high principle but also by raw apprehension of the embarrassment to be suffered should heliocentrism prove true.

For . . . if Galileo wins out, our theologians of the Roman faith will be the cause of a great deal of ridicule among the heretics, for his theory and the use

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SOURCES: Thomas Campane
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of the telescope have by now been enthusiastically accepted in Germany, France, England, Poland, Denmark, Sweden, etc. . . . Therefore I think that this philosophical theory should not be condemned. One reason for this is that it will be embraced even more enthusiastically by the heretics and they will laugh at us. For we know how greatly those who live north of the Alps complained about some of the decrees adopted at the Council of Trent. What will they do when they hear that we have attacked the physicists and astronomers? Will they not immediately proclaim that we have done violence to both nature and the Scriptures?

The book containing these words was published not in 1616, when it was written, but only six years later, in 1622, and not in Italy but in Germany. Moreover, the anxious questions of Campanella, a Dominican, appear prophetic when we consider John Milton's defense of free enquiry after truth (his Areopagitica*), written some two decades later in another northern country—England—in which he cites his firsthand experience of Italy and the Roman establishment's most famous prisoner:*

Lords and Commons, . . . I could recount what I have seen and heard in other countries, where this kind of inquisition tyrannizes; when I have sat among their learned men, for that honor I had, and been counted happy to be born in such a place of philosophic freedom, as they supposed England was, while themselves did nothing but bemoan the servile condition into which learning amongst them was brought; that this was it which had damped the glory of Italian wits; that nothing had been there written now these many years but flattery and fustian. There it was that I found and visited the famous Galileo, grown old a prisoner to the Inquisition, for thinking in astronomy otherwise than the Franciscan and Dominican licensers thought.

And having made this reference, Milton goes on to endorse once more the principle upon which Campanella's defense of Galileo is founded: the consistency of truth with truth.

To be still searching what we know not by what we know, still closing up truth to truth as we find it (for all her body is homogeneal and proportional), this is the golden rule in theology as well as in arithmetic.

SOURCES: Thomas Campanella, *A Defense of Galileo the Mathematician from Florence*, trans. Richard J. Blackwell, Notre Dame and London: U of Notre Dame P, 1994; John Milton, *Areopagitica*, London, 1644.

28

They Hoist the Earth Up and Down Like a Ball

Robert Burton

Robert Burton's monumentally digressive Anatomy of Melancholy *(1638) offers a glimpse of how the astronomical and cosmological debates in the century after Copernicus may have appeared to a learned non-scientist. Burton's copious prose conveys a sense of the mental and psychological readjustment which the ordinary seventeenth-century observer was forced to undergo in confronting the new cosmology with its denial of impenetrable spheres and annihilation indeed of entire elements. The readjustment was expressed perhaps most famously and succinctly by John Donne, in 1611, in "An Anatomy of the World":*

> And new philosophy calls all in doubt,
> The element of fire is quite put out,
> The sun is lost, and th'earth, and no man's wit
> Can well direct him where to look for it.
> And freely men confess that this world's spent,
> When in the planets and the firmament
> They seek so many new; they see that this
> Is crumbled out again to his atomies.
> 'Tis all in pieces, all coherence gone . . .

Although Burton in 1638 seems somewhat less grudging than Donne in 1611, he wavers between comprehension of the main reasons for the Coper-

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In the following section Burton moves from a dry cataloguing of positions against the old notion of impenetrable crystalline orbs to an imaginative stirring at the prospect that comes into view "if the heavens then be penetrable."

Saluciensis and Kepler take upon them to demonstrate that no meteors, clouds, fogs, vapors, arise higher than fifty or eighty miles, and all the rest to be purer air or element of fire. . . . Cardan, Tycho, and John Pena manifestly confute by refractions, and many other arguments, there is no such element of fire at all. If, as Tycho proves, the moon be distant from us fifty and sixty semidiameters of the earth, and, as Peter Nonius will have it, the air be so august, what proportion is there betwixt the other three elements and it? To what use serves it? Is it full of spirits which inhabit it, as the Paracelsians and Platonists hold, the higher the more noble, full of birds, or a mere vacuum to no purpose? It is much controverted between Tycho Brahe and Christopher Rotman, the Landgrave of Hesse's mathematician, in their astronomical epistles, whether it be the same *Diaphanum*, clearness, matter of air and heavens, or two distinct essences. Christopher Rotman, John Pena, Jordanus Brunus, with many other late mathematicians contend it is the same and one matter throughout, saving that the higher still the purer it is, and more subtle, as they find by experience in the top of some hills in America: if a man ascend, he faints instantly for want of thicker air to refrigerate the heart. . . . Tycho will have two distinct matters of heaven and air. But to say truth, with some small qualification they have one and the selfsame opinion about the essence and matter of the heavens: that it is not hard and impenetrable, as Peripatetics hold, transparent, of a fifth essence; "but that it is penetrable and soft as the air itself is, and that the planets move in it, as birds in the air, fishes in the sea."

This they prove by motion of comets . . . and as Tycho, Roeslin, Haggesius, Pena, Rotman, Fracastorius demonstrate by their progress, parallaxes, refractions, motions of the planets, which interfere and cut one another's orbs, now higher, and then lower, as Mars amongst the rest, which sometimes, as Kepler confirms by his own and Tycho's accurate observations, comes nearer the earth than the sun, and is again eftsoons aloft in Jupiter's orb; and other sufficient reasons, far above the moon; exploding in the meantime that element of fire, those fictitious first watery movers, those heavens I mean above the firmament, which Delrio, Lodovicus Imola, Patricius, and many of the fathers affirm; those monstrous orbs of eccentrics, and epicycles departing from the eccentric, which—howsoever Ptolemy, Alhasen, Vitellio, Purbachius, Maginus, Clavius, and many of their associates stiffly maintain to be real orbs, eccentric, concentric, circles equant, etc.—are absurd and ridiculous. For who is so mad to think that there should be so many circles, like subordinate wheels in a clock, all impenetrable and hard, as they feign, add, and subtract at their pleasure? . . .

If the heavens then be penetrable, as these men deliver, and no lets, it were not amiss in this aerial progress to make wings and fly up . . . or if that may not be, yet with a Galileo's glass, or Icaromenippus's wings in Lucian, command the spheres and heavens, and see what is done amongst them.

If the penetrability of the heavens encourages one optimistically to imagine exploration of them by means of telescope or by winged travel, the new astronomy also introduces pessimism or at least anxiety (see Pascal, chapter 31) when we consider the relative magnitudes of earth and other heavenly bodies. In other words, Donne's image of earth "crumbled out again to his atomies" can be read quite literally as implying earth's atomic size relative to the rest of what is out there. This, as Burton indicates, is only one of a torrent of questions the ongoing controversies generate.

Examine . . . whether the stars be of that bigness, distance, as astronomers relate, so many in number, 1026, or 1725, as J. Bayerus; or as some Rabbins, 29,000 myriads; or as Galileo discovers by his glasses, infinite, and that Milky Way a confused light of small stars, like so many nails in a door; or all in a row, like those 12,000 isles of the Maldives in the Indian Ocean. Whether the least visible star in the eighth sphere be eighteen times bigger than the earth; and as Tycho calculates, 14,000 semidiameters distant from it. Whether they be thicker parts of the orbs, as Aristotle delivers; or so many habitable worlds, as Democritus. Whether they have light of their own, or from the sun, or give light round, as Patritius discourseth. Whether they be equally distant from the center of the world. Whether light be of their essence; and that light be a substance or an accident. Whether they be hot by themselves, or by accident cause heat. Whether there be such a precession of the equinoxes as Copernicus holds, or that the eighth sphere move.

Burton repeats the claim that for Copernicus heliocentrism was a hypothesis. Yet, he recognizes that it has become more than merely hypothetical, even if it is apparently (in 1638) still a minority opinion.

To omit all smaller controversies as matters of less moment and examine that main paradox, of the earth's motion, now so much in question: Aristarchus Samius, Pythagoras maintained it of old, Democritus and many of their scholars, Didacus Astunica, Anthony Fascarinus, a Carmelite, and some

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other commentators, will have Job to insinuate as much (Job 9:6)—"Which shaketh the earth out of her place", etc.—and that this one place of Scripture makes more for the earth's motion than all the other prove against it; whom Pineda confutes, most contradict. Howsoever, it is revived since by Copernicus, not as a truth, but as a supposition, as he himself confesseth in the preface to Pope Nicholas, but now maintained in good earnest by Calcagninus, Telesius, Kepler, Rotman, Gilbert, Digges, Galileo, Campanella, and especially Lansbergius, as comporting with nature, reason, and truth. . . . For if the earth be the center of the world, stand still, and the heavens move, as the most received opinion is, which they call "a disordered arrangement of the heaven," though stiffly maintained by Tycho, Ptolemeus, and their adherents, . . . that shall drive the heavens about with such incomprehensible celerity in twenty-four hours, when as every point of the firmament and in the equator must needs move (so Clavius calculates) 176,660 in one 246th part of an hour; and an arrow out of a bow must go seven times about the earth whilst a man can say an Ave Maria, if it keep the same space, or compass the earth 1884 times in an hour, which is beyond human conceit.

Wavering again between the poles of comprehension and even assent, at one extreme, and bewilderment or incredulity at the other, Burton segues from a neutral summary of the Copernican system to a charged recognition of the magnitudes that it implies, and again to renewed speculation about extraterrestrial life.

They ascribe a triple motion to the earth, the sun immovable in the center of the whole world, the earth center of the moon alone, above Venus and Mercury [and] beneath Saturn, Jupiter, Mars, . . . a single motion to the firmament, which moves in thirty or twenty-six thousand years; . . . and so solve all appearances better than any way whatsoever, calculate all motions . . . without epicycles, intricate eccentrics, etc., "more accurately and fittingly by means of a single motion of the earth," says Lansbergius, much more certain than by those Alphonsine or any such tables, which are grounded from those other suppositions. And 'tis true they say, according to optic principles, the visible appearances of the planets do so indeed answer to their magnitudes and orbs, and come nearest to mathematical observations and precedent calculations, there is no repugnancy to physical axioms, because no penetration of orbs. But then between the sphere of Saturn and the firmament there is such an incredible and vast space or distance (7,000,000 semidiameters of the earth, as Tycho calculates) void of stars; and besides, they do so enhance the bigness of the stars, enlarge their circuit, to solve those ordinary objections or parallaxes and retrogradations of the fixed stars, that alteration of the poles, elevation in several places or latitude of cities here on earth (for, they say, if a man's eye were in the firmament, he should not at all discern that great annual motion of the earth, but it would still appear "an indivisible point" and seem to be fixed in one place, of the same bigness) that it is quite opposite to reason, to natural philosophy, and all out as absurd as disproportional (so some will) as prodigious, as that of the sun's swift motion of heavens.

But to grant this their tenet of the earth's motion: if the earth move, it is a planet, and shines to them in the moon, and to the other planetary inhabitants, as the moon and they do to us upon the earth. But shine she doth, as Galileo, Kepler, and others prove, and then it follows that the rest of the planets are inhabited, as well as the moon, which he grants in his dissertation with Galileo's *Nuncius Sidereus* "that there be Jovial and Saturn inhabitants," etc. . . .

We may likewise insert with Campanella and Brunus . . . there be infinite worlds, and infinite earths or systems, in an infinite ether. . . . For if the firmament be of such an incomparable bigness as these Copernical giants will have it, infinite, or approaching infinity, so vast and full of innumerable stars, as being infinite in extent, one above another, some higher, some lower, some nearer, some farther off, and so far asunder, and those so huge and great, insomuch that if the whole sphere of Saturn and all that is included in it—"if the whole entirety," as Fromundus argues, "were carried off among the stars, we would not even be able to see it, it would be like a mere point, so enormous is the distance between earth and the fixed stars." If our world be small in respect, why may we not suppose a plurality of worlds, those infinite stars visible in the firmament to be so many suns with particular fixed centers, to have likewise their subordinate planets, as the sun hath his dancing still round him? Which Cardinal Cusanus, Walkarinus, Brunus, and some others have held, and some still maintain (albeit spirits fed on Aristotle and educated in minute speculations may think otherwise). Though they seem close to us, they are infinitely distant, and so it follows that they are infinite habitable worlds. What hinders? Why should not an infinite cause (as God is) produce infinite effects? . . .

Kepler (I confess) will by no means admit of Brunus's infinite worlds, or that the fixed stars should be so many suns, with their compassing planets, yet the said Kepler between jest and earnest . . . seems in part to agree with this, and partly to contradict; . . . and so doth Tycho in his astronomical epistles . . . break into some such like speeches, that he will never believe those great and huge bodies were made to no other use than this that we perceive, to illuminate the earth, a point insensible in respect of the whole. But who shall dwell in these vast bodies, earths, worlds, "if they be inhabited? rational creatures?" as Kepler demands, "or have they souls to be saved? or do they inhabit a better part of the world than we do? Are we or they lords of the world? And how are all things made for man?" . . . This only he proves, that we are in the best place, best world, nearest the heart of the sun. . . .

The anxiety that emerges from Burton's account has less to do with the movement of the earth or with the incoherence of the universe than with the jumble of theories that astronomers and mathematicians propose. It is still a familiar lay person's complaint against scientists that, if they know so much, how can they disagree so radically with each other? Something like this (potentially) ad hominem *response causes Burton's prose to take a delightfully satirical turn.*

But to avoid these paradoxes of the earth's motion (which the Church of Rome hath lately condemned as heretical . . .) our later mathematicians have rolled all the stones that may be stirred, and to solve all appearances and objections have invented new hypotheses, and fabricated new systems of the world, out of their own Daedalian heads. Fracastorius will have the earth stand still, as before; and to avoid that supposition of eccentrics and epicycles, he hath coined seventy-two homocentrics, to solve all appearances. Nicholas Ramerus will have the earth the center of the world, but movable. . . . Tycho Brahe puts the earth [at] the center, the stars immovable, the rest with Ramerus, the planets without orbs to wander in the air, keep time and distance, true motion, according to that virtue which God hath given them. Roeslin censureth both, with Copernicus, whose hypothesis about the earth's movement Lansbergius hath lately vindicated. . . . The said Lansbergius, 1633, hath since defended his assertion against all the cavils and calumnies of Fromundus . . . , Morinus, and Bartholinus. Fromundus, 1634, hath written against him again, J. Rosseus of Aberdeen, etc. (sound drums and trumpets) whilst Roeslin (I say) censures all and Ptolemeus himself as insufficient. . . . In his own hypothesis he makes the earth as before the universal center, the sun to the five upper planets; to the eighth sphere he ascribes diurnal motion, eccentrics, and epicycles to the seven planets, which hath been formerly exploded. And so . . . as a tinker stops one hole and makes two, he corrects them, and doth worse himself; reforms some, and mars all. In the meantime, the world is tossed in a blanket amongst them; they hoist the earth up and down like a ball, [and] make it stand and go at their pleasure.

SOURCE: Robert Burton, *The Anatomy of Melancholy*, London, 1638; rpt. London, 1886.

29

A World in the Moon

John Wilkins

John Wilkins (1614–1672) had a great career in university, church, and scientific affairs in the England of the Interregnum and the Restoration. Among other things, he served as Master of Trinity College, Cambridge, and as Bishop of Chester. He was also one of the founders of the Royal Society. However, part of the charm of the writing presented here, excerpted from The Discovery of a World in the Moon *(1638), is that it is the work of a young person, only 24 years old, but powerfully aware that he stands on the brink of a brave new universe, one that is yet only dimly understood by those whose reading is limited to the English language.*

Though appearing more than sixty years after Digges's presentation of the outlines of the Copernican system in English, Wilkins's Discovery *clearly anticipates an audience that will find some of its suggestions shocking. The heliocentric "hypothesis" itself may at first, he says, seem "horrid." Having appealed to the authority of writers from Aristarchus to Copernicus and Lansbergius, he cites Campanella to the effect that*

Very many others both English and French . . . affirmed our earth to be one of the planets, and the sun to be the center of all, about which the heavenly bodies move. And how horrid soever this may seem at the first, yet is it likely enough to be true, nor is there any maxim or observation in optics . . . that can disprove it.

Now if our earth were one of the planets (as it is according to them), then why may not another of the planets be an earth?

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It is this pivotal inference—in Kepler, Wilkins, and others—that unleashed the entire genre of science fiction and began the modern history of speculation concerning extraterrestrial life—both that genre and that history, of course, themselves providing new ways of examining our world and its inhabitants. Such a reciprocal process engages the imaginative potential of what Hans Blumenberg calls "reflexive telescopics": No sooner did Galileo observe the moon through his telescope than the human race started to wonder how the earth and its inhabitants would look to someone observing them through a telescope on the moon. At a moral level we may see claims concerning extraterrestrials as involving a planetary reciprocity akin to "doing unto others as we would have them do unto us." If physical reality is homogeneous, then the planets represent a kind of society in which it is only fair to grant similar privileges to all.

In any case, Wilkins prefaces his main hypothesis with an examination of the hurdles that true science must overcome. Sounding a little like Francis Bacon a generation earlier, he acknowledges how hard it can be to transcend mere appearance and settled opinion.

Many evident truths seem incredible to such who know not the causes of things. You may as soon persuade some country peasants that the moon is made of green cheese (as we say) as that 'tis bigger than his cart-wheel, since both seem equally to contradict his sight, and he has not reason enough to lead him farther than his senses. Nay, suppose (saith Plutarch) a philosopher should be educated in such a secret place where he might not see either sea or river, and afterwards should be brought out where one might show him the great ocean, telling him the quality of that water, that it is blackish, salt, and not potable, and yet there were many vast creatures of all forms living in it, which make use of the water as we do of the air. Questionless, he would laugh at all this, as being monstrous lies and fables, without any color of truth.

Just so will this truth which I now deliver appear unto others. Because we never dreamt of any such matter as a world in the moon, because the state of that place hath as yet been veiled from our knowledge, therefore we can scarcely assent to any such matter. Things are very hardly received which are altogether strange to our thoughts and our senses. The soul may with less difficulty be brought to believe any absurdity, when it has formerly been acquainted with some colors and probabilities for it. But when a new and an unheard of truth shall come before it, though it have good grounds and reasons, yet the understanding is afraid of it as a stranger and dares not admit it into its belief without a great deal of reluctancy and trial. And besides, things that are not manifested to the senses are not assented unto without some labor of mind, some travail and discourse of the understanding. And many lazy souls had rather quietly repose themselves in an easy error than take pains to search out the truth.

The strangeness then of this opinion which I now deliver will be a great hindrance to its belief. . . . I have stood the longer in the preface because that prejudice which the mere title of the book may beget cannot easily be removed without a great deal of preparation. . . .

I must needs confess, though I had often thought with myself that it was possible there might be a world in the moon, yet it seemed such an uncouth opinion that I never durst discover it for fear of being counted singular and ridiculous. But afterward, having read Plutarch, Galileo, Kepler, with some others, and finding many of my own thoughts confirmed by such strong authority, I then concluded that it was not only possible there might be, but probable that there was another habitable world in that planet.

Wilkins's speculations do not concern the nature of the lunar inhabitants themselves but only what their world is like. In hindsight, we may find his thesis amusing, but this is a risk he knows he is taking. Moreover, his speculations, like most good science fiction (though Wilkins would not consider it fiction), are built upon a foundation of scientific plausibility. Part of Wilkins's foundation, as provided largely by Galileo, is the advantageous light that the moon receives from the earth. His eleventh proposition is "that as their world is our moon, so our world is their moon."

If there be such a world in the moon, 'tis requisite that their seasons should be some way correspondent unto ours, that they should have winter and summer, night and day, as we have.

Now that in this planet there is some similitude of winter and summer is affirmed by Aristotle himself, since there is one hemisphere that hath always heat and light, and the other that hath darkness and cold. True indeed, their days and years are always of one and the same length, but 'tis so with us also under the poles, and therefore that great difference is not sufficient to make it altogether unlike ours, nor can we expect that everything there should be in the same manner as it is here below, as if nature had no way but one to bring about her purposes. . . .

However, it may be questioned whether it doth not seem to be against the wisdom of providence to make the night of so great length, when they have such a long time unfit for work. I answer no, since 'tis so, and more with us also under the poles; and besides, the general length of their night is some-

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Wilkins spends more time supporting this opinion than we might think necessary, simply because it was indeed a new and as yet undigested idea. Only once space itself was firmly conceived of as homogeneous ("but one region"), and the two "planets" thought of (in Wilkins's words) as "loving friends," could their reciprocal relationship clearly be seen as involving what Galileo had called a "grateful exchange" of light.

'Tis the general consent of philosophers that the reflection of the sunbeams from the earth doth not reach much above half a mile high, where they terminate the first region, so that to affirm they might ascend to the moon were to say there were but one region of air, which contradicts the proved and received opinion.

Unto this it may be answered: that it is indeed the common consent that the reflection of the sunbeams reach only to the second region; but yet some there are, and those too philosophers of good note, who thought otherwise. Thus Plotinus is cited by Calius, "If you did conceive yourself to be in some such high place, where you might discern the whole globe of the earth and water when it was enlightened by the sun's rays, 'tis probable it would then appear to you in the same shape as the moon doth now unto us." Thus also Carolus Malapertius, whose words are these: "If we were placed in the moon, and from thence beheld this our earth, it would appear unto us very bright, like one of the nobler planets." Unto these doth Fromondus assent, when he says, "I believe that this globe of earth and water would appear like some great star to any one who should look upon it from the moon." Now this could not be, nor could it shine so remarkably, unless the beams of light were reflected from it. . . .

If you behold the moon a little before or after the conjunction, when she is in a sextile with the sun, you may discern not only the part which is enlightened but the rest also to have in it a kind of duskish light. But if you choose out such a situation where some house or chimney (being some 70 or 80 paces distant from you) may hide from your eye the enlightened horns, you may then discern a greater and more remarkable shining in those parts unto which the sunbeams cannot reach. Nay, there is so great a light that by the help of a good perspective [i.e., a telescope] you may discern its spots. . . .

But now this light is not proper to the moon. It doth not proceed from the rays of the sun which doth penetrate her body, nor is it caused by any other of the planets or stars. Therefore it must necessarily follow that it comes from the earth. . . . This light must necessarily be caused by that which with a just gratitude repays to the moon such illumination as it receives from her.

And as loving friends equally participate of the same joy and grief, so do these mutually partake of the same light from the sun, and the same darkness from the eclipses, being also severally helped by one another in their greatest wants. For when the moon is in conjunction with the sun, and her upper part receives all the light, then her lower hemisphere (which would otherwise be altogether dark) is enlightened by the reflection of the sunbeams from the earth. When these two planets are in opposition, then that part of the earth which could not receive any light from the sunbeams is most enlightened by the moon, being then in her full. And as she doth most illuminate the earth when the sunbeams cannot, so the grateful earth returns to her as great, nay greater, light when she most wants it. So that always that visible part of the moon which receives nothing from the sun is enlightened by the earth, as is proved by Galileo, with many more arguments. . . .

The manner of this mutual illumination betwixt these two you may plainly discern in this figure [on the opposite page], where A represents the sun, B the earth, and C the moon.

Now suppose the moon C to be in a sextile of increase, when there is only one small part of her body enlightened, then the earth B will have such a part of its visible hemisphere darkened as is proportionable to that part of the moon which is enlightened. And as for so much of the moon as the sunbeams cannot reach unto, it receives light from a proportional part of the earth which shines upon it, as you may plainly perceive by the figure.

You see then that agreement and similitude which there is betwixt our earth and the moon. Now the greatest difference which makes them unlike is this: that the moon enlightens our earth round about, whereas our earth gives light only to that hemisphere of the moon which is visible unto us, as may be certainly gathered from the constant appearance of the same spots, which could not thus come to pass if the moon had such a diurnal motion about its own axis as perhaps the earth hath. And though some suppose her to move in an epicycle, yet this doth not so turn her body round that we may discern both hemispheres.

At the end of his book, Wilkins returns to the question of the progress of knowledge—and, we would say, of technology. He won't speculate on the nature of the moon's inhabitants, "because I know not any ground whereon to build any probable opinion." But he does expound an enthusiastic dream of the expansion of human knowledge, a dream some parts of which have in-

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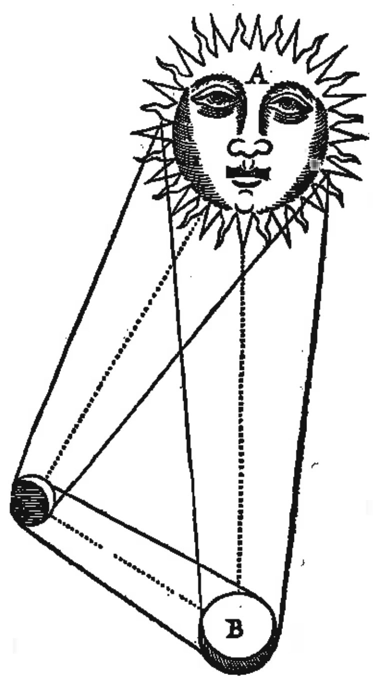
durst venture, there being f
vast ocean. And yet now h
cowardly nature?

be caused by that which with a
ation as it receives from her.
f the same joy and grief, so do
n the sun, and the same dark-
elped by one another in their
unction with the sun, and her
ver hemisphere (which would
by the reflection of the sun-
ts are in opposition, then that
ıy light from the sunbeams is
her full. And as she doth most
not, so the grateful earth re-
she most wants it. So that al-
eives nothing from the sun is
ılileo, with many more argu-

vixt these two you may plainly
where A represents the sun, B

of increase, when there is only
e earth B will have such a part
ortionable to that part of the
ı of the moon as the sunbeams
roportional part of the earth
ive by the figure.
e which there is betwixt our
ce which makes them unlike is
nd about, whereas our earth
n which is visible unto us, as
ppearance of the same spots,
n had such a diurnal motion
And though some suppose her
ı her body round that we may

e question of the progress of
y. He won't speculate on the
now not any ground whereon
pound an enthusiastic dream
some parts of which have in-



deed come true, even if the progress of time has not turned up evidence of lunar inhabitants.

I think that future ages will discover more; and our posterity, perhaps, may invent some means for our better acquaintance with these inhabitants. 'Tis the method of providence not presently to show us all, but to lead us along from the knowledge of one thing to another. 'Twas a great while ere the planets were distinguished from the fixed stars, and sometime after that ere the morning and evening star were found to be the same. And in greater space I doubt not but this also, and far greater mysteries, will be discovered.

In the first ages of the world, the islanders either thought themselves to be the only dwellers upon the earth, or else if there were any other, yet they could not possibly conceive how they might have any commerce with them, being severed by the deep and broad sea. But the after-times found out the invention of ships, in which notwithstanding none but some bold daring men durst venture, there being few so resolute as to commit themselves unto the vast ocean. And yet now how easy a thing is this, even to a timorous and cowardly nature?

So, perhaps, there may be some other means invented for a conveyance to the moon. And though it may seem a terrible and impossible thing ever to pass through the vast spaces of the air, yet no question there would be some men who durst venture this as well as the other. True indeed, I cannot conceive any possible means for the like discovery of this conjecture, since there can be no sailing to the moon.... We have not now any Drake or Columbus to undertake this voyage, or any Daedalus to invent a conveyance through the air. However, I doubt not but that time who is still the father of new truths, and hath revealed unto us many things which our ancestors were ignorant of, will also manifest to our posterity that which we now desire but cannot know. "Time will come," saith Seneca, "when the endeavors of after-ages shall bring such things to light as now lie hid in obscurity." Arts are not yet come to their solstice; but the industry of future times, assisted with the labors of their forefathers, may reach unto that height which we could not attain to.... As we now wonder at the blindness of our ancestors, who were not able to discern such things as seem plain and obvious unto us, so will our posterity admire [i.e., wonder at] our ignorance in as perspicuous matters. Kepler doubts not but that as soon as the art of flying is found out, some of their nation will make one of the first colonies that shall inhabit that other world. But I leave this and the like conjectures to the fancy of the reader, desiring now to finish this discourse, wherein I have in some measure proved what at the first I promised, a world in the moon.

SOURCE: John Wilkins, *The Discovery of a World in the Moon: or, A Discourse tending to prove that 'tis probable there may be another habitable World in that Planet*, London, 1638.

A Ver

The ideas of René Descar
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