

Galileo's Science And the Trial of 1633

"Nature . . . is inexorable and immutable; she never transgresses the laws imposed upon her." Thus did Galileo argue in 1615 for the authority of science over that of Scripture in the physical world. The Catholic Church's 1633 condemnation of Galileo is popularly seen as the response of theological dogmatism. But the issue debated by scholars today is whether Galileo actually *proved* that the Earth revolves around the sun. Here, as he analyzes Galileo's ordeal, historian William A. Wallace explores the complexities of demonstrating truth in science.

by William A. Wallace

The casual tourist in Rome, should he climb the Spanish Steps and approach the imposing palace to which they lead, might notice a green marble pillar bearing an inscription in Italian that translates as follows:

The next palace is the Trinità dei Monti, once belonging to the Medici; it was here that Galileo was kept prisoner of the Inquisition when he was on trial for seeing that the Earth moves and the sun stands still.

The first part of that inscription is undoubtedly true, but less certain is the claim that Galileo was brought to trial "for seeing that the Earth moves and the sun stands still." One cannot actually observe the Earth's movement; proof of this now commonplace notion is considerably more complex.

Notwithstanding the conservatism, overzealousness, and incompetence

of the Catholic Church officials who prosecuted him, Galileo's defense, scientifically speaking, was not nearly so strong as is commonly thought. All of the evidence marshalled *after* his time distorts modern judgments of the trial. We must return to Galileo's assessment of his own work to appreciate his real achievements.

Polish astronomer Nicolaus Copernicus (1473–1543) brought the theory of a rotating Earth that revolved around the sun into public discourse with the publication in 1543 of *On the Revolutions of the Heavenly Spheres*. But it was Galileo's work that sparked debate, almost 70 years later, over this heliocentric theory.

Galileo Galilei was born at Pisa on February 15, 1564, and in his early years he apparently thought of becoming a monk. His father per-

sueded him to study medicine instead, and he pursued courses at the University of Pisa with that intention from 1581 to 1585, when he dropped out, without a degree, and devoted himself increasingly to the study of mathematics.

Such was his competence in mathematics, both pure and applied, that the University of Pisa called him back in 1589 to teach courses in geometry and astronomy. In 1592, he was offered a more prestigious position at the University of Padua, and there, for the next 18 years—which Galileo recalled as “the happiest of my life”—he flourished as professor of mathematics. He taught courses in astronomy; experimented with pendulums, inclined planes, and falling bodies; and perfected the telescope as a reliable instrument for astronomical observations.

On the basis of such observations, he published his *Sidereus nuncius*

(*The Starry Messenger*) in Venice in 1610, and soon won acclaim throughout Europe as the foremost astronomer of his time.

Galileo's teaching notes from his stays at Pisa and Padua have survived, and from these we know that he was aware of the Copernican theory. But he preferred to teach the geocentric theory of Ptolemy (second century A.D.), which at the time was the dominant theory in the universities. Half a century after the appearance of Copernicus's book, only a few scholars had seriously entertained his views.

One such scholar was the German astronomer Johann Kepler (1571–1630), who corresponded with Galileo, and to whom Galileo wrote in 1597 that he himself had become a committed Copernican. Recent research suggests, however, that Galileo wavered in his commitment; his treatises on astronomy published



Aristotle, Ptolemy, and Copernicus (left to right) are depicted in the frontispiece to the first edition of Galileo's *Dialogue* (1632).

during the early 1600s show him still arguing for the Ptolemaic system. What transformed Galileo after 1610 into an enthusiastic supporter of the Polish astronomer were his own discoveries with the telescope.

Between 1609 and 1611, he discovered the moons of Jupiter, which showed that not all motions in the heavens had to be around the Earth as a center. He saw mountains on Earth's moon, which suggested that Earth and moon were made of the same material and possibly underwent similar motions. He discerned the phases of Venus, which showed that its orbit had to be around the sun, not around the Earth as had previously been supposed.

Citing the Cardinal

On the strength of the publication of *Sidereus nuncius*, Galileo obtained the patronage of the Grand Duke of Tuscany, Cosimo II de Medici. He gave up his teaching duties at Padua and moved to Florence where he served as mathematician and philosopher to the Grand Duke.

His advocacy of the Copernican theory as the true explanation of the universe soon came under attack from two camps. On the one hand, Italian philosophers were concerned over the Copernican system's apparent violation of the principles of Aristotelian physics. Theologians, on the other hand, claimed that Copernicanism violated Scripture, notably the Old Testament's assertions that the sun moves across the heavens (e.g.,

Joshua commanded the sun to stand still, Josh. 10:12), and that the Earth is the immovable center around which God made the heavenly luminaries rotate (e.g., Ps. 93:1).*

Encouraged, it seems, by his patron, Galileo responded to both parties: to the conservative Aristotelian philosophers with a *Discourse on Floating Bodies* (1612), and to the theologians with a *Letter to Castelli*, later enlarged as the *Letter to Christina* (1615), wherein he suggested that the Scriptures could be reconciled with the Copernican system by interpreting the Bible allegorically rather than literally. He cited Caesar Cardinal Baronius, a contemporary who said: "The intention of the Holy Spirit is to teach us how one goes to heaven, not how heaven goes."

Meanwhile, a Carmelite friar, Paolo Foscarini, had published in 1615 a theological treatise in which he interpreted the Scriptures in a fashion similar to Galileo's. The works of both men were brought to the atten-

*According to Aristotelian physics (which St. Thomas Aquinas and other Scholastics had followed), the Earth's position in the center of the universe explained local motions such as the downward fall of bodies. Further, the heavenly bodies appeared to be immutable; such perfect spheres, it was thought, could only move in circles. The Earth appeared to be so unlike the celestial luminaries that it seemed impossible to attribute to it the same heavenly motion. Even before Galileo's time, astronomical observations had cast some doubt on some features of this cosmology, and philosophers were divided into those committed to preserving it (the Peripatetics) and those willing to revise it (the more progressive Scholastics).

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tion of Robert Cardinal Bellarmine, a learned Jesuit in Rome who at that time was investigating the criticisms of the Reformers and what the Roman church regarded as their heretical interpretations of Scripture.

In April 1615, Bellarmine wrote to both Foscarini and Galileo, advising them that the Copernican system was as yet only a hypothesis, since the motion of the Earth had not been conclusively demonstrated. He cautioned that until such time as solid proof was offered, the commonly accepted interpretation of Scripture was to be preserved.

Shortly thereafter, in 1616, the Congregation of the Index (a church agency that judged works as heretical or correct) published a decree against the Copernican teaching, condemning Foscarini's book outright and suspending publication of Copernicus's work of 1543 pending correction of its text.

Necessary Demonstrations

Oddly enough, in his *Letter to Christina*, Galileo had agreed with Bellarmine that the traditional interpretation of Scripture was to stand unless the new system could be "well founded on manifest experiences and necessary demonstrations." He apparently felt that he would soon provide such evidence. But, as we shall see, he subsequently ran into difficulties.

In February 1616, when he was in Rome, Galileo had an important meeting with Cardinal Bellarmine. In the files of the Holy Office, a much-discussed document is preserved, dated February 26, which states that Galileo, while in Bellarmine's household, was enjoined not to hold, teach, or defend the Copernican system "in any way whatever."

The document seems to be a record

of an injunction that was to be served on Galileo should he not agree to Bellarmine's instructions. It appears that the injunction was never actually served on Galileo, and thus there is some doubt whether he was told that he could teach the Copernican system as a mathematical *hypothesis* that simplified astronomical predictions, or whether he was told that he was not to hold, teach, or defend it in any way whatsoever.

I will return to this matter later, for the question of whether the injunction was actually served on Galileo assumed some importance at the trial of 1633.

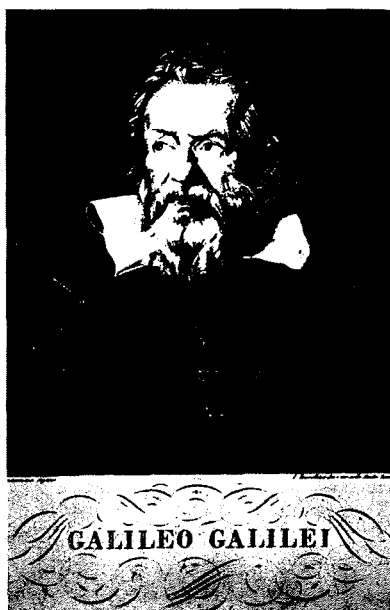
Difficult Dialogue

Galileo's early relations with the papacy and the Jesuits were, on the whole, good. Cardinal Bellarmine had questioned the Jesuit astronomers at the Collegio Romano about the accuracy of the new observations with the telescope; they had promptly confirmed Galileo's findings. The Collegio's greatest mathematician, Christopher Clavius, knew of Galileo's work and had helped him get his teaching positions.

Clavius died in 1612, however, and soon after, Galileo got into a nasty dispute with a German Jesuit, Christopher Scheiner, over the nature and motion of sunspots. The situation worsened a few years later, in 1618, when Galileo launched another attack on one of Clavius's successors at the Collegio, Orazio Grassi, over the paths and appearances of comets.

While this argument was raging, in 1621 three important figures died: Pope Paul V, Cardinal Bellarmine, and Galileo's patron, Cosimo de Medici. Fortunately, Paul V was succeeded by a Florentine cardinal, Matteo Barberini, who had been sympathetic to Galileo during the

Portrait by Flemish painter Justus Susterman of Galileo, who was elected in 1611 to the Academy of the Lynx-eyed, Europe's first scientific society.



troubles of 1616 and who generally took Galileo's side in his battles with the more orthodox Jesuits.

When Barberini assumed the papacy in 1623 as Urban VIII, Galileo took the opportunity to dedicate his definitive answer to Grassi on comets, *The Assayer*, to the new pope. No doubt Urban VIII was pleased and flattered by this action; Galileo was granted the favor of six papal audiences. Most scholars agree that Galileo secured some kind of permission from Urban to resume work on the Copernican system.

By 1630, he had finished his great work, the *Dialogue on the Two Chief Systems of the World*. In it he evaluated all of the evidence and arguments for and against the Ptolemaic and Copernican systems, coming down rather hard on the side of the Copernicans and making the Ptolemaists and the Aristotelians look

somewhat foolish in the process. Galileo caricatures their positions through a fictional character, the inept Simplicio, a Peripatetic who finds his philosophy in the text of Aristotle rather than in the book of nature.

The importance of the *Dialogue* is twofold. It was the first frontal attack on the whole of Aristotelian physics. It focused on the weakest point of Aristotelian physics—its account of the motions of bodies.

Galileo had difficulty obtaining permission to have the *Dialogue* published. The Dominican Niccolò Riccardi, charged with censoring the work, was mindful of the decree against Copernicanism handed down in 1616. But, by doctoring the manuscript, Galileo was able to get Riccardi's approval, and his book was printed by Landini at Florence in 1632. He had added a preface and a

note at the end, wherein he disclaimed giving any actual proof of the Copernican system and labeled it a pure mathematical hypothesis.

The "dialogue" takes place over four days among the fictional characters Salviati, Sagredo, and Simplicio, with a different series of arguments being developed in the course of each day. On the first day, Salviati, Galileo's mouthpiece, argues that there is no clear dichotomy between the celestial and terrestrial regions, a central tenet of Aristotelian cosmology. He says the world is one, probably constructed of the same kind of material (e.g., the mountains on the moon, just like those on Earth) and probably undergoing the same kinds of motion.

On the second day, the main topic is the rotation of the Earth on its axis. Here Galileo rebuts most of the proofs that the Earth is at rest (such as the fact that a stone dropped from a tower always falls at its foot) and shows that, if one knows the proper principles of mechanics, the proofs offered yield the same results whether the Earth is still or turning.

Rejecting Kepler

The arguments, he admits, do not *prove* that the Earth is rotating. They simply destroy the proofs of his adversaries that it must be at rest. The Earth's diurnal rotation is thus left an open question.

The third day is devoted to a more difficult problem: whether the Earth is immobile in the center of the universe or actually travels in a large, annual orbit around the sun. Arguing by analogy, Galileo asks: Since the other planets revolve around the sun, why should not the Earth do likewise? Further, earthly revolution can explain the movement of sunspots.

Finally, on the fourth day, Galileo

puts together the conclusions of the second and third days' discussions, showing how they provide a simple explanation of a universally observed phenomenon, the motion of the tides.

His argument, in summary, is that the combination of the Earth's daily rotation on its axis with its annual revolution around the sun results in unequal forces being exerted daily on the waters on the Earth's surface. These unequal forces give rise to the tides.

To make his point, Galileo had to reject Kepler's theory of tides—that they are caused by lunar attraction—the theory that is accepted by scientists today. In the preface, Galileo himself refers to his argument on tides as an "ingenious fantasy"; he labored over it for years without removing all its flaws.

Coming to Trial

With the publication of the *Dialogue* in 1632, Galileo found himself in deeper trouble than he had ever imagined. Pope Urban VIII was furious, probably because he felt Galileo had betrayed his earlier pledge that he would write impartially, and almost certainly because he felt that Galileo had misused, and ridiculed, Urban's own preferred answer to the Ptolemaic-Copernican controversy, namely that it could not be definitively resolved by human intellect.

In August 1632, all further publication and sales of the book were prohibited by the Holy Office. Galileo was summoned to Rome from Florence to be tried by a tribunal of 10 cardinals on the charge that he had willfully taught the Copernican doctrine despite its condemnation as contrary to Scripture. In preparing for the trial, the clerical prosecutors discovered the written injunction

that had putatively been given to Galileo on February 26, 1616, enjoining him not to hold, teach, or defend the Copernican system in any way.

Accordingly, a number of theologians examined the *Dialogue* to ascertain whether Galileo had or had not actually held, taught, or defended Copernicanism in that work. The results were, predictably, that Galileo had undoubtedly *taught* the motion of the Earth and the immobility of the sun in the *Dialogue*, and that he had also *defended*, without a doubt, the same teaching.

House Arrest

But had Galileo actually *held* a belief in this teaching? Basing their judgment on the preface Galileo had written (presumably to please Ricciardi and so get his work approved for publication), the theologians gave him the benefit of the doubt and decided that he might not have proffered the work as a statement of his own personal conviction.

During the course of the trial, Galileo, for whatever motive, took the obvious way out and said that the theologians' finding on the third point was correct. As a devout son of the church, he would not personally believe anything that was contrary to sacred Scripture. He was made to swear that he did not believe in the Earth's motion, and on this basis he was given a salutary penance ("for the spiritual benefit of former heretics who had returned to the faith") and confined to house arrest. The *Dialogue* was banned, and Galileo was forbidden to write any more on Copernicanism.

Galileo then retired to his villa at Arcetri, outside Florence, and there spent the remaining years of his life studying and writing. In 1638 (four years before his death), he published

Two New Sciences, a work regarded by scientists as laying out the principles of the modern science of mechanics. It has earned him the title "Father of Modern Science."

The work is replete with claims that the author has founded a "new science," that he has provided demonstrations or strict proofs pertaining to the motions of earthly bodies. Such claims are conspicuously absent from the earlier *Dialogue on the Two Chief Systems of the World*, and their absence, I argue, necessitates reevaluation of what Galileo did and thought he did in *that* book, and of why he recanted.

Return to the inscription on the pillar in Rome and its implication that Galileo actually *saw* the Earth's motion, i.e., that he was able to prove, on the basis of incontrovertible evidence, that the Earth was rotating on its axis and revolving in a closed orbit around the sun. Did Galileo believe he had done this? To answer this, one must know precisely what he took to be scientific proof.

Galileo's Sources

Unfortunately, this has proved difficult for historians of science to discover. My study, over the past 15 years, of three notebooks that Galileo composed while he was a young math professor at Pisa, has turned up an unsuspected possibility. These notebooks, now in the Biblioteca Nazionale Centrale in Florence, cast an entirely new light on the way Galileo structured his *Dialogue*.

What is surprising about the notebooks is that they summarize and explore the logical and physical treatises of Aristotle, not in the conservative and textual style of the Peripatetics in the Italian universities, but rather in a progressive application of Aristotle's principles to cur-

rent problems. For example, in the third notebook, Galileo applies Aristotelian principles to the motions of heavy bodies.

Even more surprising are the sources on which the notebooks draw, since Galileo has been so often cast in opposition to both the church and the Aristotelians. The first two volumes were drawn from Latin notes used by Jesuit lecturers at the Collegio Romano on logic and natural philosophy, respectively. The third is an adaptation of the same materials to Galileo's own study of the motion of projectiles and falling bodies. Galileo apparently obtained the lecture notes through his correspondence with the Jesuit Clavius.

Using Suppositions

The key to my solution is an expression that occurs repeatedly throughout Galileo's writings from his earliest to his last years, namely, the Latin term *suppositio*, especially as applied to a type of demonstration. Reasoning *ex suppositione* is rarely discussed in the present day, but it assumed considerable importance at the end of the 16th century among progressive Aristotelians. It is in these notebooks that the clearest statement of Galileo's methodology, that of *ex suppositione*, is found, and its debt to Aristotle is unmistakable.

Identifying the Jesuit Aristotelian precursors of his thought gives us a new appreciation of Galileo's later contacts with Jesuits such as Bellarmine, Scheiner, and Grassi, particularly in evaluating Galileo's claims for demonstration and proof. All of these men used precisely the same terminology employed in Galileo's early notebooks. When we reread the *Dialogue*, we can assume that his later Jesuit protagonists understood and to some extent shared both the

concept of *ex suppositione* and the methods for evaluating such reasoning as applied therein.

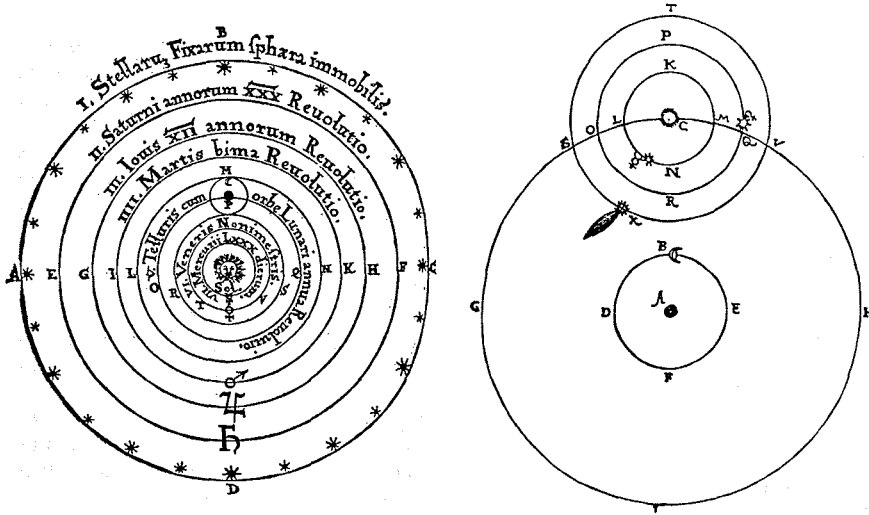
What is reasoning *ex suppositione*? Unlike the hypothetico-deductive method scientists use today (which denies that there can be positive, incontestable proof of any conclusions based on hypotheses), it allows the possibility of *demonstrating* the truth and certainty of some results through the use of appropriate suppositions. Both Galileo and the Jesuits recognized that there were two types of *suppositiones*: some would be merely imagined situations that could not be verified, whereas others would be capable of verification, either by induction from sense experience or by measurement to within a specified degree of accuracy.*

In all of Galileo's serious scientific writings up to, but not including, the *Dialogue*, he is at pains to identify and verify the suppositions on which his reasoning is based, to justify his claims for strict proof. He follows the same procedure in *Two New Sciences*, where the new science of local motion is finally worked out. But in the *Dialogue*, such claims are strangely absent. Thus one must wonder whether Galileo really did think in 1632 that he had proved the Earth's motion. Was the question, in his own eyes, still debatable?

My suspicion is that Galileo himself was aware, in 1632, that he lacked rigorous proof of the Earth's motion. He supported the Coperni-

*For example, the supposition of epicycles in the geocentric theory was postulated *merely* for predicting planets' positions—not because it was believed to be physically true. On the other hand, Galileo's supposition in the *Two New Sciences* that a body falls with uniformly increasing velocity is mathematically formulated in terms of time and distance; this formula he then verifies experimentally.

THE COPERNICAN CHALLENGE... VS. THE TYCHONIAN COMPROMISE...



can system anyway on the grounds that the arguments he had been able to muster, though not conclusive, were better than his opponents'.

We now know that during his 1592–1610 stay at Padua, Galileo continued to work on problems of motion and mechanics and that he made drafts of proofs and demonstrations on which his “science of motion” would one day be erected. By 1609, when he started to work with the telescope, he had completed all the investigations that would be required to write the *Two New Sciences*—a book that would not be published for another 30 years.

Galileo's familiarity with the subject was such that in 1609 he had implicitly grasped the demonstrative force of the arguments he would later formalize in the *Two New Sciences*. He had already experimentally validated the *suppositiones* (e.g., the definition of accelerated motion; the negligible effects of fric-

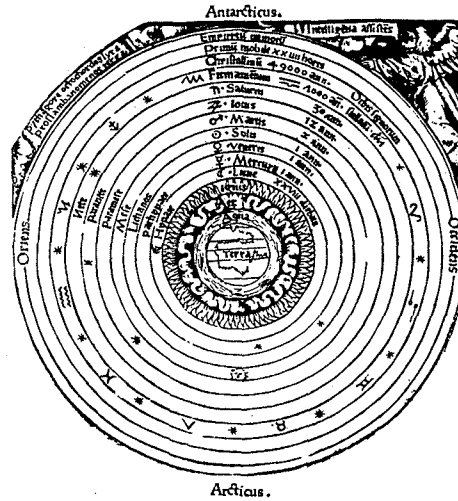
tion) on which his work would be based, and he spoke with confidence of the book's imminent appearance.

It was a confident Galileo, then, who gazed through the telescope, and his intuition was this: If he could systematize his new observations, and couple these with the principles of motion he was soon to formulate, he could quickly extend his demonstrations to cover the Earth's motion—not only in its diurnal rotation but in its revolution around the sun as well. Such a comprehensive system would be an imposing rival to Aristotelian physics.

It was the prospect of these demonstrations that led him to make the extravagant claims in the *Letter to Christina*. And it was the same prospect that was to haunt him when he came to write his definitive treatise defending the Copernican system. He had to cast it as a dialogue precisely because the proof of the suppositions on which the reasoning was based

VS. THE MEDIEVAL WORLDVIEW

The Copernican system's (far left) main attraction was its mathematical simplicity. Galileo sought the same simplicity in motions on Earth. The Tychonian system (left) appealed to those who believed the Earth could not possibly move as fast as Copernicus's theory required. It, too, simplified the Aristotelian model (right), whose defects Ptolemy had sought to remedy with complex devices such as epicycles and equants.



(i.e., the Earth's rotation and revolution, and the sun's immobility) still eluded him in 1632.

Both before and after the publication of the *Dialogue*, then, Galileo gives abundant evidence of his awareness of and adherence to the canons of demonstrative proof as required by the method of reasoning *ex suppositione*. In the *Dialogue* itself, persuasive argumentation is used, not demonstration, and no mention is even made of the Tychonian system, favored by Galileo's real opponents, which could just as readily explain all of the observational evidence provided with the telescope.*

Finally, as if to add insult to injury, the rebuttal to Galileo's proof of the tides—perhaps dictated by Ur-

*Danish astronomer Tycho Brahe (1546–1601) maintained that the other planets circled the sun, and that this system as a whole revolved around the Earth, thus preserving the geocentric theory of the universe.

ban VIII—is voiced at the end of the work by Simplicio, the “simpleton,” whose judgment and credibility have already been questioned at every turn. Urban's argument was that God in his infinite power could effect the tidal motion in many ways beyond the reach of man's intellect, and thus that no human explanation, however ingenious, should be regarded as true and conclusive.

But the rebuttal also leads one to wonder whether Galileo was really forced to make the statements in the preface and endnote. Did he use them freely, aware that his arguments for the Earth's motion had barely progressed beyond the level of hypothetical reasoning, appealing enough, but still short of incontestable proof? More important, did he perjure himself when he swore after his trial that he personally did not believe in the Earth's motion?

If his concept of proof was indeed the one outlined of necessity *ex sup-*

positione, then one must conclude that he did not verify the mathematical principles on which the *Dialogue* was based. And only if one concludes that Galileo himself was aware of this shortcoming, do we give proper credit to his intelligence and to his character, to both his brilliance and his will. He was perceptive enough to recognize the limitations of his argument, skillful though it was, and he was honest enough, as a believer, to acquiesce in the church's interpretation of the Scriptures when he lacked the "necessary demonstrations" to show it was otherwise.

Such a resolution of the problem posed by Galileo's abjuration of Copernicanism is not easy to grasp in the late 20th century, when there is no clear and accepted demarcation between the provinces of faith and reason. But in Galileo's day, in the Italy of the late 16th and early 17th centuries, an important teaching of Aquinas prevailed: Faith and reason have radically different spheres.

This means that a person cannot assent to one and the same truth by faith and by reason at the same time. If one *knows* something by reason, for example, one cannot assent to it by faith. If one *believes* something, on the other hand, one does so only because one's *reason* is unable to decide whether it is true or not.

In light of this teaching, the human intellect can go only so far in penetrating the secrets of the universe. Yet reasoning does not exhaust the sphere of the knowable, as it can be supplemented by faith—in those instances where God chooses to reveal something important.

Galileo, on such an accounting,

would have two options on the matter of the Earth's motion: either he could *prove* it, and so *know* the truth of the proposition "the Earth moves" on the basis of his own reasoning; or he could *not prove* it, leaving it an open question which could still be decided by faith.

Early on in his investigations, if my analysis is correct, Galileo thought that convincing proof of the Earth's motion was within his grasp. Later, he saw the difficulty and complexity of the situation and came to admit, begrudgingly, that the opposite conclusion would have to be accepted on faith—because the church was proposing it to him as something beyond man's knowing powers and directly revealed by God.

Galileo's only "crime," to use historian Giorgio de Santillana's term, was that he was too precipitate in urging his intuitions on others, too presumptuous in expecting others to "see" what he could "see." Very human are faults such as these. But we need not add to these the further charges of arrogance and insincerity, of stubborn adherence to a position he was finally unable to defend, of swearing under oath that he did not believe what he truly believed.

It is much better, in my view, to see him as a true son of his church, willing to accept its teachings when his reason—despite its strong intuitions—was unable to establish their opposite. And, as a true scientist, he not only admitted that he failed to meet the standards of his profession but also persevered during his last years in the quest for a new science that would, one day, be able to furnish the proofs that eluded his grasp.