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Ancestors of Apollo

Ten bold astronomers, five centuries ago, performed feats of imagination that prepared for the advent of human space flight 50 years ago

Dennis Danielson

The spring of 2011 marks the 50th anniversary of the beginning, in earnest, of the race to land a man on the Moon. On April 12, 1961, Yuri Gagarin, flying the Soviet *Vostok 1* spacecraft, became the first human in outer space as well as the first person to orbit the Earth. He was followed into space by Alan Shepard in America's *Freedom 7* on May 5. Less than three weeks later, on May 25, President John F. Kennedy stood before a joint session of the United States Congress and urged the nation to adopt "the goal, before this decade is out, of landing a man on the moon and returning him safely to the Earth"—a dream realized with the success of the *Apollo 11* mission only eight years later.

Yet Americans were able to take up President Kennedy's challenge only because they could already do something that humans had not always been able to do: imagine the physical possibility of space travel. Even those thrilling words that were suddenly on everybody's lips back in the spring of 1961—"astronaut" and "cosmonaut," coined from the ancient Greek via "Argonaut" and "aeronaut"—bespoke the ability to sail among the stars or out into the cosmos.

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This capacity to think concretely about space flight is something we have taken for granted since the advent of science fiction, so it's natural to think of stories such as Jules Verne's *From the Earth to the Moon* (1865) as the imaginative precursors of actual lunar voyages. In fact, the true ancestors of the space race were those who, centuries earlier, took small but crucial steps toward conceptualizing a universe in which earthlings could "sail" extraterrestrially. The 50th anniversary of human space flight is a good time to honor those intellectual adventurers who first imagined breaking the bonds of our earthly quarantine.

Going Back Centuries

So who were those pioneers of space travel? What steps (or leaps) did they take, and how did they take them? Most famous among them are Nicolaus Copernicus and Galileo Galilei—and their crucial contributions to space travel are best appreciated if we see what mental barriers they and fellow cosmological trailblazers had to overcome. Whereas his predecessors offered a scheme of the universe in which the Earth stood motionless in the center of the universe, with all stars and planets (including the Sun) circling about it, Copernicus switched around the positions of the Sun and the Earth, so that instead the Sun stood still at the center and the Earth circled about it.

This may sound simple enough to us, because we're used to the idea of living on a planet that is "third rock from the Sun" and makes an annual orbit. But if one compares the diagrams of the pre-Copernican and the Copernican systems, it's not as if the latter is simpler or more intuitively attractive than the former. Even if you were an accomplished mathematician with exceptional observational data to rely on, there was hardly any chance four or five centuries ago that you'd actually believe Copernicus. Copernicus himself, in his 1543 letter to Pope Paul III, admitted that his cosmology would initially seem absurd, and before 1600 there were only a dozen or so serious scientists anywhere in the world convinced that his cosmological proposal was correct.

Yet *unless* Copernicus was right, you probably couldn't imagine space flight. Nobody can conduct interplanetary travel from something that's not a planet, and before the advent of heliocentrism scarcely anybody thought of the Earth as a heavenly body or even as having things physically in common with what we see in the night sky. Once you did truly believe the Earth is a planet, you could imagine the other planets (the Moon among them) possibly sharing enough earthlike features that in principle earthlings might visit them. Until about 400 years ago, however, it's highly unlikely that you or any other smart, educated person *could* have believed it. Here are seven reasons why not.

For well over a thousand years, almost the only physics in town—that of Aristotle—had pictured what Arthur Koestler calls a "two-storey" universe, with the orbit of the Moon marking the boundary between the upper and lower storeys. Down here, below the Moon, there were four elements—earth, water, air and fire—but above the Moon was another type of material altogether: ether, also known as quintessence. There was no reason to think we could physically enter the ethereal realm, especially considering that earth, water, air and fire are also what *we* are composed of.

The laws of motion, as well as matter, were also assumed to be different above and below the orbit of the Moon. Natural motion down here, according to Aristotle, is straight-line motion toward the center (try simply dropping a pebble and see what it does). Natural mo-

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Figure 1. Earthrise, as seen by the *Apollo 8* mission to the Moon in 1968, shows a view of our world that may not surprise humans anymore, but would have been inconceivable to our ancestors until about five centuries ago. The concept that Earth was even a planet, that it was something we could physically disembark from, has been built up through the musings of philosophers since the 14th century. (Image courtesy of NASA.)

tion above the Moon is circular motion about a center (witness the observed circular courses of the stars). Contrary to this simple, well-established physics, Copernicanism, with its intertwined rotations and revolutions, entails an apparently inelegant tangle of motions. As the Jesuit astronomer Giovanni Battista Riccioli wrote in 1651, "More motions are imposed upon the system of the universe if the earth is moving rather than at rest, and without—in fact contrary to—sensible evidence."

Moreover, according to long tradition, the heavenly bodies were carried about in their revolutions by crystalline spheres. In the absence of Newtonian gravitation to explain orbital motion, how else could you explain the fact that swiftly circling bodies don't just fly off centrifugally? Yet if such crystalline spheres existed, they would function as a series of cosmic glass ceilings preventing travel from one planetary sphere to another. Galileo referred to this problem as "the impenetrability of the Peripatetic [Aristotelian] heavens."

There were observational as well as theoretical objections. The stars appear to move in circles about the Earth, and the Earth doesn't seem to move at all. Look out the window: Do you see the Earth moving? Stand still and concentrate: Do you feel the Earth moving? Of course you don't. So why would anybody believe anything so absurd?

Another experiment: Throw something straight up in the air and observe its behavior. The thrown object seems to come straight back down. Surely it wouldn't do this if the Earth were spinning like a top. (The expected deflection would be an instance of what is now known as the Coriolis effect.) Similar objections pointed to the apparently identi-

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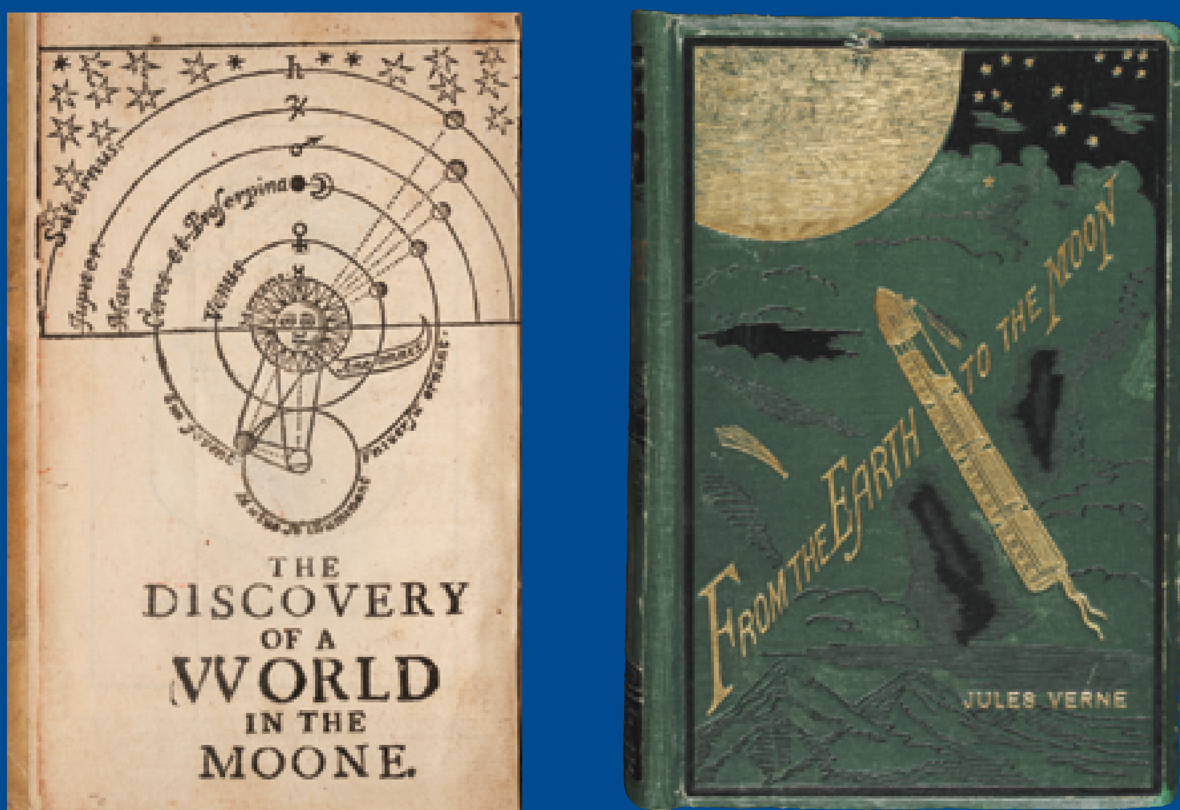

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Figure 2. It is often thought that the beginnings of space travel started with fictional works such as Jules Verne's novel *From the Earth to the Moon,* published in 1865 *(right).* In fact, the roots extend back much further, to works such as *The Discovery of a World in the Moone,* written by John Wilkins and published in 1638 *(left).* The title page of the book illustrates, among other concepts, light "traveling a two-way street" and thereby enabling the Earth and the Moon to share illumination.

cal behavior of cannon balls shot toward the east and toward the west. If the Earth were rotating, shouldn't these objects take different paths from each other?

For many centuries the planets were held to be heavenly, divine. For various cultures, each planet was associated with, or even embodied, a particular deity. For Copernicus to claim that Earth is one of them easily could have appeared as little less than chutzpah. Earth, in the Aristotelian tradition, is the cosmic low-point, the pit—in the words of the 15th-century Italian philosopher Pico, "the excrementary and filthy parts of the lower world." By contrast, the Sun is the most divine planet of them all. Surely it doesn't belong in the cosmic cellar. (In 2006 the International Astronomical Union voted to deny little Pluto its planetary status, and a great public uproar ensued, even though Pluto was discovered only 76 years earlier, and was never considered divine. How much worse, how blasphemous, that Copernicus should seek to demote the Sun by stripping it of its planetary status!)

Finally, Copernicanism implies that the universe is immensely larger than anyone had ever thought. The stars display no annual parallax, which implies they must be immeasurably distant from the Earth (with astonishing amounts of wasted space between us and them). Yet at those unbelievable distances, the stars—even viewed through a telescope—appeared as disks of measurable size, implying in some cases that their diameters are as great as that of the Earth's annual orbit. Incredible indeed.

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Figure 3. A portrait of Nicolaus Copernicus, by Polish artist Arthur Szyk in 1942, was commissioned as part of the quadricentennial anniversary of the astronomer's death. The style of the portrait was meant to echo medieval illuminated manuscripts.

This is but a partial list of objections. In 1651 Riccioli cited not seven but 77 arguments against Copernicanism. Taken individually, some of these were relatively weak, but some remained scientifically unanswerable until the 19th century. In any case, their cumulative mass presented a huge impediment to the relatively aerospace-friendly universe offered by the first Copernicans. A similarly massive collective effort was thus demanded before the cosmos of Copernicus could gain wide credibility. And like many collective efforts, the job of establishing the heliocentric system whose physics Newton would explain—physics that permitted space

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Figure 4. The Ptolemaic cosmos (from Peter Apian's *Cosmographia*, 1550) puts the Earth at the center of the universe, with the Moon and Sun among the seven planets that revolve around it *(left)*. The Copernican cosmos (taken from Copernicus's *De revolutionibus*, 2nd edition, 1566), now familiar to us, puts the Sun at the center, with the Earth as the third planet. Furthermore, it also has more than one center, as the Moon revolves around the Earth *(right)*.

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flight—required many brilliant individuals working over long periods of time. Although they themselves had outstanding ancient predecessors such as Pythagoras and Plutarch, in addition to the atomists, at least 10 of them from the late Middle Ages and the Renaissance deserve to be named as ancestors of the Apollo program.

Radical Thinkers

Two of the individuals who helped settle the question of Earth's place in the cosmos preceded Copernicus and were not themselves Copernicans. The first, French philosopher Nicole Oresme, articulated already in the 14th century the hypothesis that the Earth, not the universe, rotates once every 24 hours. Oresme argued that immobility could just as economically be attributed to the heavens as to the Earth and offered a thought experiment involving an extraterrestrial observer:

> If a man were in the sky and moving along with it in its presumed daily rotation, and if he could see the earth clearly … then it would seem to him that the earth made a daily rotation, just as it seems to us here on earth that the heavens do. Similarly, if the earth made a daily rotation and the heavens did not, then it would seem to us that the earth was at rest and that the heavens moved. … Therefore we could make no observation that would establish that the heavens perform a daily rotation and that the earth does not.

Although Oresme himself did not conclusively assert the motion of the Earth, his careful reasoning rendered the notion thinkable, even respectable.

In the next century, German philosopher Nicolaus Cusanus emphasized a similar principle of relative motion: "Anyone on board a ship but not knowing that the water is flowing, nor able to see the riverbanks, [may not] apprehend that the ship is moving." He declared, accordingly, that "it is actually this earth that moves, though to us it does not appear to do so." Unlike Copernicus a hundred years later, Cusanus did not follow up this assertion with any systematic model of the universe. However, he did sketch what would come to be known in Big Bang cosmology as the "principle of mediocrity," whereby "to anyone at all, whether he be on earth, or on the sun or another planet, it always seems as if he is

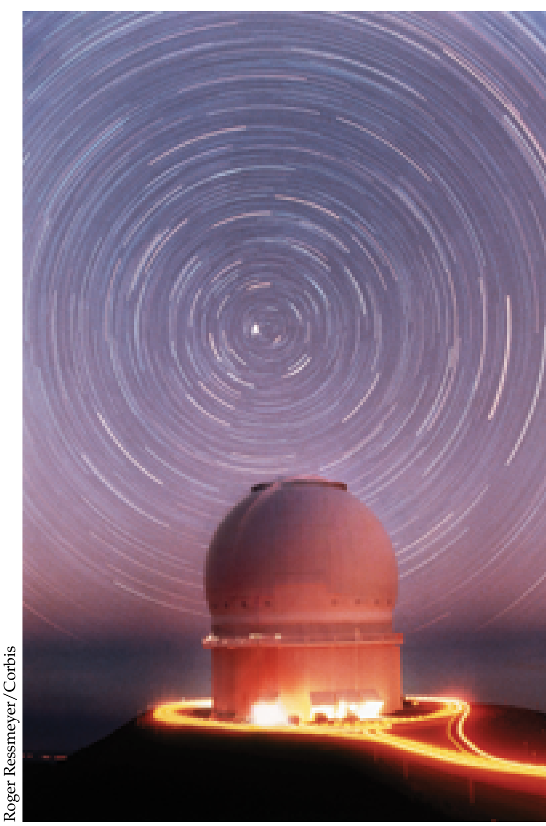

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Figure 5. This time-exposed view of star trails circling the North Star, from the Canada-France-Hawaii observatory on Mauna Kea in Hawaii, shows how stars seem to move in circular paths when viewed from Earth. It might not be surprising that this observation led philosophers millennia ago to conclude that the laws of motion differed above and below the Moon. Aristotle believed that natural motion on Earth is a straight line toward the center, whereas above the Moon it is circular about a center.

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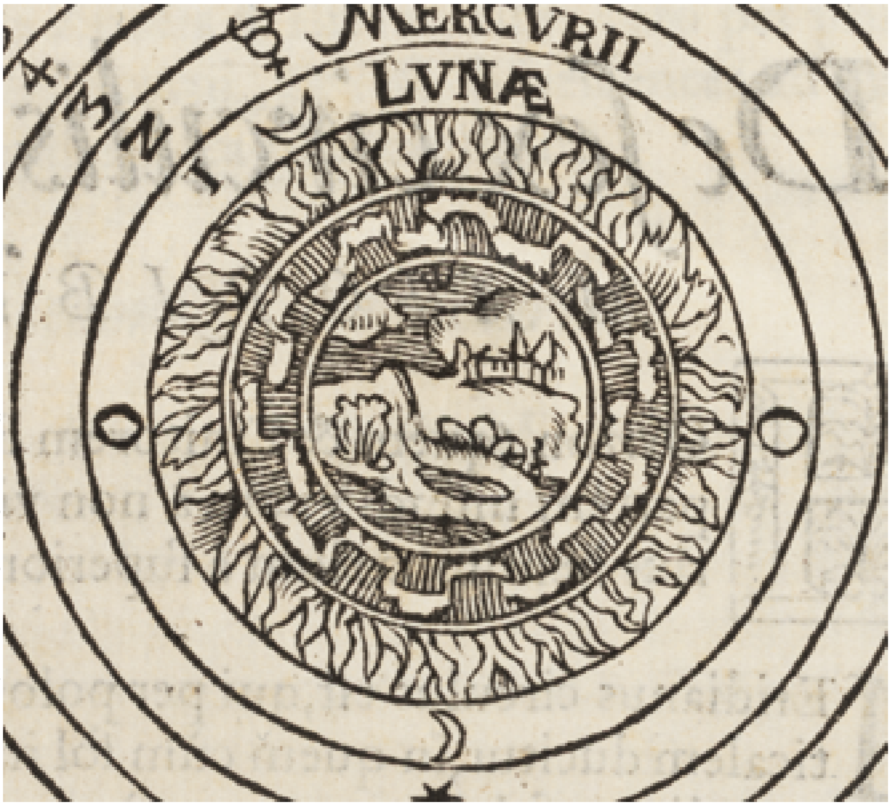

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Figure 6. For well over a thousand years, Aristotelean physics had dictated a "two-storey" universe, with the orbit of the Moon marking the boundary between the upper and lower stories. Below the Moon, there were four elements—earth, water, air and fire—as illustrated in this detail from *Cosmographica* by Peter Apian from 1550. But above the Moon was another type of material altogether: ether, also known as quintessence. Humans, being composed of the four elements, had no reason to think they could physically enter the ethereal realm.

in the center, immobile as it were, while everything else is in motion."

Just as radical was Cusanus's implied removal of the Earth from its Aristotelian quarantine in the cosmic "dead center." For him, the Earth should be seen as a dynamic part of the wider universe, "a magnificent star possessing light, heat and influence." In this way Cusanus exalted the Earth, denying its "utter corruptibility" and reimagining it as a shining component of "a single cosmos in which each star influences every other." So much for the old two-storey universe.

Of course in the Middle Ages and on into the Renaissance, the concept of stars also included "wandering stars"—which we call planets. Declaring Earth a planet was probably Copernicus's chief contribution to our ability to imagine space travel. For once Earth was reconceived as a planet, it was only a small step to thinking of the planets, including the Moon, as other Earths.

At the same time, Copernicus anticipated resistance to his new cosmology because of how he seemed to be causing the Sun, in his student Georg Joachim Rheticus's words, to "descend to the center of the universe." Copernicus's response to this concern was as much poetic as scientific. He sought to renovate the cosmic basement by declaring it a place of splendor, one befitting the Sun's dignity and its proper governance of the planets:

> Behold, in the midst of all resides the sun. For who, in this most beautiful temple, would set this lamp in another or a better place, whence to illuminate all things at once?... Truly indeed does the sun, as if seated upon a royal throne, govern his family of planets as they circle about him.

In this way Copernicus aimed to avoid dethroning the Sun even while raising Earth into the celestial realms, where, in Rheticus's words, it "moves among the planets as one of them."

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Figure 7. This engraving depicts a practical application of "God's geometry in heaven and on earth," a phrase used by Copernicus's student Georg Joachim Rheticus, as illustrated in Peter Apian's *Introductio Geographica* from 1533. Rheticus, an Austrian mathematician, helped pioneer trigonometry in hopes that better mathematics would convince more people that his teacher was right. Although he met with limited success during his lifetime, his work furthered an assumption that was—and is—crucial for exploration of the heavens: namely, that geometry can legitimately and effectively be applied astronomically.

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Rheticus, an Austrian mathematician, not only discovered Copernicus, but convinced the great astronomer to finish his work, and actually carried his manuscript from northern Poland to its publisher in central Germany. After Copernicus's death he also helped pioneer trigonometry in hopes that better mathematics (combined with further observations) would convince more people that his teacher was right. Although he met with limited success during his lifetime, his work furthered an assumption that was—and is—crucial for exploration of the heavens: namely, that geometry can legitimately and effectively be applied astronomically.

Although this may sound perfectly obvious to us today, a leap of imagination was required before geometry (literally, "earth measure") could be extended beyond our earthly domain. Demonstrating that it could be—asserting what Rheticus called "God's geometry in heaven and on earth"—further undermined the two-storey universe. What replaced it was a vision of a unified kingdom of which Earth was a full member and in which earthlings might properly dream of traveling to other parts of the realm.

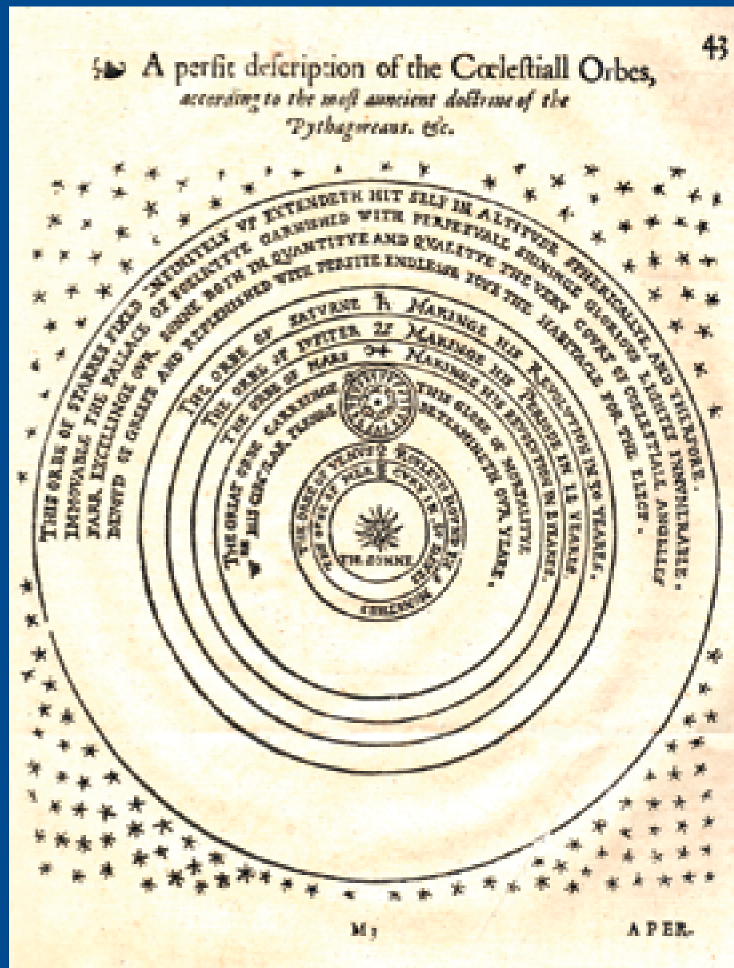

Figure 8. Thomas Digges, the foremost astronomer in 16th-century England, translated key chapters of Copernicus's works into English, endorsed Copernicus's explanations of gravity as attractions of mass, and even went much farther than Copernicus in his descriptions of the stellar sphere. Copernicus saw the universe as vast but finite, whereas Digges published in 1576 this graphic in which the realm of the stars "infintely up extendeth." (Image courtesy of Owen Gingerich.)

Through the Centuries

Thomas Digges, 16th-century England's foremost astronomer, helped place another nail in the coffin of the two-storey universe when he took measurements of the "New Star" of 1572 (now known as Tycho's Supernova) and so demonstrated that changes were indeed taking place in the superlunary realm. Digges also enthusiastically translated the core cosmological chapters of Copernicus into English so that "noble English minds … might not be altogether defrauded of so noble a part of philosophy." Digges endorsed Copernicus's highly preliminary but necessary attempt to explain gravity in terms of attraction to mass rather than place: "Gravity is nothing else but a certain proclivity or natural coveting of parts to be coupled with the whole."

Furthermore, Digges dealt with objections concerning the magnitude of Copernicus's universe by admitting "what little portion of God's frame" our Earth is, while piously acknowledging that we can "never sufficiently … admire the immensity of the rest"—which simply reflects the magnificence of the Creator. But here Digges went much farther than Copernicus. For although Copernicus retained an immense but finite stellar sphere, Digges, as indicated by his famous graphic, dramatically offered a universe whose realm of stars "infinitely up extendeth."

Attempts to forge a new, non-Aristotelian physics were also assisted by William Gilbert, another English astronomer, who actually never fully declared for Copernicanism but who strongly asserted the daily rotation of the Earth. His studies of magnetism and the behavior of lodestones (published as *De Magnete* in 1600) provided ways of grasping how the movement of the Earth could be thought of as natural and nonviolent.

A spherically shaped lodestone was called a *terrella*, literally a "little earth," and when hung up or floated on water, it would turn about of its own accord, moved by its "natural desire" to conform to the magnetic fields of the Earth. Gilbert's experiments led him to assert that the Earth itself is a giant magnet rotating once every 24 hours. He offered this model as much more coherent and economical than one in which the entire sphere of fixed stars is "swept round in [a] rapid headlong career." Finally, as part of the same discussion, Gilbert declared groundless any belief in Ptolemy's "adamantine spheres," those cosmic glass ceilings that would have been so inimical to space travel.

In 1610, a decade after Gilbert's book on terrestrial magnetism, Galileo Galilei published history's first account of astronomical observations performed with a telescope. What most thrilled Galileo was his discovery of the moons

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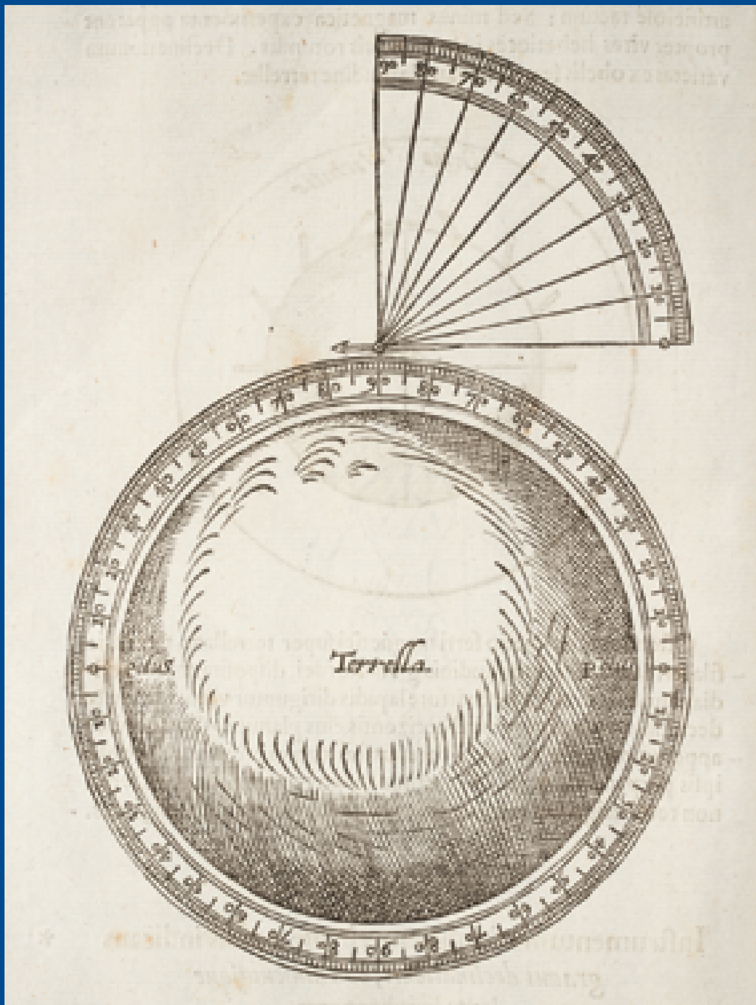

Figure 9. English astronomer William Gilbert in 1600 published his work with "terella," a miniature magnetic model of the Earth. The lodestone, when hung, would rotate of its own accord, conforming to the magnetic fields of the Earth. Gilbert's results led him to declare that the Earth itself is a giant magnet that rotates once every 24 hours.

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of Jupiter, because they confirmed, as Copernicus had declared, that in the universe there were "several centers."

But for purposes of space travel, two of Galileo's other telescopic discoveries stand out: his demonstration of how Earth reflects light onto the surface of the Moon (classically "planetary" behavior, which also guaranteed that Earth would be visible from the heavens); and his calculation, using simple geometry and the measurement of shadows, of the heights of lunar mountains. These helped establish as never before the affinity and likeness between the Earth and the Moon, and immeasurably enhanced humans' capacity to imagine setting foot on the less-well-explored of these two wandering stars.

Galileo's discoveries also helped establish the trend toward wondering whether other beings might already be leaving footprints on the Moon and other planets. Such speculation about extraterrestrials has of course continued to animate space exploration right up to the present day. Even 400 years ago, the German astronomer Johannes Kepler, Galileo's most prominent fellow Copernican, instantly recognized and pursued this connection.

Upon reading Galileo's *Starry Messenger* in 1610, Kepler asserted the probability "that there are inhabitants not only on the moon but on Jupiter too," and went on to speculate that the "Jovians" may enjoy four moons rather than one as consolation for the fact that they are

The Gallery Collection/Corbis

Figure 10. Italian astronomer Galileo Galilei (shown in this portrait by Ottavio Mario Leoni from the 1600s) published the first account of astronomical observations made with a telescope. He discovered the moons of Jupiter and also demonstrated how the Earth reflects light onto the surface of the Moon.

less ideally located in the universe than we earthlings. Kepler also boldly prophesied the day when we might launch our own lunar and planetary expeditions. For surely "settlers from our species … will not be lacking," and "given ships or sails adapted to the breezes of heaven, there will be those who will not shrink from even that vast expanse."

Coming Together

The cumulative work of these early Copernicans, along with that of anti-Aristotelian (if not quite fully Copernican) thinkers such as Gilbert, led to what one historian has called "England's lunar moment." In 1638, two influential works appeared that helped awaken more thoughts of space travel than ever before.

The first of these, published posthumously, was the imaginative fiction of an English bishop, Francis Godwin, titled *The Man in the Moon: or a Discourse of a Voyage Thither*. Some elements of his narrative, such as the tethered flock of geese that conveys the main character to the Moon, are indeed fanciful. But the journey offers a vivid, non-Aristotelian account of physical features such as gravitation (interpreted under the influence of Gilbert as a kind of magnetism) and the daily rotation of the Earth ("according to the late opinion of Copernicus"). What

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Figure 11. German astronomer Johannes Kepler, upon reading Galileo's reports in 1610 about the discovery of moons around Jupiter, asserted that Jupiter is probably inhabited and that the Jovians had received four moons, instead of Earth's one, as consolation for their less-ideal location in the universe.

Godwin's fiction perhaps most movingly conveys, however—something that was repeated in fact by the Apollo missions—is a vision of our own planet as a "new star" masked "with a kind of brightness like another moon."

A second work appearing in 1638, one powerfully influenced by Galileo and Kepler, was *The Discovery of a World in the Moone*, by John Wilkins, a clergyman as well as a founder of the Royal Society in England. Wilkins was a strong defender of Copernican astronomy, and extrapolated from it the idea of an inhabited Moon. Like Godwin, whose work he had yet to read, Wilkins not only vividly described conditions on the Moon but also imagined the shining appearance of our native globe from space: "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."

Admitting the difficulties of a lunar voyage but building, like others, on the recent success of journeys to earthly places such as America (the "New World"), Wilkins concluded by eloquently reprising the prophetic strains of Kepler. He could not, he admitted, conjecture how one might sail 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 … will also manifest to our posterity that which we now desire but cannot know."

Still today, of course, humankind has much to learn in its pursuit of new truths about the universe of which we are undeniably a part. But in commemorating the beginnings of the modern race to the Moon half a century ago, we may also savor the achievements of those ancestors of Apollo who in an earlier age prepared the way for lunar expeditions—as well as cherishing their added gift: heavenly glimpses of this noble blue-green wandering star.

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