GALILEO THE COPERNICAN

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We See Through a Glass Darkly

Seeing is believing, but we do not see with our eyes only. We look at the world with the aid of inherited images that we may strive to improve but that we do not work to replace unless something dramatic occurs. The traditional Earth-centred system was confirmed not just by the everyday experience of seeing the Sun rise and set, but by the high-powered geometry that was embodied in Ptolemy's *Almagest,* the result of centuries of diligent observation and detailed computation. Anyone who opens that great classic today cannot fail to be impressed by the mathematical sophistication that is displayed on virtually every page. Better still, those who use the Ptolemaic methods to determine the position of the planets find that they work. Indeed, elementary astronomy is still presented from the standpoint of a motionless Earth, and we learn to calculate where Venus or Mars will be in the night sky on the assumption that the celestial vault revolves once every twenty-four hours. We know, of course, that this is a fiction, but it remains a convenient fiction. It would not merely be pedantic, but foolish, to correct people who say that the Sun moves from east to west by pointing out that it is really the Earth that rotates from west to east. If you doubt this, try playing the rigorous astronomer at the next cocktail party. You may well discover that people are neither impressed nor amused.

A more contemporary instance of outmoded representation is our way of conceiving the celestial vault as a two-dimensional surface, a grid on which to plot the position of stars, although we know that there is a third dimension and that the stars are strewn at enormous distances in the vast profundity of space. Bigger telescopes and more advanced instruments enable us to plunge ever deeper into the stellar and galactic sea. We reach greater distances because we are carried there by high-tech. If technological development were to come to halt, we could see no further. Our vision is limited by our optics and the reliability of our remote sensors. We could, of course, allow our mind to go on wandering through interstellar space but we would not want to say that a theory, however ingenious, is true unless it is confirmed by evidence. In the absence of telling facts, we can only have suggestive ideas. Current astrophysics is full of clever hypotheses waiting to be winnowed out from the chaff. It is a case of, "Wait and see", or, rather, "Wait until you see".

I labour this point because it is essential to our understanding of Galileo's achievement. Copernicus' *De Revolutionibus Orbium Caelestium* was published in Nuremberg in 1543, nineteen years before Galileo's birth, and he was only two years old when the second edition appeared in Basel in 1566. In other words, by the time Galileo got his first university appointment at the University of Pisa in 1589, Copernicanism was no longer a shocking novelty. Professional astronomers had moved on to Tycho Brahe's compromise system where the planets were made to revolve around the Sun, while the Sun itself continued to wheel around a stationary Earth. The Jesuits, who had the best educational establishments in Catholic Europe, favoured this idea and contributed to its refinement. The *Almagestum Novum* that was published by one of their professors, Giovan Battista Riccioli, in 1651, almost ten ears after Galileo's death, offered a revised version of Tycho's system. It became the most authoritative textbook in astronomy, and was only supplanted by Newton's *Philosophiae Naturalis Principia Mathematica* in 1687.

The most creative and daring Copernican of Galileo's generation was Johann Kepler, Tycho's erstwhile assistant, who placed the Sun squarely at the centre of planetary motions after hundred of pages and several years of calculation. The results of his painstaking efforts were incorporated into a pair of laws that overthrew two fundamental notions of traditional Aristotelian physics –that celestial objects move in circles, and that those movements are uniform. First, Kepler wrote, the orbit of each planet is an ellipse. Second, while travelling along that ellipse, the planet slows down as it moves away from the Sun and speeds up as it nears the Sun.[1] Later, Kepler added a third law: the farther a planet's average distance is from the Sun, the longer it takes to orbit around the Sun; the nearer the shorter. Kepler determined the ratio: the square of the time it takes a planet to complete one orbit around the Sun is proportional to the cube of the average distance of the planet from the Sun.

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[1] See Job Kozhamthadam, *The Discovery of Kepler's Laws*. Notre Dame and London: Notre Dame University Press 1994.

Kepler was born in 1571 and was Galileo's junior by seven years. His first two revolutionary laws appeared in his *Astronomia Nova* in 1605, when Galileo was teaching at the University of Padua. It would seem that Galileo never bothered to read the weighty volume or, if he did, he was not convinced. To his dying day, he continued to believe, and to urge upon others, that celestial bodies move in perfect circles. Galileo did not become a Copernican because mathematics, at the hands of Kepler, accorded with observations. What happened was something quite different, and this paper is an attempt to show that it had much more to do with optics than with philosophy or mathematics.

Look Before You Leap

Galileo had been investigating the idea that the Earth might be in motion since at least the early 1590's when he discussed astronomical models with colleagues and friends in Padua and Venice.[2] He may be said to have had Copernican leanings rather than Copernican convictions until 1609, when something radically new happened. The novelty had nothing to do with ethereal speculation; it was the mundane outcome of playing around with concave and convex lenses, in Italy around 1590, in the Netherlands in 1604, and in the whole of Europe by the summer of 1609. Out of a toy to make objects appear larger, Galileo made, first, a naval, and then a scientific instrument. In the *Sidereus Nuncius*, which appeared in April 1610, he tells us how he heard of the telescope:

> About ten months ago a report reached my ears that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect several experiences were related, to which some persons gave credence while others denied them. A few days later the report was confirmed to me in a letter from a noble Frenchman at Paris, Jacques Badovere, which caused me to apply myself wholeheartedly to investigate means by which I might arrive at the invention of a similar instrument. This I did soon afterwards, my basis being the doctrine of refraction.[3]

The phrase "my basis being the doctrine of refraction" has sometimes been interpreted as though Galileo claimed to have worked out the properties of

[2] Stillman Drake, "Galileo's Steps to Full Copernicanism, and Back", *Studies in History and Philosophy of Science* 18 (1982), pp. 93-103.

[3] Galileo Galilei, *Sidereus Nuncius* [1610] in *Le Opere di Galileo Galilei*, edited by A. Favaro, 20 vols. Florence: 6. Barbèra, 1890-1909). vol I, p. 60 (this edition will be cited as *Opere*). English translation in Stillman Drake, *Telescopes, Tides and Tactics*. Chicago: Chicago University Press, 1983, p. 19.

lenses the way Kepler was to do a year later in his *Dioptrics*. Actually Galileo's theory was more modest and, significantly, more empirical. He saw that he would need lenses at both ends of a tube, and he tried a combination of a concave and a convex one. The result was what we know as the opera glass where the object is shown upright and not upside down, as in rival telescopes where two convex lenses were used.

Rumors of the invention of the telescope had probably reached Galileo in July 1609 when he visited friends in Venice to explore ways of increasing a salary that had become inadequate for an elder brother expected to provide dowries for two sisters. He received little encouragement from the Venetian patricians who controlled the University of Padua, but he had a flash of insight when he heard that someone had presented Count Maurice of Nassau with a spyglass by means of which distant object could be brought closer. The Venetians might not see how they could increase his salary, but what if he succeeded in enhancing their vision?

When Galileo returned to Padua on August 3, his fertile mind was teeming with possibilities. By August 21, he was back in Venice with a telescope capable of magnifying eight times. He convinced worthy senators to climb to the top of a tower from whence they were able to see boats coming to port a good two hours before they could be spotted by the naked eye. The strategic advantage of the new instrument was not lost on a maritime power, and it suddenly became clear to all that Galileo's salary should be increased from 520 to 1000 florins per year.

Unfortunately, after the first flush of enthusiasm, the senators heard the sobering news that the telescope was already widespread throughout Europe, and when the official document was drawn up it stipulated that Galileo would only get his raise at the expiration of his existing contract a year later, and that he would be barred, for life, from the possibility of subsequent increase.

This incident understandably made Galileo sour. He had not claimed to be the inventor of the telescope, and if the Senators had compared his instrument with those made by others they would have found that his own was far superior. Let the Venetian Republic keep the eight-power telescope! He would make a better one and offer it to a more enlightened patron. Better still, he would show that much more could be revealed not only on land and sea, but beyond the reaches of human navigation.

The Moon's New Face

Galileo pointed the telescope to the heavens, and for the first time the human eye had a close-up view of the Moon. His reason for examining the Moon was probably to confirm a conjecture that he had made in a satirical book published under the pseudonym of Alimberto Mauri in

1606.[4] The changes in the features of the lunar surface that can be seen with the naked eye had already been adduced in Antiquity as evidence that there are mountains on the Moon.[5] Galileo's eight-power telescope was sufficient to strengthen this hypothesis, and by November 1609 he had a fifteen-power telescope that enabled him to set all doubt aside. By March 1610, he had devised an instrument that magnified thirty times.

Galileo's construction of the telescope was the result of ingenuity and inventiveness rather than theoretical know-how. He remained in the dark about the laws of optics that lay behind his success. But although he could not determine the magnifying power from the focal lengths of the concave and convex lenses as we do today, he found a practical and reliable method that bypassed geometrical considerations:

> Now, to determine without great trouble the magnifying power of an instrument, trace on paper the outlines of two circles (or two squares) of which one is 400 times as large as the other, as will be the case when the diameter of one is 20 times that of the other. Then, with two such figures attached to the same wall, observe them both simultaneously from a distance, looking at the smaller one through the telescope and at the larger one with the other, unaided eye. This may be done without difficulty, holding both eyes open at the same time, and the two figures will appear to be of the same size if the instrument magnifies objects in the said ratio.[6]

This simple technique gives us a good idea of Galileo's resourcefulness and his practical cast of mind. The results were spectacular. In his own words, he found,

> that the surface of the Moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and all other heavenly bodies) to be, but uneven, rough, and full of cavities and prominences, it being not unlike the surface of the earth, in relief with mountain chains and deep valleys.[7]

Hence the possibility of a daring inference:

> Should anyone wish to revive the old Pythagorean opinion that the Moon is like another earth, its brighter parts might very fitly represent the surface of the land and its darker regions that of the water. I have never doubted that if our globe were seen from afar when flooded with sunlight, the land areas would appear brighter and the watery regions darker.[8]

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[4] The work is translated in Stillman Drake, *Against the Philosophers*. Los Angeles: Zeitling and Ver Brugge, 1976.

[5] The main source in Antiquity is Plutarch, *The Face on the Moon*, edited and translated by H. Cherniss, in *Plutarch's Moralia*, vol. XII. Cambridge, Ma: Harvard University Press, 1957.

[6] *Sidereus Nuncius*, *Opere*, I, 61; Drake trans. pp. 21-22.

[7] *Opere*, I, 62-63; Drake trans. p. 24.

[8] *Opere*, I, 65, Drake trans. p. 27.

The analogy of the Moon with the Earth received additional support from another startling discovery: earthshine! When the waxing or waning Moon is examined through a telescope, a partial or secondary illumination of the dark portion can be correlated with the sunlight that is reflected by the Earth. It cannot be the Moon's own light or a contribution of starlight, since it would then be seen during eclipses, which is not the case. "The Earth", Galileo wrote, "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".[9]

The New Heavens

Meanwhile the telescope continued to produce marvels and filled the night sky with new stars. In the Pleiades, the known population grew from six to forty stars and, in Orion, a constellation became richer by five hundred members literally overnight. The Milky Way, the faintly luminous band of light in the night sky that had puzzled astronomers from time immemorial turned out to be jam-packed with countless starlets.

But the most momentous discovery was still to come. It began, quite innocently, on the evening of 7 January 1610 when Galileo noticed three stars he had never seen before in the vicinity of Jupiter. They did not seem particularly noteworthy at the time but he happened to mention them in a letter as an instance of the kind of thing that was cropping up with every round of observation. On the following evening, he was struck by the fact that whereas two of the stars had appeared to the east of Jupiter, and the third to the west, they were now all three to the west. Stars do not wander about like planets and so Galileo asked himself whether Jupiter, contrary to all astronomical charts, was moving to the east instead of going west. If this was the case he thought he might be in a position to improve the existing ephemerides, and he eagerly awaited the next evening. Unfortunately, as astronomers experience only too often, the weather let him down. The sky was overcast and he had to wait until the 10th. This time only two of the stars were visible, both to the east, the planet itself presumably obscuring the third. On the 11th the two stars ware still to the east, but the farthest from Jupiter was now much brighter (see Figure 1).

The problem was to calculate how the planet could be travelling in such a way as to create these changing arrangements, and it began to dawn on Galileo that it might not be Jupiter that was moving, but the new stars themselves. Over the following days he found himself returning to this possibility. On the 12th, the third star reappeared to the west of Jupiter. On the 13th, a fourth star became visible; three stars were now to the west and one

[9] *Opere*, I, 74; Drake trans. p. 44.

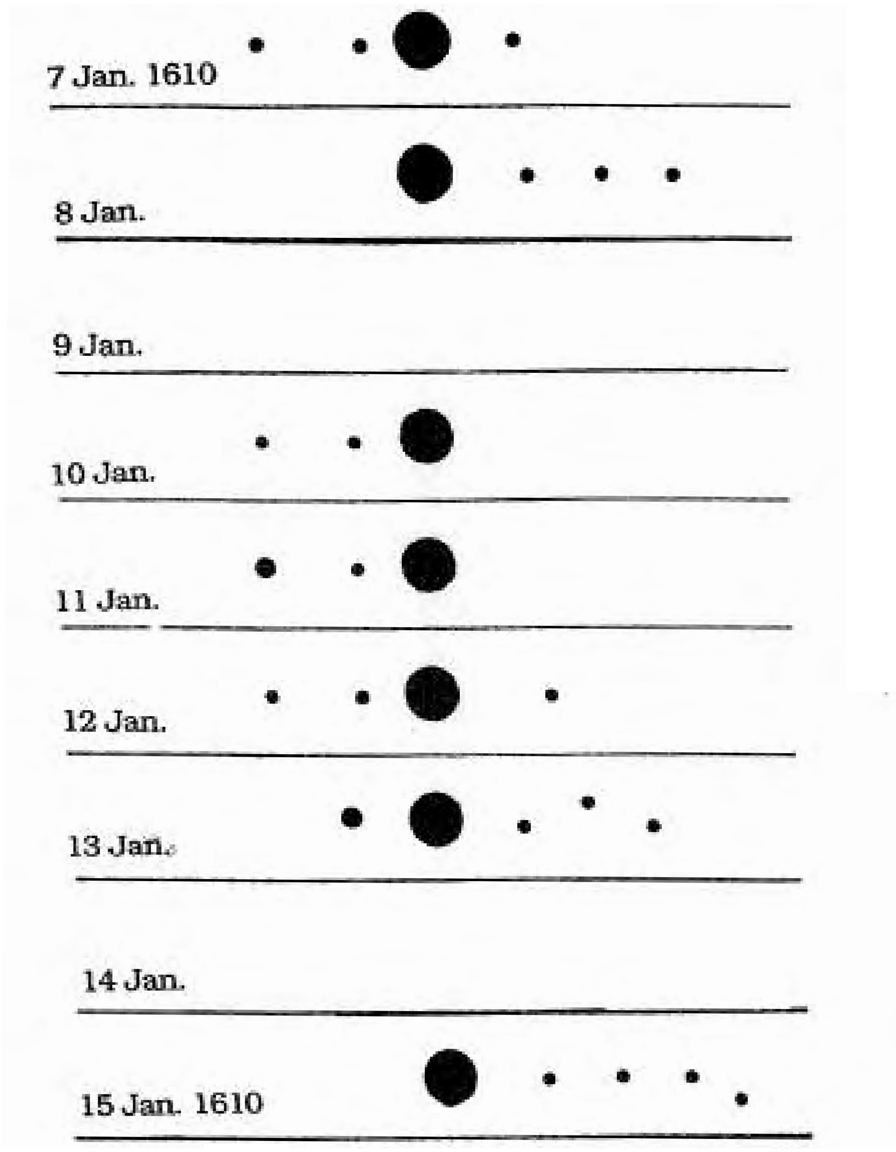

Fig. 1. Jupiter and its satellites.

the east. On the 14th, the sky was again overcast. On the 15th, Galileo added a refinement that might seem obvious to us but that he had hitherto neglected: the times of observations. Now, "in the third hour of the night", he found four stars again, all to the west in a row, "but in the seventh hour only three stars were present in this arrangement with Jupiter". Between these two observations Galileo had taken a significant step. He had begun copying the previous week's rough notes, and he had switched from the informality of Italian to scholarly Latin. There was only one possible explanation for what he had been observing: the four objets were not fixed stars but little planets circling Jupiter the way the Moon goes around the Earth. Why this was so exciting, Galileo tells us himself:

> Here we have a powerful and elegant argument to quiet the doubts of those who calmly accepted that the planets revolve around the Sun in the Copernican system, are so disturbed to have the Moon alone revolve around the Earth while accompanying it in an annual revolution about the Sun, that they hold that this structure of the universe should be rejected as impossible. But now we have not just one planet revolving around another; our eyes show us four stars that wander around Jupiter as does the Moon around the earth, and that all together they trace out a great circle around the Sun in the space of 12 years.[10]

To those who objected that the Earth could not wheel around the Sun without losing its Moon, Galileo could now point to Jupiter circling around the Earth, as they believed, or the Sun, as Copernicus argued, without losing not one but four satellites. If Galileo could not explain why the Earth did not shed its Moon, the Aristotelians were equally at a loss to say why Jupiter held on to its satellites. From challengers, the geocentrists were becoming the challenged!

From time immemorial, no new planets had been sighted, and Galileo saw that the satellites of Jupiter could be made to serve not only an astronomical but a wordly cause. Anxious to ingratiate himself with the Grand Duke of Tuscany, he named the new "stars" *Medicean* after the family of the reigning Prince, Cosimo II, and he rushed into print with a fifty-eight page pamphlet that came off the press in Venice on 13 March 1610. It was entitled *Sidereus Nuncius*, which Galileo intended as "the message from the stars", but the Latin could be read as "the messenger from the stars", and from the start translations favoured the latter. If this allowed Galileo's friends to praise him as a herald from above, it also provided his rivals with an opportunity to scoff at his arrogance.

The news was so sensational that on the very day that the *Sidereus Nuncius* appeared, the English Ambassador, Sir Henry Wotton, forwarded a copy to his King, James I. In the covering letter, he wrote, "I send herewith unto his Majesty the strangest piece of news (as I may justly call it) that he hath ever yet received from any part of the world". The Ambassador did not give the author's name, Galileo Galilei, but referred to him as the Professor of Mathematics at Padua. He provided a brief but faithful summary of the celestial novelties: the mountains on the Moon, the new stars, the nature of the Milky Way, and Jupiter's satellites. Strangest of all to Wotton was that the Moon should be illuminated by the Sun's light reflected from the Earth. He was not sure he had got this last point right, or perhaps not sure that it

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10 *Opere*, I, 95; Drake trans. pp. 88-89.

was credible, for he adds, "as he seemeth to say". But he had no doubt that Galileo "hath first overthrown all former astronomy –for we must have a new sphere to save the appearances– and next all astrology". Although Galileo had avoided discussing the possible implications of his discovery of new sources of astral influences, Wotton voiced his concern: "For the virtue of these new planets must needs vary the judicial part [namely horoscopes], and why may there not yet be more"? Before concluding, by promising to send one of the new instruments by the next ship, the Ambassador realised that he might have been carried away, and to show that he had not cast all caution to the wind, he added, "And the author runneth a fortune to be either exceeding famous or exceeding ridiculous".[11] Such residual qualms were not echoed by the British natural philosopher William Lower who declared upon hearing the news, "Me thinkes my diligent Galilaeus hath done more in his three fold discoverie than Magellane in openinge the streightes to the South sea".[12] A few months later the Scottish poet Thomas Seggeth published nine epigrams in which the rhetoric of compliment becomes pure adulation. Seggeth declares that Galileo made gods of mortals by enabling them to reach stars known hitherto only to then; that Galileo owes much to God, to be sure, but that Jupiter himself owes much to Galileo; that Columbus gave man new worlds to be conquered by bloodshed, Galileo gave man new worlds harmful to none. Which he asks, is the greatest? In one of the epigrams, Seggeth groups together Kepler and Galileo and introduces into his verses the famous *Vicisti Galilaee*, the alleged dying words of Julian the Apostate (332-363), which mean "You have conquered, Galilean," but can also be rendered, "You have conquered, Galileo".[13]

Not to be undone, the German physician Johann Faber later proclaimed:

> Yield, Vespucci, and let Columbus yield. Each of these
> Holds, it is true his way through the unknown sea,
> But you, Galileo, alone gave to the human race the sequence of stars,
> New constellations in heaven.[14]

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[11] Henry Wotton to the Earl of Salusbury, 13 March 1610, quoted in Marjorie Nicolson, "The *New Astronomy* and English Literary Imagination", *Studies in Philology* XXXII (1935), p. 440.

[12] William Lower to Thomas Harriot, 21 June 1610, quoted in Marjorie Nicolson, "The *New Astronomy* and English Literary Imagination", *Studies in Philology* XXXII (1935), p. 441.

[13] Seggeth published his epigrams as an appendix to Kepler's *Account of my Observations of Jupiter's Satellites* published in October 1610, but bearing 1611 as the date on the frontispiece. *Opere*, III, 188-190.

[14] Faber published these verses at the beginning of Galileo's *Il Saggiatore*. *Opere*, VI, 205-206.

A second Look

The prompt, judicious and accurate reporting of the English Ambassador, and the poetical rhapsodies of well-wishers might lead us to believe that Galileo's discoveries were fêted everywhere. What the Imperial Ambassador to Venice, Georg Fugger, wrote to Kepler a month after the publication of the *Sidereus Nuncius* reveals another side of the coin. Replying to a query that Kepler had made, the Ambassador declared that many competent people in the mathematical sciences found the *Sidereus Nuncius* mere show, a dry and baseless discourse. Galileo was the kind of person who was accustomed to decorate himself with others' feathers, like Aesop's crow. He would like to be thought the inventor of the spyglass, which had been brought to Venice and shown to the Ambassador and others by a Fleming. Galileo saw it and copied it, perhaps adding something, "which would be easy enough", declares Fugger.[15] There was no question of sending such a shoddy work to the Emperor. This petty and second-hand report did not turn Kepler against Galileo He had already seen the copy of the *Sidereus Nuncius* that had been sent to the Tuscan ambassador in Prague and his response was characteristically generous and enthusiastic. He also hailed Galileo as a new Columbus.

Ambassador Fugger was annoyed that Galileo should have implied that he had invented the telescope when he had, according to him, seen the one that was offered for sale by a travelling salesman from Flanders, but there is no indication that he was disturbed by the Copernican intimations. Fugger thought of himself as a high-principled diplomat, who had every right to be irritated at the guile of an academic non-entity. He was wrong, of course, but his conceit should not lead us to assume that everyone who experienced difficulties with Galileo's claims was equally prejudiced. Everyone wanted to see what Galileo claimed to have observed but only a handful of persons had access to a decent telescope

Galileo had realised that the *Sidereus Nuncius* should be accompanied by a telescope but he experienced considerable difficulty in producing good ones. On 19 March 1610 he wrote to Belisario Vinta, the Tuscan Secretary of State: "Spyglasses of high quality capable of showing all the objects observed are very rare. Out of over sixty that I had made at considerable expense and trouble, I could only keep a very small number that I intend to send to great princes".[16] In the draft of the letter Galileo had written that only ten out of one hundred could be considered satisfactory. Two were destined "to friends and relatives of the Grand Duke", another three to meet requests received from Maximilian, the Duke of Bavaria, his uncle Ernest, the Archbishop and Prince Elector of Cologne, and Cardinal Francesco Maria del Monte. The remaining five he hoped to send to heads of state in

[15] Georg Fugger to Kepler, 16 April 1610,*Opere*, X, 316.
[16] Galileo to Belisario Vinta, 19 March 1610, *Opere*, X, 301.

Spain, France, Poland, Austria and Urbino, if the Grand Duke so wished and was willing to grant him access to such high personages.

Galileo had not made as many as ten good telescopes, and he was more cautious in the letter he actually sent to Vinta in which he only mentions that he has a very small number of good specimens. The first to get one was of course the Grand Duke of Tuscany. The second was almost certainly Cardinal del Monte but he only received his in April. Duke Maximilian and Archbishop Ernest, who were at the top of the list, had to wait longer. On 12 May, Thomas Mermann, Maximilian's personal physician and advisor, wrote to say that the Duke was eagerly awaiting the spyglass and suggested that it be forwarded through Andrea Minucci, the Bavarian Ambassador to Venice. The telescope, made in Padua, was only delivered to Minucci on 28 May. The Archbishop and Prince Elector of Cologne had to wait even longer, and the instrument he received was rather poor. He complained to Kepler that "for convenience of observation, it was much inferior to others he had because it showed the stars as rectangular".[17] On 19 April 1610, the Tuscan Ambassador in Prague, Giuliano de' Medici, requested a telescope for the Emperor Rudolph II in Prague. On 29 May Cardinal Scipione Borghese, the nephew of the Pope, asked for one which arrived with remarkable speed on 19 June. Unfortunately, it should have gone to the Emperor, who found out in August and complained bitterly to the Ambassador Giuliano de' Medici that priests had robed him of his telescope. Meanwhile he had charged his Ambassador in Venice, the very Georg Fugger who had shown himself so nasty, to find one, which he did in July. Galileo probably felt that he no longer had to send one to Prague, and he provided Cardinal Alessandro Peretti di Montalto with a telescope in July. Cardinal Francesco Maria del Monte also received a telescope at this time, his second. It would seen that del Monte demonstrated the use of the instrument to other cardinals who were less proficient in astronomy, and that he had been made to part with the first one that Galileo had given him. In thanking Galileo, he promised that he would never surrender the new one "whoever it may he who asks for it".[18] Meanwile, the Tuscan Ambassador in Paris, Matteo Botti, had informed Belisario Vinta that Queen Marie de' Medici wanted a telescope from Galileo because those she could purchase in Paris were second-rate. She had to wait until September because the next telescope that Galileo made had been promised to Cardinal Odoardo Farnese to whom it was delivered in August. By this time Galileo had been appointed mathematician and philosopher of the Grand Duke of Tuscany and he saw no point in spending time in his workshop in Padua. As he explained to Kepler:

[17] Reported by Kepler in his *Account of my Observations of Jupiter's Satellites*. *Opere*, III, 184.

[18] Cardinal Francesco Maria del Monte to Galileo, 24 July, 1610, *Opere*, X, 407.

> I have devised a few machines to grind and polish lenses but I decided not to make them here because I could not transport them to Florence, my future place of residence. I'll build them there as soon as possible.[19]

Galileo sometimes found it difficult to teach his colleagues how to use the new instrument. On his way back to Padua from Pisa he stopped at Bologna on 24 April to show Jupiter's satellites to Antonio Magini. An account of this visit is provided in the letter that Martin Horky, Magini's assistant, wrote to Kepler the day after Galileo left. None of the several learned men present could see the two satellites that Galileo saw and recorded in his own log of observations for the evening. According to Horky, although the telescope "worked wonders on earth, in the heavens it failed because it made other fixed stars appear double". Galileo had tried "to hawk a fable", and early on the morning of 26 April slunked away in disgrace. But the really disgraceful person was Horky, who switches from Latin to German to brag to Kepler: "I have secretly taken wax impressions of his lenses from which I will make a better spyglass than Galileo when God enables me to get back home".[20]

The problem was that the act of seeing through a telescope was not so simple. The lenses placed at both ends of a tube not only magnified the image, they also produced distortions: elongations, blurriness, colour fringes. The field of vision of Galileo's telescope was very narrow and he could not see more than a small fraction of the Moon at a time. It was virtually impossible to focus the meter-long instrument without fixing it to a windowsill or a stand. Elderly scholars, who tried to handle the telescope, were annoyed when the objet kept jumping about. Cesare Cremonini, the professor of philosophy at Padua, complained that looking through the telescope gave him a headache. His colleague at Pisa, Giulio Libri, had the same problem. Neither were very patient and like many philosophers, now as well as then, they did not want to waste their precious time fooling around with optical tubes. The astronomer Magini was willing to invest more energy, and when Galileo visited him again in September 1610 he found that he could use a telescope. Philosophers, who write as though the history of science is the unfolding of ideas, have blinded themselves to the fact that seeing is in some respects an art that must be learned. Practice makes the master, whether it be seeing through a telescope, playing a luthe, or drawing a portrait.

The Mother of Love and Cynthia

The satellites of Jupiter were the last of Galileo's discoveries in Padua. Shortly after his return to Florence, Venus, Saturn, and the Sun provided more celestial news.

[19] Galileo to Kepler, 19 August 1610, *Opere*, X, 421-422.
[20] Martin Horky to Kepler, 23 April 1610, *Opere*, X 343.

Among the difficulties raised against Copernicus' theory was the fact that Mercury and Venus, like the Moon, should display phases since they lie between the Sun and the Earth. Copernicus had replied that the phases were invisible to the naked eye and Galileo was anxious to see whether his telescope would enable him to see them. Venus was usually too close to the Sun to be observed in the summer of 1610 and it was only in the autumn that he was able to confirm that Copernicus had been right.

At the time, anagrams were frequently used to guarantee the priority of a discovery without having to rush into print. On 11 December, Galileo wrote to the Ambassador of Tuscany in Prague and enclosed the following mock sentence for Kepler: "*Haec immatura a me iam frustra leguntur*". Kepler made a number of attempts to guess the hidden message but he had to give up and wait for Galileo's letter of 1 January to learn that the letters, once transposed, read: "*Cynthiae figuras aemulatur mater amorum*", namely, "The mother of love (Venus) imitates the appearances of Cynthia (the Moon)".[21]

The point is the following: If Venus revolves around the Sun, it will not only go through a complete series of phases, but it will vary considerably in size. At its greatest distance from the Earth, it will be seen as a perfectly round disk, fully illuminated. As it moves toward the Earth it will grow in size until at quadrature (corresponding to the first and third quarter of the moon) it will be half-illumined. At its closest to the Earth, it will have become invisible (like the Moon when it is new). This is exactly what Galileo observed. Such a phenomenon would be impossible in the Ptolemaic system where Venus is said to move on an epicycle attached to a large deferent circle whose centre always lies on the line that joins the Earth to the Sun. Because Venus never goes behind the Sun, a complete sequence of phases is ruled out (see Figure 2).

The discovery of the phases of Venus was a powerful argument against the ancient astronomy but it did not supplant the rival hypothesis of the Danish astronomer Tycho Brahe, who agreed that Venus and Mercury and all the other planets went around the Sun but maintained that the Sun itself revolved around the Earth.

The Ears of Saturn and the Sun's Spots

Since Jupiter had four "assistants", it was natural that Galileo should examine the other planets to see whether they also had satellites. He searched for many months in vain. The result was a disappointment but it was also a source of complacency, for it was becoming clear that he was the only one whom God had predestined to discover new celestial bodies.

[21] Galileo to Giuliano de' Medici, 1 January 1611, *Opere*, XI, 12.

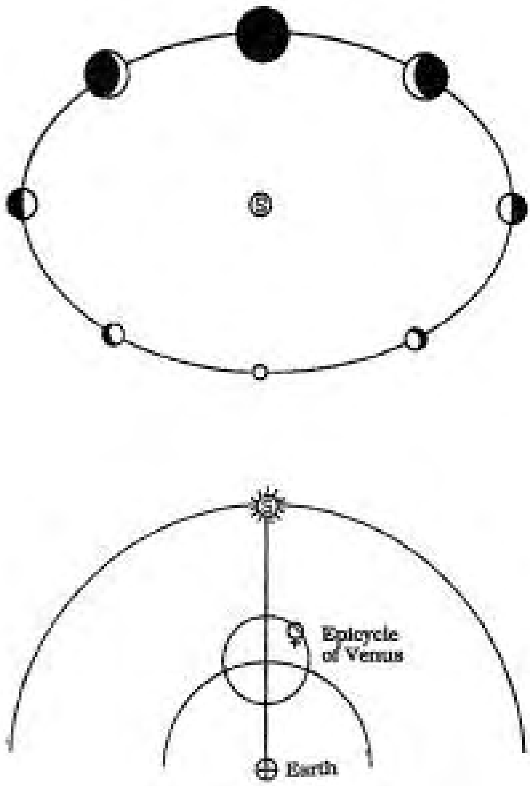

Fig. 2. Venus in the Copernican and the Ptolemaic systems.

Nonetheless, Galileo was sorry not to be able to meet the request of the French Court which *begged* him to find a new planet and name it after their King Henry IV.

In the summer of 1610, however, Saturn presented an unsuspected aspect and showed itself as a conglomerate of three stars. Galileo, fearing that someone else might publish the news before him, immediately sent an anagram to the Tuscan ambassador in Prague, but he waited until 13 November, 1610, before disclosing its meaning and offering the following information:

> I have observed that Saturn is not a single star but three together, which always touch each other. They do not move in the least among themselves and have the following shape oOo, the middle being much larger than the lateral ones.

Galileo went on to say,

> If we look at them with a telescope of weak magnification, the three stars do not appear very distinctly and Saturn seems elongated like an olive, thus ⬭. But with a telescope that multiplies the surface over a thousand times [i.e., magnifies a little over 30 times] the three globes will be seen very distinctly and almost touching, with only a thread of dark space between them. A court has been found for Jupiter, and now for this old man two attendants who help him walk and never leave his side.[22]

Galileo had barely send off his letter when the two attendants began to dwindle to the point of vanishing entirely by the end of 1612. With a fine sense of melodrama, Galileo commented upon their disappearance to his friend Mark Welser:

> What can be said of so strange a metamorphosis? Were the two smaller stars consumed like spots on the sun? Have they suddenly vanished and fled? Or has Saturn devoured his own children?... I cannot resolve what to say in a change so strange, so new, so unexpected.[23]

But Galileo soon plucked up his courage and, in the same letter, conjectured that the two attendants would reappear after revolving around Saturn, and that by the summer solstice of 1615, they would reappear. When they did they had the shape of "ears" on each side of Saturn, but soon they vanished again!

As was later discovered, Galileo had been observing Saturn's rings. These are sometimes at right angle to the line of sight when they are virtually invisible, while at other times they are more or less slanted and can be detected. The so-called ears were the most visible parts of these rings, and they remained a mystery until Christiaan Huygens was able to identify them with a better telescope in 1656.

It was natural for Galileo to wish to explore the Sun as well as the planets, but he could not observe the flaming ball of the Sun for more than a fleeting instant without being blinded. A neutral blue or green lens could be placed over the objective of the telescope, or the glass could be covered with soot. But the best method was found by Galileo's former student, Benedetto Castelli, who had the idea of projecting the image of the Sun on a screen just behind the telescope. Galileo was therefore able to see clearly the black spots on the surface of the Sun.

A Jesuit professor, Christoph Scheiner, observed the sunspots at the same time, and declared that they were hitherto unknown satellites revolving around to the Sun. With geometrical rigor and devastating wit, Galileo showed that the spots lie on the surface or very near the Sun.[24] This was a momentous discovery at the time since the Aristotelians maintained that

[22] Galileo to Giuliano de' Medici, 13 November 1610, *Opere*, X, 474.
[23] Galileo to Mark Welser, 1 December 1612, *Opere*, XI, 237.
[24] Galileo' *Letters on the Sunspots* were published in 1613.

nothing could change in the heavens, and surely not on the eternal and immutable Sun! Galileo's discovery that devastating change occurred on the very face of the Sun was yet another blow to the traditional world view.

The Troublesome Moon

Good telescopes may have been slow in spreading but by 1611 they were common enough for astronomers to agree that the heavens had radically changed, and when Galileo visited Rome in the Spring of 1611 he was fêted everywhere. Cardinal Francesco Maria del Monte, who had been instrumental in promoting his triumph, even wrote to the Grand Duke: "If we were in the ancient Roman Republic, I am certain that a statue would have been erected in his honour on the Capitol".[25] Since the equestrian statue on the Capitol is that of the emperor Marcus Aurelius, the Cardinal had no small honour in mind.

Within a month of his arrival in Rome the Jesuits gave Galileo the equivalent of a modern honorary doctorate in a lavish ceremony at the Roman College. Father Odo Van Maelcote read an address in Latin about Galileo's discoveries in presence of the entire Roman College, several cardinals, and other notabilities including Prince Cesi, the founder of the Lyncean Academy. The Jesuit scientist first discussed the newly invented telescope and the geometrical proofs of the magnification it provided. Next he offered a brief description of Galileo's observations of the lunar body, the moons of Jupiter, the fixed stars, the phases of Venus, and the curious shape of Saturn. The address, entitled *The Sidereal Message of the Roman College,* was not published but excerpts were prepared by Grienberger, presumably for distribution in the Order.

Father Van Maelcote was enthusiastic about the celestial novelties but the appearance of the Moon clearly posed problems for him and his colleagues. Here is his picturesque description of the potted surface of the Moon:

> One can observe at the tips of the Moon's horns certain brilliant peaks, or rather, I might say, small globules like the shining beads of a Rosary, some scattered among themselves, others strung together as if by a thread. So, too, can many bubble-like spots be seen especially around the lower horn: that part of the lunar surface is adorned and painted by them as if by the eyes of a peacock's tail.[26]

All this colourful language to avoid saying that mountains and valley are really to be found on the Moons. In deference to objections expressed ear-

[25] Cardinal Francesco Maria del Monte to Grand Duke Cosimo, 31 May 1611, *Opere*, X, 119.

[26] Van Maelcote's address delivered his oration in May 1611, *Nuncius Sidereus Collegii Romani, Opere*, III, 293-298.

lier by Christoph Clavius, he recalled that he was himself only a celestial messenger and that his audience was free to attribute the spots on the Moon to "the uneven density and rarity of the lunar body" or "to something else", as they chose.

Why this difficulty with the features of the Moon?

Clavius' reluctance to accept that the Moon was not smooth and polished but rough and covered with deep depressions was not arbitrary but rested on four serious objections, the first scientific, the second symbolic, the third philosophical, and the fourth theological. The first was that the illuminated edges of the Moon in all its phases show themselves perfectly round, without those indentations that one would expect from the inequalities of its surface. The second reason is the popular religious representation of the Virgin Mary with her feet resting on the surface of an equally pure and perfect Moon. Clavius would not have wished to make a doctrinal point out of an icon, but we can understand his regard for the Marian convention and his reluctance to admit too readily the bumps and dents that would render a traditional image inappropriate.

The third reason rested on the Aristotelian cosmological system where the Earth was fixed at the centre of the universe, and was surrounded concentrically by the elemental and heavenly spheres arranged like the skins of an onion. The sphere of the Moon divided the universe into two sharply distinct regions, the terrestrial and the celestial. Bodies in the latter were composed of a fifth element or quintessence, which was ingenerable and incorruptible and underwent only one kind of change, uniform motion in a circle. Bodies between the Earth and the Moon were subject to all kinds of change, and the kind of motion natural to them was rectilinear motion towards their natural place in the sphere of the element to which they belonged. Evidence for this view was the unconstrained motion of bodies to and from the centre of the Earth: in fire which moves straight up, or in earth which falls straight down. In order to replace this *double-tiered* cosmos by the Copernican *universe*, Clavius felt that it was necessary to show that the apparently natural distinction between rectilinear and circular motions upon which Aristotle rested his case was wrong. Until that was done it was unreasonable to jettison a system that explained so many other natural phenomena.

The destruction of the pure and perfect Moon was a lengthier process than Galileo had anticipated. When Ludovico delle Colombe heard about Clavius' scepticism about mountains on the Moon, he wrote to say that he shared his doubts.[27] A copy of the letter was passed on to Galileo by the secretary of Cardinal Joyeuse, who wanted to know how he would reply. Galileo, at his wittiest, complied:

> If anyone is allowed to imagine whatever he pleases and someone says that the Moon is surrounded by transparent invisible crystal, I shall willingly

[27] Lodovico delle Colombe to Clavius, 27 May 1611, *Opere*, XI, 118.

> grant this provided that, with equal courtesy, I be allowed to say that this crystal has on its outer surface a great number of enormous mountains, thirty times as high as terrestrial ones, which, being of diaphanous substance, is invisible.[28]

One might just as well, Galileo added, define *Earth* to include the atmosphere at the top of the highest mountain and then say, "the Earth is perfectly spherical". We witness here how Galileo's sarcasm could be amusing but also dangerous. He laughed delle Colombe off the stage, but what was really required was a scientific answer and, in this instance, Galileo failed to provide the correct explanation, which is that the mountains are close together, so that at the distance of the Earth the intervening depressions are not discernible.

Clavius' fourth reason for doubting that the Moon was another Earth was theological and concerns the existence of rational creature on other planets and the doctrine of original sin. It was not explicitly stated by the Jesuit but Galileo's friend, Giovanni Ciampoli, made it very clear a few years later:

> Your opinion of the phenomena of light and shade on the clear and spotted surfaces of the Moon assumes some analogy between the Earth and the Moon. Someone adds to this and says that you assume that the Moon is inhabited by men. Then another starts discussing how they could be descended from Adam or how they could have gotten out of Noah's ark, and many other extravagant ideas that you never dreamed of. It is indispensable, therefore, to remove the possibility of malignant rumours by repeatedly protesting of one's willingness to defer to the authority of those who have jurisdiction over the human intellect in matters of the interpretation of the Scriptures.[29]

Galileo was driven to take defensive action but only much later when he realised the gravity of the theological problem. In a long letter to Giovanni Muti in 1616 he denied that there was water and hence organic matter on the Moon,[30] and in his *Dialogue* of 1632 he stressed that plants and animals similar to ours cannot be produced there.[31] The similarity between the Moon and the Earth had been the clinching argument in favour of Copernicanism for Galileo, and he had ended his description of the Moon with a promise to show in his *System of the World* (the early title of the *Dialogue*) that reflection of solar light from the Earth is quite real. He kept his promise.

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[28] Galileo to Gallanzone Gallanzoni, Cardinal Joyeuse's secretary, 16 July 1611, *Opere*, XI, 143.

[29] Ciampoli to Galileo, 28 February 1615, *Opere*, XII, 146.

[30] Galileo to Cardinal Giacomo Muti, 28 February 1616, *Opere*, XII, 240-241.

[31] Galileo, *Dialogue on the Two Chief World Systems*, *Opere*, VII, 125-126. English translation by Stillman Drake, *Dialogue Concerning the Two Chief World Systems*. Berkeley: University of California Press, 1962, pp. 99-101.

Conclusion

The fact that Galileo became aware of the importance of the theological difficulties that were at the forefront of the concerns of the Jesuits long after he had seen mountains on the Moon tells us much about his intellectual stance. He was a mathematician by training and, as such, enjoyed a relative freedom from the Aristotelian philosophy and the thomistic theology of his period. He trusted the science of optics and was willing to accept the telescope as a way of extending our vision of the world. Whereas he peered through the telescope without blinking, many of his contemporaries still squinted and kept at least one eye on the Bible or Aristotle's Physics.