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The Galileo Affair

In arguing that the earth circles the sun Galileo adopted a mode of reasoning that led not only to his prosecution by the church but also to the new scientific methodology of hypothesis testing

by Owen Gingerich

Galileo's difficulties with the Roman Catholic church, which ultimately led to his trial and humiliation, have often been described as a confrontation between empirical science and blind dogmatism. Notwithstanding his abjuration, Galileo clearly believed in the truth of the heliocentric Copernican system. Today, with the sun-centered arrangement of the planets firmly established, it is easy to see Galileo as right and the church as wrong. In Galileo's time, however, the issues were by no means obvious or clear-cut.

Galileo defended the Copernican system by a series of ingenious arguments, many of them based on his new telescopic observations. From a modern point of view Galileo's defense seems immediately compelling, but when he presented his ideas, there was as yet no observational proof of the new cosmology, and even he remarked that he could not admire enough those who had adopted the heliocentric system in spite of the evidence of their senses. By the standards of his time his reasoning was not only contrary to traditional church doctrine but also flawed in its logic. Indeed, I would contend that Galileo was breaking the accepted rules of science, but by doing so he created new rules that have been accepted ever since.

The outcome of the Galileo affair, in which the church won the battle but lost the war, had important historical consequences, most notably a shift of scientific enterprise northward into Protestant countries. Three hundred and fifty years later, at a time when some individuals are again asserting a religious claim on cosmology, Galileo's experience still has much to say about the practice and the philosophy of science. What was at issue was both the truth of nature and the nature of truth.

To understand the Galileo affair it is necessary to know something about the introduction of the Copernican cosmology some decades earlier. In 1543, when Copernicus' magnum opus, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*) was finally published, there was not a single item of unambiguous observational evidence in its favor. Copernicus' achievement had been in the mind's eye. What he had noted was that by rearranging the planetary orbs so that the sun was near their center a wonderful regularity emerged. The fastest planet, Mercury, had the orbit closest to the sun; the slowest planet, Saturn, was at the outside, and the planets in between also were placed in the order of their periods. Furthermore, the scheme gave a natural explanation to several previously unrelated observational facts, such as the geometry of each planet's retrograde arc (the segment of the orbit in which the planet seems to reverse direction across the sky). This explanatory power came at a high cost, however: it threw the earth into a dizzying flight around the sun, and the earth somehow had to bring the moon along with it. In the framework of the accepted Aristotelian physics the entire scheme was ridiculous. "'Tis all in pieces, all coherence gone," John Donne was to lament a few generations later. And coherency is cherished above all else in science; it is the touchstone by which crank theories can be rejected.

In order to convey the viewpoint of the astronomical community about 50 years after the publication of *De revolutionibus,* I should like to describe an imaginary congress of the International Astronomical Union in 1592. The vice-president, Christoph Clavius of Rome, has risen to praise the remarks of the president, Tycho Brahe of Denmark. Tycho has lately introduced still another cosmological system, in which the planets orbit the sun but the sun itself and the accompanying planets are in orbit around a motionless earth. Clavius remarks that Tycho's system beautifully preserves the relations found by Copernicus in the harmonious spacing of the planets and gives a fully natural explanation of retrograde motions, just as Copernicus' hypothesis does. As Tycho himself has said, the Copernican arrangement nowhere offends the principles of mathematics, but it gives to the earth—this lazy, sluggish body, unfit for motion—a movement as swift as that of the ethereal planets. The Tychonic system brilliantly saves physics by keeping the earth at rest, and it is consistent with the scriptures, such as Psalm 104: "O Lord my God... who laid the foundations of the earth, that it should not be removed for ever."

An informal poll I have taken among the delegates indicates a somewhat mixed reaction: about half accept Tycho's view, but the rest say the choice of systems does not matter since all such geometric schemes are only hypothetical anyway. Some of those who adopt the latter attitude cite the anonymous preface to Copernicus' book: "Beware if you expect truth from astronomy lest you leave this field a greater fool than when you entered." Fewer than 10 percent agree with the Sicilian astronomer Franciscus Maurolycus that Copernicus deserved whips and lashes. The great majority find the Copernican tables preferable for calculating planetary positions, but that does not require a commitment to the heliocentric cosmology because the tables are set up independent of any particular arrangement of the planets.

Although gracious amity prevails be-

COSMOLOGICAL DISPUTE is represented in the frontispiece of Galileo's *Dialogue concerning the Two Chief World Systems,* printed in Florence in 1632. The three figures are Aristotle (*left*), Ptolemy (*middle*), who carries a model of nested geocentric spheres, and Nicolaus Copernicus (*right*), who bears an emblem of his own heliocentric theory. In discussions with Pope Urban VIII, Galileo had agreed to write a neutral account of the Ptolemaic and the Copernican systems, but the *Dialogue* was far from impartial. Galileo's advocacy of the heliocentric cosmology led to his prosecution by the Congregation of the Inquisition. The banner carries the dedication of the *Dialogue* to Ferdinand II de' Medici, the Grand Duke of Tuscany. "Linceo" identifies Galileo as a member of the Academy of Lynxes, a scientific society formed in 1603.

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hac ordinatione admirandam mundi ſynmetriam, ac certũ harmoniæ nexum motus & magnitudinis orbium: qualis alio modo reperiri non poteſt. Hic enim licet animaduertere, non ſegniter contemplanti, cur maior in Ioue progreſſus & regreſſus appareat, quàm in Saturno, & minor quàm in Marte: ac rurſus maior in Venere quàm in Mercurio. Quod ⁊ frequentior appareat in Saturno talis reciprocatio, quàm in Ioue: rarior adhuc in Marte, & in Venere, quàm in Mercurio. Præterea quòd Saturnus, Iupiter, & Mars acronycti propinquiores ſint terræ, quàm circa eorũ occultationem & apparitionem. Maxime uero Mars per nox factus magnitudine Iouem æquare uidetur, colore duntaxat rutilo diſcretus: illic autem uix inter ſecundæ magnitudinis ſtellas inuenitur, ſedula obſeruatione ſectantibus cognitus. Quę omnia ex eadem cauſa procedũt, quæ in telluris eſt motu. Quòd autem nihil eorum apparet in fixis, immenſam illorum arguit celſitudinem, quæ faciat etiam annui motus orbem ſiue eius imaginem ab oculis euaneſcere. Quoniam omne uiſibile longitudinem diſtantiæ habet aliquam, ultra quam non amplius ſpectatur, ut demonſtratur in Opticis. Quòd enim à ſupremo errantium Saturno ad fixarum ſphæram adhuc plurimum interſit, ſcintillantia illorum lumina demonſtrant. Quo indicio maxime diſcernũtur à planetis, quodq̃ inter mota & non mota, maximam oportebat eſſe differentiam. ~~Tanta nimirum eſt diuina hæc Opt. Max. fabrica.~~

De hypothesi triplicis motus ad Rem, eiusq; demonstrationem.

~~De triplici motu telluris demonſtratio.~~

CVm igitur mobilitati terrenæ tot tantaq̃ errantium ſyderũ conſentiant teſtimonia, iam ipſum motum in ſumma exponemus, quatenus apparentia per ipſum tanquam hypoteſim demonſtrentur, quem triplicem omnino oportet admittere. Primum quem diximus νυχθημερινὸν à Græcis uocari, diei noctisq̃ circuitum proprium, circa axem telluris, ab occaſu in ortum uergentem, prout in diuerſum mundus ferri putatur, æquinoctialem circulum deſcribendo, quem nonnulli æquidialem dicunt, imitantes ſignificationem Græcorum, apud

c ij quos

CENSORED PASSAGES of Copernicus' *De revolutionibus orbium coelestium* were altered to make the heliocentric cosmology acceptable to the church by making it strictly hypothetical. The emendations shown are in Galileo's copy and were entered in his own hand. Following the instructions of the Holy Congregation of the Index, Galileo struck out the last sentence of chapter 10, which had read: "So vast, without any question, is the divine handiwork of the most excellent Almighty." He also changed the title of the next chapter from "On the Explication of the Threefold Motion of the Earth" to "On the Hypothesis of the Threefold Motion of the Earth and its Explication." The decision to censor *De revolutionibus* rather than ban it was made in 1616, partly at the urging of Maffeo Cardinal Barberini, who later became Pope Urban VIII. At the same time Galileo was warned against speaking too forcefully in favor of the Copernican cosmological system, although he was not officially enjoined against teaching it.

tween the Jesuit Clavius and the Lutheran Tycho, international tensions are evident. Michael Maestlin of Tübingen is vociferous in his criticism of Clavius' new calendar. Maestlin is also nettled that his graduate student Johannes Kepler, who has come along on a young astronomer's grant, does not agree that the Gregorian calendar is the work of the devil. As for the 27-year-old Galileo Galilei, an untenured mathematics professor at Pisa, no one at the congress has heard of him.

Nearly four centuries later millions of people who could not identify Tycho, Clavius, Maestlin or Kepler know the name of Galileo. One reason for Galileo's prominence is the importance of his contributions to both physics and astronomy, but his trial at the hands of the Inquisition has surely added to his fame. In the quaint words of the 19th-century physicist David Brewster, Galileo became a "martyr of science." Now, almost 350 years after his trial and abjuration, the Vatican itself has moved to reopen his case.

Galileo's ordeal is often referred to as a trial for heresy. Strictly speaking the Copernican system was never officially declared heretical, nor was Galileo condemned for heresy. The judge, who was out to get Galileo, raised a charge of "a vehement suspicion of heresy." He also found that an unofficial panel of theologians had agreed the Copernican system ought to be considered heresy, but this opinion never became the official position of the church. To understand these points it is necessary to examine both the historical circumstances of the trial and what was at stake philosophically.

At the end of the 16th century there was still no compelling reason to accept the Copernican doctrine as a physical picture of the universe. Astronomers were all well aware of its general idea, yet few believed it described the real world. There was widespread agreement that truth resided not in astronomy but in the Bible. Since the Book of Scripture had been literally dictated by God, it had a unique status. Even Galileo accepted this doctrine without hesitation. He did not necessarily agree, however, that the intellectual road to truth lay solely within the territory of the theologians. The Book of Scripture could be ambiguous, he argued, whereas God's Book of Nature could be probed and tested. He conceded that the Bible had its place, but he also believed the Bible told how to go to heaven, not how the heavens go.

How *do* the heavens go, and how is their motion revealed by the Book of Nature? A flippant answer might be: by observing with the telescope. For Galileo the telescope had an enormous psychological impact. For years he had been at best a timid or even an indifferent Copernican, and he had taught his

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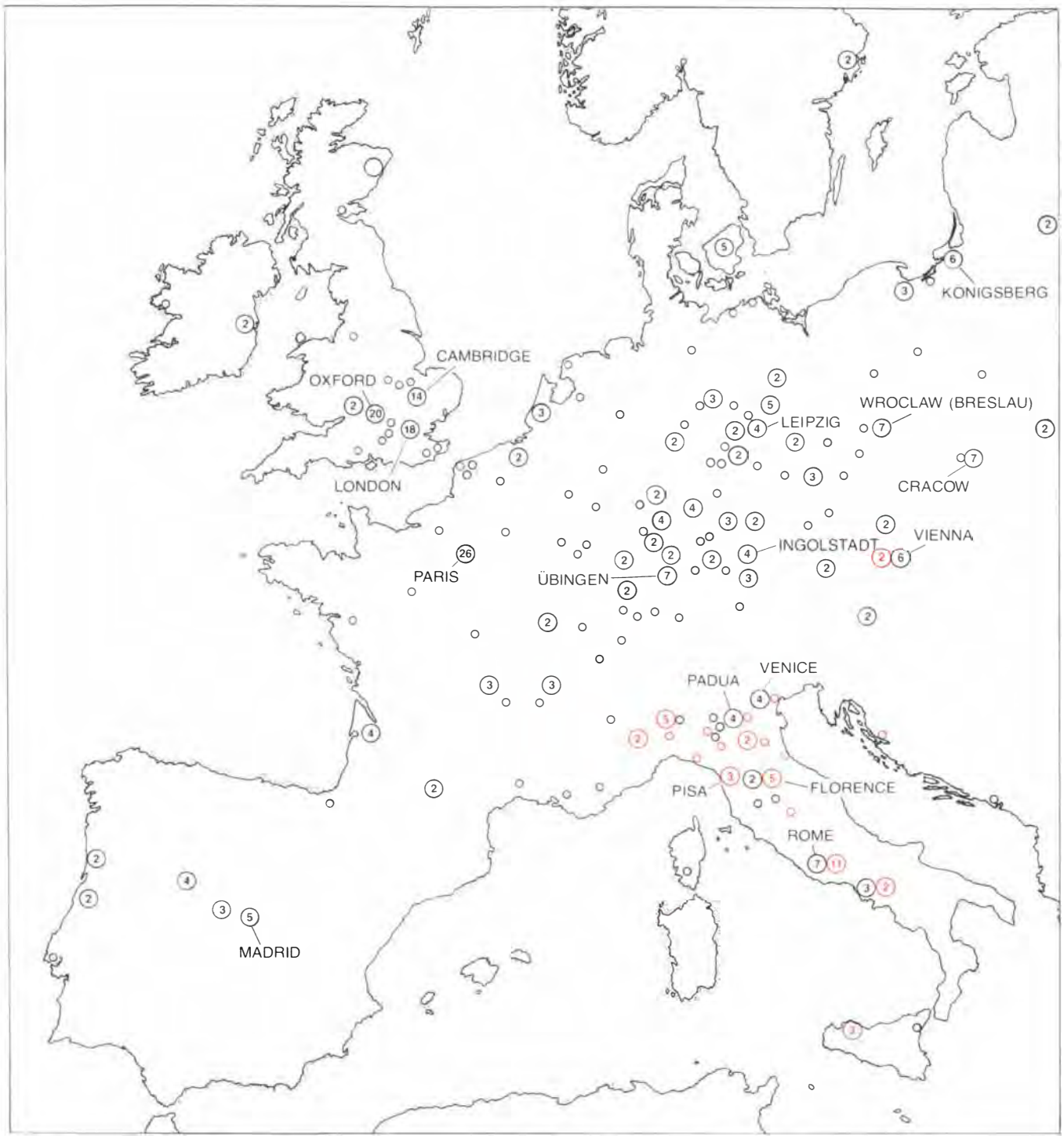
students in Pisa and later in Padua the standard arguments for a fixed, central earth. Then, in the fall of 1609, with an optical tube of his own making, a perspicillum as he called it, he turned his attention to the heavens and was staggered by what he saw. Within a few months his book reporting on his observations was off the presses: *Sidereus nuncius,* or *The Starry Messenger.* It told of mountains on the moon and of stars and satellites unknown to the ancients. The moon was earthlike and not the ethereal globe of pure crystal imagined by his predecessors. The Milky Way was revealed to be the confluence of innumerable stars. Most unexpected of all, Jupiter was circled by four companions. Galileo craftily called them the Medicean stars, with hopes of a government-supported position in Tuscany at the court of Grand Duke Cosimo II de' Medici.

Galileo's observations with the telescope must have shaken his complacency, but his account in *The Starry Messenger* gives no unambiguous evidence that he espoused the Copernican system. The book had only just been printed, however, when he made another remarkable finding: the phases of Venus, which in a stroke falsified the Ptolemaic system.

Venus had been too close to the sun to observe when Galileo was making his



PROBABLE DISTRIBUTION of censored copies of *De revolutionibus* in 1620 suggests that the 1616 decree of the Holy Congregation of the Index was effective mainly in Italy; even in other Catholic countries, such as Spain, the decree was evidently not enforced. Censored copies are represented by colored circles and uncensored copies by black circles. Where there were multiple copies in one place the number is given. The map was compiled by examining the histotory of some 500 surviving copies of the first two editions. There were probably another 500 copies with a distribution similar to that of the approximately 380 books whose locations are given here.

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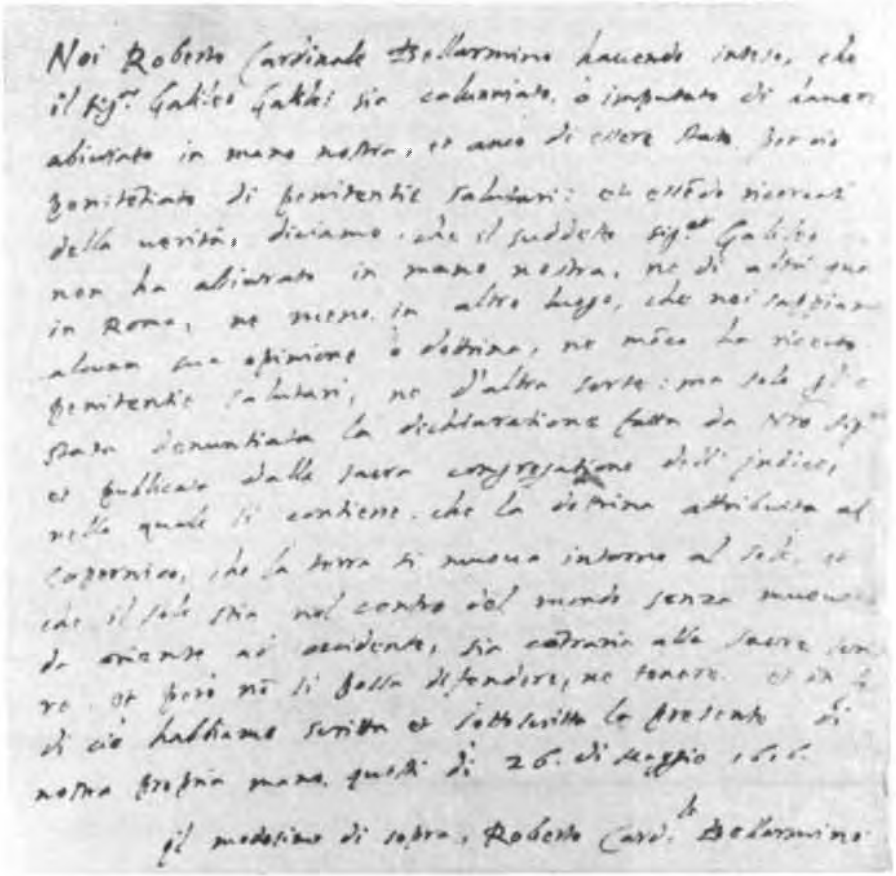

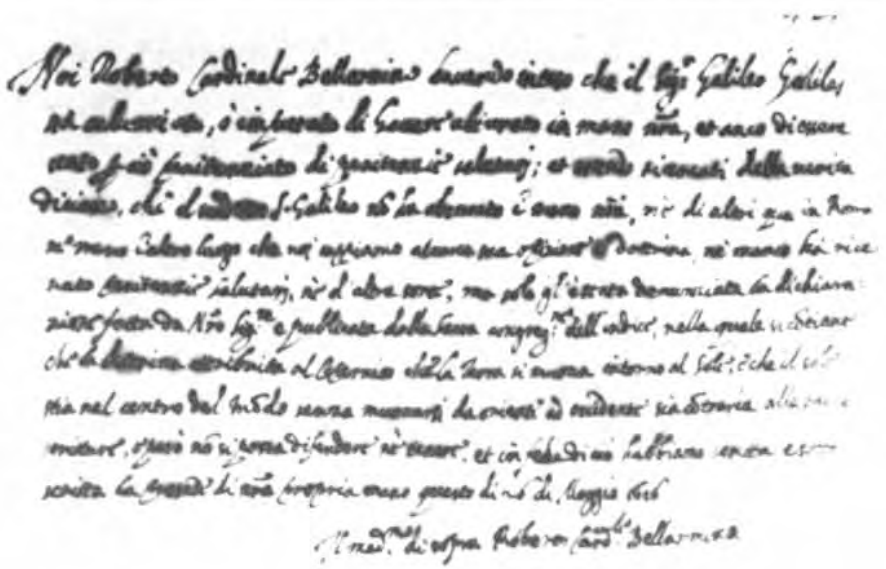

We, Roberto Cardinal Bellarmino, having heard that it is calumniously reported that Signor Galileo Galilei has in our hand abjured and has also been punished with salutary penance, and being requested to state the truth as to this, declare that the said Signor Galileo has not abjured, either in our hand, or the hand of any other person here in Rome, or anywhere else, so far as we know, any opinion or doctrine held by him; neither has any salutary penance been imposed on him; but that only the declaration made by the Holy Father and published by the Sacred Congregation of the Index has been notified to him, wherein it is set forth that the doctrine attributed to Copernicus, that the Earth moves around the Sun and that the Sun is stationary in the center of the world and does not move from east to west, is contrary to the Holy Scriptures and therefore cannot be defended or held. In witness whereof we have written and subscribed these presents with our hand this twenty-sixth day of May, 1616.

astonishing discoveries at the end of 1609 and the beginning of 1610. Sometime late in the summer a former student, Benedetto Castelli, remarked to Galileo that in the Copernican system Venus should show the entire range of phases, from a dark disk through crescent and gibbous forms to a fully illuminated disk. In the Ptolemaic system, on the other hand, the epicycle of Venus is locked between the earth and the sun, and Venus therefore has only crescent phases; it never passes behind the sun for full illumination.

Not until October did Galileo train his perspicillum on Venus, which was then in its distant gibbous phase. By early December, when the planet had waned to a miniature half moon, he put forth his discovery in an anagram: "Haec immatura a me iam frustra leguntur o.y." ("These are at present too young to be read by me." The letters "o.y." are part of the original sentence but did not fit into the anagram.) He undoubtedly chose this veiled form of announcement to give himself time to be sure of his finding; after all, Venus might lie always beyond the sun, in which case it would go back into a gibbous phase. By this stratagem Galileo also guarded his priority; since Castelli had mentioned the possibility in the first place, others might have been on the verge of making the same discovery.

Galileo was a scrambling social climber. His discoveries had gained him a new post as mathematician to the Medici and had brought him the fame he greatly relished. Fame in turn brought power of a kind, perhaps the power to persuade the entire Catholic hierarchy to adopt the Copernican system. At least Galileo was egotistical enough to expect that it would.

In Galileo's rush to assert a claim of priority he was sometimes more aggressive than might seem prudent. He got into a squabble with the Jesuit Christoph Scheiner when each asserted he had been the first to observe sunspots. Moreover, Scheiner preferred to believe the sun was unblemished and the spots were intervening clouds. Galileo proved otherwise, with rather little charity to Scheiner. Giorgio de Santillana, in his book *The Crime of Galileo,* hints darkly that Scheiner never forgot and years later led the Jesuits in a vendetta. It is true Scheiner was in Rome at the time of

LETTER TO GALILEO from Roberto Cardinal Bellarmino sets forth the nature of the warning issued to Galileo in 1616. The original is at the top and Galileo's copy is in the middle. In 1633, when the Inquisition hinted that Galileo had been forbidden to write on the Copernican cosmology, he responded by producing first his copy and later the original letter. Both are now among the Galileo papers in the Secret Archives of the Vatican.

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Galileo's trial, but there is no evidence he had anything to do with those machinations. Nevertheless, the story might make a play along the lines of *Amadeus,* the current Broadway production about the supposed poisoning of Mozart.

By New Year's Day of 1611, just after Venus had rounded its western elongation, the crescent phase began to emerge and Galileo unscrambled his anagram for Kepler. It read, "Cynthiae figuras aemulatur mater amorum." ("The mother of love imitates the shapes of Cynthia"), or in other words, Venus goes through the same series of phases as the moon. When Galileo realized that the observed phases of Venus are incompatible with the Ptolemaic arrangement, he could hardly fail to notice that the Book of Nature was indeed saying something about how the heavens go. With the Ptolemaic scheme eliminated Galileo threw his support behind the Copernican system, ignoring the Tychonic plan.

At a breakfast with Cosimo de' Medici and his mother, the Dowager Grand Duchess Cristina, the question of the reality of the Jovian satellites came under discussion. Galileo himself was not present but Castelli was there. Through Galileo's influence Castelli had just become professor of mathematics at Pisa, and he entered into a spirited discussion with Cristina on the issue of whether there is any conflict between the Bible and the heliocentric theory. As a direct result of that debate Galileo was challenged to defend his view that the Book of Scripture raises no insuperable objections to the Copernican system. Galileo wrote a cogent analysis, including the splendid epigram about the Bible's teaching how to go to heaven, not how the heavens go. (Actually Galileo had borrowed the saying from Caesar Cardinal Baronius, the librarian of the Vatican.)

It was one thing to argue that the heliocentric arrangement is compatible with the Book of Scripture and quite another to prove that the Book of Nature speaks unmistakably in favor of Copernicus. To understand this part of the controversy it is necessary to keep in mind the two forms of Aristotelian logic: induction and deduction.

Induction is the process of drawing general conclusions from particular instances; it is, I think, the basic process whereby learning takes place. Consider the reproduction of birds: chickens lay eggs, robins lay eggs, ostriches lay eggs and so on, and thus we generalize that all birds reproduce by laying eggs. We have not proved this conclusion, however, since there is always the possibility that a counterexample will be found. For this reason inductive reasoning, as all the scholastic philosophers of Galileo's time knew, cannot lead to indubitable truth.

Deduction is another matter. Given true premises, a conclusion reached by valid deduction must be rigorously true. Consider this syllogism:

A. If it is raining, the streets are wet.
B. It is raining.
C. Therefore the streets are wet.

Now consider the converse:

A. If it is raining, the streets are wet.
B. The streets are wet.
C. Therefore it is raining.

To students of logic this procedure of confirming the consequent was a well-known fallacy. After all, the streets could be wet for other reasons: the winter snow could be melting, the street-cleaning department might be out in force or the Lippizaner horses might have been on parade.

How does this logical analysis apply to Galileo's defense of Copernicanism? Consider this syllogism:

A. If the planetary system is heliocentric, Venus will show phases.
B. The system is heliocentric.
C. Therefore Venus will show phases.

True enough, but this was not the form of Galileo's argument. He had exchanged the second premise and the conclusion:

A. If the planetary system is heliocentric, Venus will show phases.
B. Venus shows phases.
C. Therefore the planetary system is heliocentric.

Clearly Galileo had committed an elementary blunder of logic, and even Kepler criticized him for it. There might well be other explanations for the observed phases of Venus; indeed, the Tychonic system also predicted them.

When Galileo's "Letter to Cristina" was circulated in Rome in 1616, it elicited the following response from Roberto Cardinal Bellarmino, the leading Catholic theologian of the day, who wrote to another Copernican, Father Paolo Antonio Foscarini:

"I have gladly read the letter in Italian and the essay in Latin that Your Reverence has sent me, and I thank you for both, confessing that they are filled with ingenuity and learning. But since you ask for my opinion, I shall give it to you briefly, as you have little time for reading and I for writing.

"First. I say that it appears to me that Your Reverence and Signor Galileo did prudently to content yourselves with speaking hypothetically and not positively, as I have always believed Copernicus did. For to say that assuming the earth moves and the sun stands still saves all the appearances better than eccentrics and epicycles is to speak well. This has no danger in it, and it suffices for mathematicians.

"But to wish to affirm that the sun is really fixed in the center of the heavens and that the earth is situated in the third sphere and revolves very swiftly around the sun is a very dangerous thing, not only by irritating all the theologians and scholastic philosophers, but also by injuring our holy faith and making the sacred Scripture false. For Your Reverence has indeed demonstrated many ways of expounding the Bible, but you have not applied them specifically, and doubtless you would have had a great deal of difficulty if you had tried to explain all the passages that you yourself have cited....

"Further, I say that if there were a true demonstration that the sun is in the center of the universe and that the sun does not go around the earth but the earth goes around the sun, then it would be necessary to be careful in explaining the Scriptures that seemed contrary, and we should rather have to say that we do not understand them than to say that something is false. But I do not think there is any such demonstration, since none has been shown to me. To demonstrate that the appearances are saved by assuming the sun at the center and the earth in the heavens is not the same thing as to demonstrate that in fact the sun is in the center and the earth in the heavens. I believe that the first demonstration may exist, but I have very grave doubts about the second." (The translation is abridged from one done by Stillman Drake.)

Galileo knew he could not logically establish the Copernican system by deduction, but the situation was not quite that simple. The Copernican system not only predicted the phases of Venus but also, as a model, explained many other things. If the earth was a planet, the other planets might well be earthlike, and so indeed the moon turned out to be when he examined it with his telescope. The Copernican system arranged the planets naturally by period; similarly, when the telescope revealed the satellites of Jupiter, they were found to be arranged sequentially by period, as in a miniature solar system.

Galileo's process of reasoning was similar to induction but more sophisticated. It was, in an embryonic state, what is now called the hypothetico-deductive method: the testing of a hypothetical model, which attains ever more convincing likelihood as it passes each test successfully. Today it is not the word "truth" but the word "model" that continually decorates the pages of scientific journals.

As far as the theologians were concerned, the Copernican system was not really the issue. I can hardly emphasize this point enough. The battleground was the method itself, the route to sure knowledge of the world, the question

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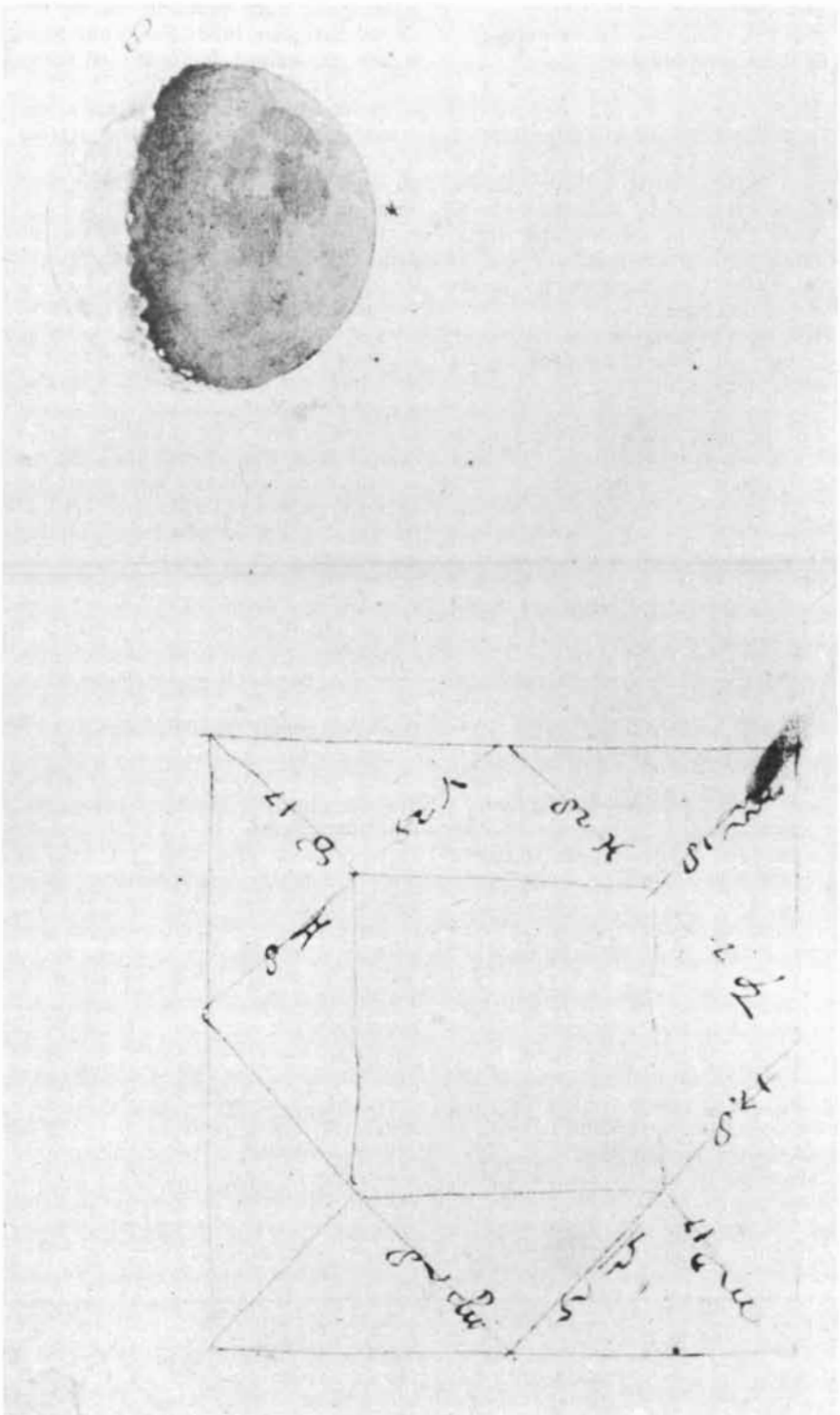
of whether the Book of Nature could in any way rival the inerrant Book of Scripture as an avenue to truth. In the opinion of Cardinal Bellarmino and the other Catholic theologians Galileo's procedures were essentially inductive and therefore potentially fallacious. Such contingent arguments were insufficient to force a reinterpretation of scripture that might erode the concept of the inerrancy of Holy Writ.

To be quite sure of avoiding confusion in the popular mind (particularly because issues of interpretation were central in the ongoing battle with the Protestants) the church officials found it prudent to condemn the Copernican teaching. The first step was to seek a theological opinion on two separate propositions: the immobility of the sun and the mobility of the earth. The report, which was essentially an internal memorandum, said the immobility of the sun was foolish and formally heretical because it violated the literal meaning of the Scriptures, but the mobility of the earth was merely erroneous. The question then was what to do about the report. Two actions were planned: to rein in Galileo and to put *De revolutionibus* on the Index of prohibited books.



EARTHLIKE FEATURES on the surface of the moon were among the observations cited by Galileo in support of the heliocentric theory. The presence of mountains, craters and other "blemishes" indicated that the heavenly bodies are not fundamentally different from the earth. It therefore became reasonable to suppose the earth is a planet and not a fixed sphere with a quite different status. The drawing was made by Galileo after he constructed an astronomical telescope in 1609. On the same page is the start of a horoscope he cast for Cosimo II de' Medici.

The latter measure, however, entailed certain practical difficulties. Copernicus' book was considered an important contribution to the reform of astronomy, on which the calendar and the accurate determination of the date of Easter depended. Accordingly the Holy Congregation of the Index decided not to proscribe the book but instead to expurgate and emend it.

From these deliberations a bit of gossip has survived in the diary of Giovanfrancesco Buonamici, a diplomatic secretary from Galileo's province of Tuscany. Buonamici wrote that "Pope Paul V was of the opinion to declare Copernicus contrary to the faith; but Cardinals Bonifacio Caetani and Maffeo Barberini withstood the Pope openly and checked him with the good reasons they gave." The two cardinals were central figures in the cosmological controversy. Barberini was later to have an even larger role in the story of Galileo's life, and Caetani drafted the opinion recommending censorship of *De revolutionibus*.

Caetani's opinion declared that the Copernican teaching was false and opposed to Scripture, but not that it was heretical. This may seem to be a distinction without a difference, but it was certainly not so in the 17th century. The instructions for the censorship read:

"If certain of Copernicus' passages on the motion of the earth are not hypothetical, make them hypothetical; then they will not be against either the truth or the Holy Writ. On the contrary, in a certain sense they will be in agreement with them, on account of the false nature of suppositions, which the study of astronomy is accustomed to use as its special right."

Even as the Holy Congregation of the Index was moving against Copernicus' book, Galileo was in Rome aggressively lobbying on behalf of the heliocentric system. It seems he was convinced he could single-handedly sway the Catholic leaders to his view. Indeed, he had powerful friends in Rome who were sympathetic to his ideas, even among the churchmen, but the conservative forces were also strong, and they included Pope Paul V.

While Galileo was in Rome the other part of the pope's response to the theological opinion was put into action. Ga-

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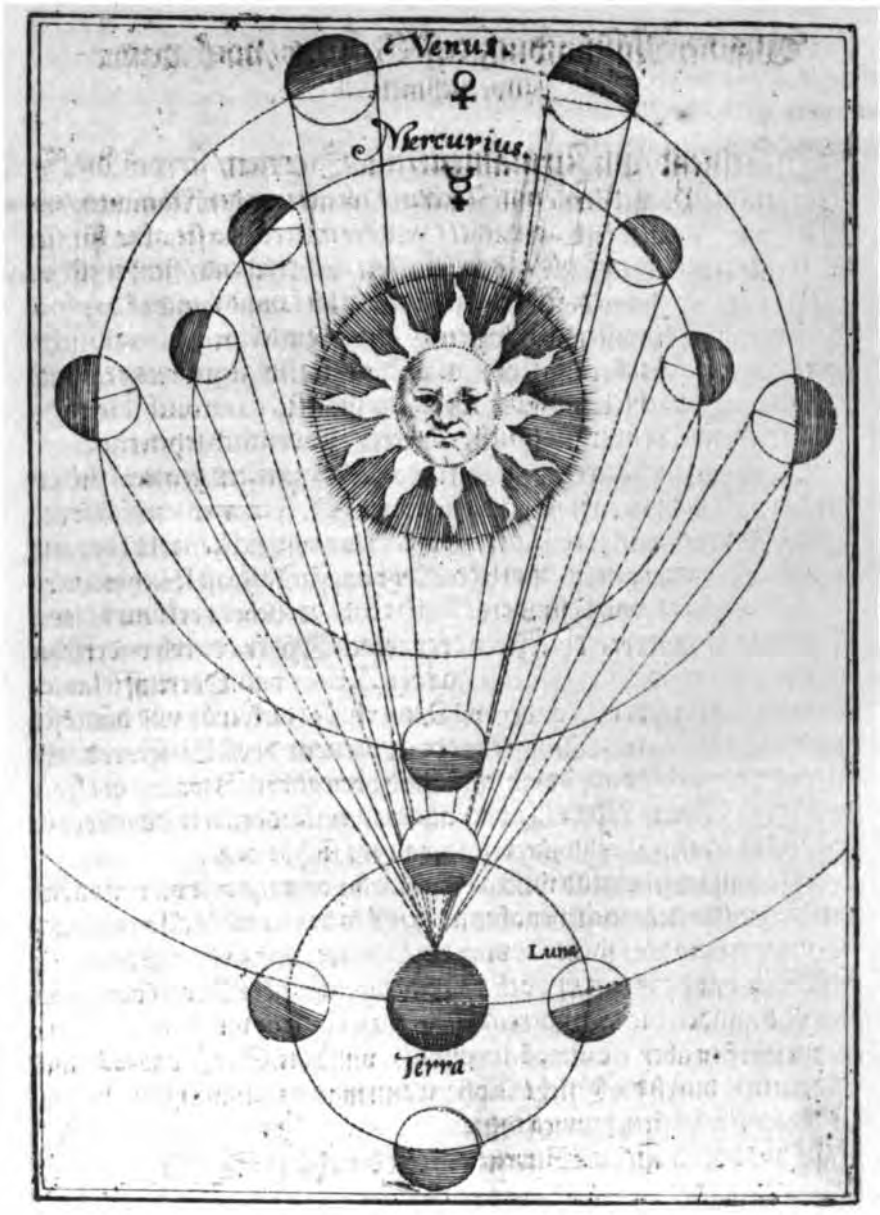
lileo was to be called before Cardinal Bellarmino and cautioned against speaking out too forcefully on behalf of the Copernican system. The pope told Bellarmino that if Galileo proved intractable, he was to be ordered to keep quiet. To be sure the pope's wishes were enforced the interview was conducted in the presence of two Dominican friars, members of the order charged with administering the Inquisition.

As it turned out Galileo was cooperative in accepting Bellarmino's warning. After the conference, however, rumors began to circulate in Rome that Galileo had been officially enjoined against teaching the Copernican doctrine. Galileo was naturally disturbed by the rumors, and he sought and received a letter from Bellarmino saying that no such thing had happened. It read in part:

"We, Roberto Cardinal Bellarmino, having heard that it is calumniously reported that Signor Galileo Galilei has in our hand abjured and has also been punished... declare that the said Signor Galileo has not abjured... any opinion or doctrine held by him; neither has any salutary penance been imposed on him; but that only the declaration made by the Holy Father and published by the Sacred Congregation of the Index has been notified to him, wherein it is set forth that the doctrine attributed to Copernicus... is contrary to the Holy Scriptures and therefore cannot be defended or held." (The translation is by de Santillana.)



PHASES OF VENUS had an important role in Galileo's own conversion to the Copernican view. A student, Benedetto Castelli, pointed out that in the Ptolemaic system Venus would show only crescent phases because it would always remain between the earth and the sun; in the Copernican system, on the other hand, Venus would show a full range of phases. In 1610 Galileo trained his telescope on the planet and was able to observe its progress from a gibbous to a crescent form. He considered the evidence for a heliocentric planetary system compelling, but others contended that such empirical findings could not supply a rigorous proof because other arrangements of the planetary system leading to the observations could be imagined. The illustration, which shows the phases of Mercury and the moon as well as those of Venus, is from a treatise by the Swiss mathematician Matthias Hirzgarter published in 1643.

Thus for the time being Galileo was silenced. For seven years he remained in Florence and complied with Cardinal Bellarmino's advice. He was as feisty as ever, but he reserved his scrappiness for other subjects, such as the comets of 1618. In his book on the comets (*Il Saggiatore,* or *The Assayer*) he avoided discussing the Copernican system, but he included so many interesting remarks on the nature of science that the book is sometimes called his scientific manifesto. He stated, in Italian:

"Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles and other geometric figures.... Without these one wanders about in a dark labyrinth."

The printing of *Il Saggiatore* was not finished when news arrived that cheered all liberal Catholics. The newly elected pope, who had taken the name Urban VIII, was Maffeo Barberini, one of the cardinals who had intervened to prevent the proscription of *De revolutionibus.* Barberini was also a friend of the arts and a fellow member with Galileo of the small Academy of Lynxes, one of the earliest scientific societies. The delighted Lynxes had just enough time to change the title page on Galileo's book so that it could be dedicated to the new pontiff. Before a year had passed Galileo was in Rome for a series of papal audiences. Urban assured him that *Il Saggiatore* had been read to him, to his great pleasure. Galileo hinted he would like to write more, in particular a book on the relative merits of the Copernican and the Ptolemaic systems, but his enemies prevented him.

From what is known of the two men it is possible to speculate on how the conversation went. "Nonsense," the pope may have responded. "I helped to keep this from becoming heresy before, and I can protect you now. But remember, your account should be neutral, since you have no physical proof of the Copernican system."

"Ah," replied Galileo, "but I do. I believe the tides are the proof of a moving earth, and I propose to call my book *On the Flux and Reflux of the Sea.*"

"No," said Urban, "that won't do at all. That title would give too much

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prominence to what you take to be a physical proof, but God could have created the tides in any way he liked, and not necessarily by moving the earth." Note that Urban's argument was the same as Bellarmino's: even if a moving earth would produce tides, the observation of tides does not necessarily imply the movement of the earth. The case is particularly ironic, because Galileo's physical argument based on the tides was quite wrong. (He attributed them to the daily change in velocity that results from the earth's compound motion of rotation and revolution.)

Galileo was elated to have the gag order removed by the highest possible authority, and he returned to Florence to work on his book. He adopted the popular form of a dialogue, just as his father, a distinguished musician, had done in writing a *Dialogue on Ancient and Modern Music.* Galileo's three speakers are Simplicio, a traditionalist, named after a sixth-century commentator on Aristotle; Salviati, who most often speaks for Galileo himself, and Sagredo, an open-minded man of the world who asks intelligent questions and is generally persuaded by Salviati's reasoning.

The arguments marshaled on behalf of the Copernican system include the phases of Venus, the harmony of the arrangement of the planets and the existence of the tides. The work could hardly be considered neutral, but it ends with the pope's argument in the following words spoken by Simplicio:

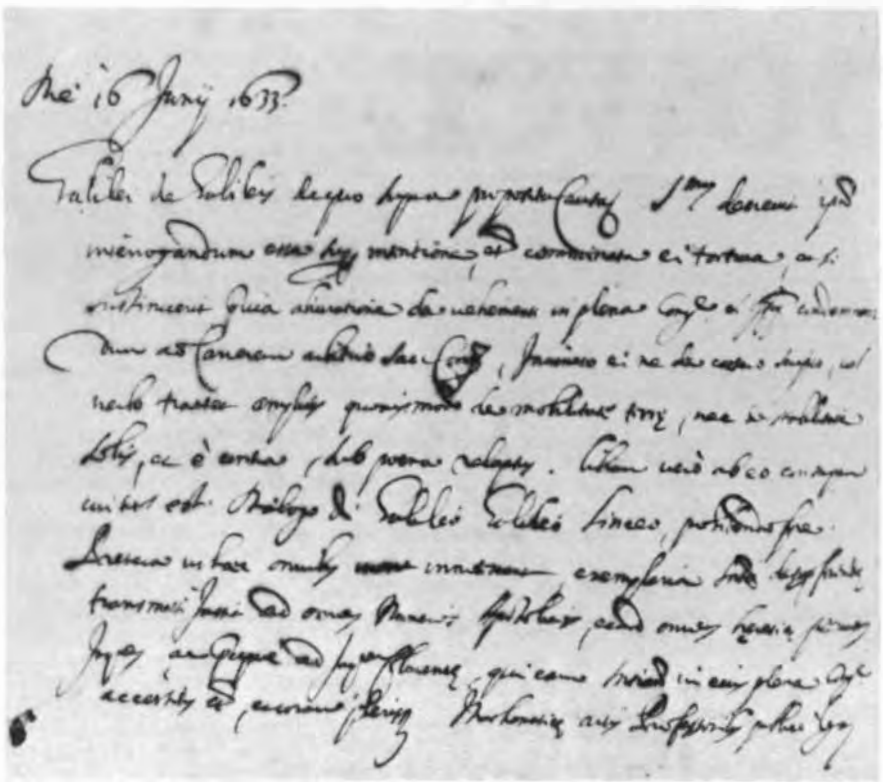
"I confess that your hypothesis on the flux and reflux of the sea is far more ingenious than any of those I have ever heard; still, I esteem it neither true nor conclusive, but, keeping always in mind a most solid doctrine I once received from a most eminent person, I know that if you were asked whether God in his infinite power and wisdom might confer upon the element of water the reciprocal motion in any other way, both of you would answer that he could, and in many ways, some beyond the reach of our intellect." (The translation is based on one by Drake.)

The passage seems quite innocuous, and yet it is singularly inappropriate as the closing argument of the preceding four days of dialogue. Throughout the work Galileo had attempted to show that reasoning from the Book of Nature can, at the very least, establish that one world view is far likelier than another. This has surely been the method of science ever since. Indeed, one might argue (as Alfred North Whitehead did) that since an omnipotent Creator could have made the world in any way he liked, it is all the more incumbent on scientists to discover which way God chose to make it.

When the *Dialogue* appeared, Galileo's enemies were outraged, and they quickly persuaded the pope that the book was heavily weighted in favor of the Copernican system. Furthermore, they convinced the pope that he had been made to look a fool by having his argument given to Simplicio, whose very name suggested "simpleton." The pope, agreeing that Galileo had gone too far, unleashed the Inquisition.

There were two stumbling blocks to prosecution: Copernicus' doctrine had never been publicly declared heretical, and the *Dialogue* had received a license from the censors. From the Vatican Archives, however, the Inquisitors produced a fascinating document: a report of the 1616 meeting between Galileo and Bellarmino. The report stated that an official injunction had indeed been served on Galileo, and that the astronomer had promised not to teach or defend the Copernican doctrine in any way. The pope was furious; it appeared Galileo not only had made him into a fool but also had deceived him about the outcome of the proceedings of 1616.

In February, 1633, Galileo was ordered to Rome, and he was told to come immediately in spite of the rigors of winter travel for a man of almost 70. Before a tribunal of 10 cardinals he was accused of disobedience. The archival evidence, however, was quite irregular: the document was neither signed nor notarized, as such an injunction should have been. Bellarmino had died, and so it was difficult to clarify the status of the document. Hence the Inquisitors, without revealing the source of their accusations, tried to get Galileo to admit that he had



16 June 1633

Galileo Galilei, for the above reasons, as decreed by his Holiness, is to be interrogated concerning the accusation, even threatened with torture, and if he sustains it, proceeding to an abjuration of the vehement [suspicion of heresy] before the full Congregation of the Holy Office, sentenced to imprisonment at the pleasure of the Holy Congregation, ordered, in either writing or speaking, not to treat further in any way either the mobility of the Earth or the stability of the Sun; or otherwise he will suffer the punishment of relapse. The book actually written by him, whose title is *Dialogo di Galileo Galilei Linceo,* is to be prohibited. Furthermore, that these things may be known by all, he ordered that copies of the foregoing sentence shall be sent to all Apostolic Nuncios, to all Inquisitors against heretical depravity, and especially the Inquisitor of Florence, who shall publicly read the sentence to his whole congregation and even in the presence of as many of those who teach mathematics as he can summon together.

BOOK OF DECREES of the Congregation of the Inquisition records the sentencing of Galileo in 1633. The proceedings against him had come to a halt after he had produced Cardinal Bellarmino's letter of 1616. Thereafter an agreement had been reached: Galileo would repent and would promise to write no more on cosmology. The agreement was overruled, however, and he was forced to submit to the humiliating ritual of abjuration, followed by house arrest, the banning of the *Dialogue* and a prohibition of further writing on the Copernican system.

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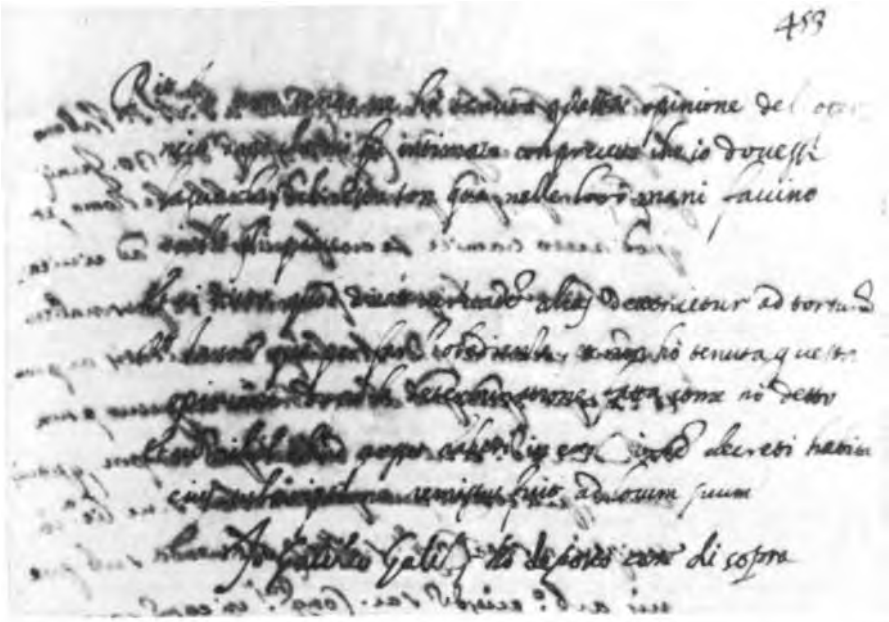
been served an injunction, which would have established the legitimacy of the earlier document. Ultimately Galileo played his trump card. Having been alerted by his friends and their spies, he knew that the Inquisition was looking into his 1616 visit to Rome, and so he had brought a copy of Bellarmino's letter. Galileo's unexpected move threw the Inquisition into disarray, and the cardinals decided to adjourn.

It was a duel of wits, and Galileo had outwitted the pope. Nevertheless, all the secular power remained in the hands of the church, and the pope could not afford the embarrassment of bringing Galileo to Rome for naught. Even Galileo could appreciate this, and so some plea bargaining ensued. It could all be settled out of court: Galileo would confess that he had gone too far, would repent and then would be sent home and enjoined to avoid writing about cosmology.

One can imagine Galileo's shock on June 16, 1633, when he found that the agreement had been overruled and the following sentence was entered in the Book of Decrees: "Galileo Galilei ... is to be interrogated concerning the accusation, even threatened with torture, and if he sustains it, proceeding to an abjuration of the vehement [suspicion of heresy] before the full Congregation of the Holy Office, sentenced to imprisonment. ..." He was also forbidden to write further on the mobility of the earth, and the *Dialogue* was banned.

On the next page the results of the interrogation are recorded. In Italian are Galileo's words: "I do not hold and have not held this opinion of Copernicus since the command was intimated to me that I must abandon it." Then he was again told to speak the truth under the threat of torture. He responded: "I am here to submit, and I have not held this opinion since the decision was pronounced, as I have stated." Finally, there is a notation that nothing further could be done, and this time the document is properly signed in Galileo's hand.

Galileo was sent back to his house at Arcetri, outside Florence, where he remained under house arrest until his death in 1642. Partly as a consequence of his persecution, the center of creative science moved northward to the Protestant countries, notably the Netherlands and England.



"I do not hold and have not held this opinion of Copernicus since the command was intimated to me that I must abandon it; for the rest, I am here in your hands—do with me what you please."

Being once more bidden to speak the truth, otherwise recourse would be had to torture:

"I am here to submit, and I have not held this opinion since the decision was pronounced, as I have stated."

And since nothing further could be done in execution of the decree, his signature was obtained, and he was sent back to his place.

"I, Galileo Galilei, testify as above."

GALILEO'S ABJURATION appears in the Book of Decrees following his sentencing. He retired to his house at Arcetri outside Florence, where he was confined until his death in 1642.

I am fascinated by the choices the Vatican confronts today in reopening Galileo's case. In the first place, it would do no good to announce that the Copernican doctrine should never have been declared heretical, since strictly speaking it never was. Second, Galileo was tried not so much for heresy as for disobeying orders, and it seems clear beyond question that he ignored the earlier decree of the Index when he published his *Dialogue*.

Where there is room for maneuver, it seems to me, is in accepting Galileo's arguments about the reconciliation of science and Scripture. The truth of the Bible, for those who wish to affirm it without rejecting the findings of science, must not be found in a literal six days of Creation, in the sun standing still for the battle of Gibeon or in a physically real star of Bethlehem. I quote Galileo, as he quoted Cardinal Baronius: "The Bible teaches how to go to heaven, not how the heavens go." Such a judgment, it seems to me, would confirm what has long since been accepted by both Catholic and Protestant theologians. It would also speak to the current controversy over Darwinian evolution and the so-called Creation science.

I had a sense of déjà vu when the creationists in California tried to have evolution presented in biology textbooks as a mere hypothesis. This was precisely the tactic the Inquisition adopted with Copernicus' book: they made it acceptable by making it appear hypothetical. I expect the creationists will have about as much success as the Holy Congregation of the Index did. Of course, Galileo believed the Copernican system could be defended as physically real, and not simply as a hypothetical geometric arrangement. It is an irony of history that Galileo's own methods of scientific argument were instrumental in showing that what passes for truth in science is only the likely or the probable; truth can never be final and never absolute. What makes science so fascinating is the task of pushing ever closer to the unattainable goal of complete knowledge.

It is this process that the poet Robinson Jeffers had in mind when he wrote: "The mathematicians and the physics men have their mythology; they work alongside the truth, never touching it; their equations are false but the things *work*." The mathematicians and the physicists cannot really claim truth, but they have certainly sorted out a lot of things that do not work, and they are building a wondrously coherent picture of the universe. The Copernican system is surely a part of that coherency. A universe billions of years old and evolving is also part of that coherency. Galileo made a noble effort to convey such a picture of beauty and rational coherency to his public. Scientists today would honor him by helping their own public to understand better not only the majesty and the beauty of the modern scientific picture of the universe but also the process of hypothesizing and testing by which that view is achieved.

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