Biographical Encyclopedia of Astronomers

Galilei, Galileo

Born Pisa, (Italy), 15 February 1564

Died Arcetri near Florence, (Italy), 8 January 1642

Although Galileo Galilei (universally known by his first name) is best remembered in the history of astronomy for his telescopic discoveries, his greatest contribution was his approach to physics, which led to the work of Christiaan Huygens and Isaac Newton. Galileo's father, Vincenzio, was a musician who made significant contributions to musicology and influenced his son's experimental approach. In 1581, Galileo enrolled at the University of Pisa to study medicine, but soon switched to mathematics, which he also studied privately. In 1585, he left the university without a degree, turning to private teaching and research. In 1589 he became professor of mathematics at the University of Pisa, and then from 1592 to 1610 at the University of Padua

During this period, Galileo's research focused primarily on the nature of motion. He was critical of Aristotelian physics, favorably inclined toward Archimedean statics and mathematics, and innovatively experimental, insofar as he pioneered the procedure of combining empirical observation with quantitative mathematization and conceptual theorizing. Following this approach, he formulated, justified, and to some extent systematized various mechanical principles: an approximation to the law of inertia, the composition of motion, the laws that in free fall the distance fallen increases as the square of the time elapsed and that the velocity acquired is directly proportional to time, the isochronism of the pendulum, and the parabolic path of projectiles. However, he did not publish any of these results during that period, indeed not publishing a systematic account of them until the *Two New Sciences* (Leiden, 1638).

The main reason for this delay was that in 1609 Galileo became actively involved in astronomy. He was already acquainted with Nicolaus Copernicus's theory of a moving Earth and appreciative of the fact that Copernicus had advanced a novel argument. Galileo also had intuited that the geokinetic theory was more consistent in general with the new physics than was the geostatic theory. In particular, he had been attracted to Copernicanism because he felt that the Earth's motion could best explain why the tides occur. But he had not published or articulated this general intuition and this particular feeling. Moreover, Galileo was acutely aware of the considerable evidence against Copernicanism: The Earth's motion seemed epistemologically absurd because it contradicted direct sense experience; Astronomically false because it had consequences that could not be observed (such as the similarity between terrestrial and celestial bodies, Venus's phases, and annual stellar parallax); mechanically impossible because the available laws of motion implied that bodies on a rotating Earth would, for example, follow a slanted rather than vertical path in free fall and would be thrown off by centrifugal force; and theologically heretical because it contradicted the words and traditional interpretations of Scripture. Until 1609, Galileo judged that the anti-Copernican arguments far outweighed the pro-Copernican ones.

However, the telescopic discoveries led Galileo to a major reassessment. In 1609, he perfected the telescope to such an extent as to make it an astronomically useful instrument that could not be duplicated by others for some time. By this means, he made several startling discoveries that he immediately published in *The Sidereal Messenger* (Venice, 1610): that the Moon's surface is full of mountains and valleys, that innumerable other stars exist besides those visible to the naked eye, that the Milky Way and the nebulae are dense collections of large numbers of individual stars, and that the planet Jupiter has four satellites revolving around it at different distances and with different periods. As a result, Galileo became a celebrity. Resigning his professorship at Padua, he was appointed philosopher and chief mathematician to the Grand Duke of Tuscany, moving to Florence the same year. Soon thereafter, he also discovered the phases of Venus and sunspots. On the latter, he published the *Sunspot Letters* (Rome, 1613).

Although most of these discoveries were made independently by others, no one understood their significance as Galileo did. This was threefold. Methodologically, the telescope implied a revolution in astronomy insofar as it was a new instrument that enabled the gathering of a new kind of data transcending the previous reliance on naked-eye observation Substantially, these discoveries significantly strengthened the case in favor of the physical truth of Copernicanism by refuting almost all empirical astronomical objections and providing new supporting observational evidence. Finally, this reinforcement was not equivalent to a settlement of the issue, because there was still some astronomical counterevidence (mainly the lack of annual stellar parallax and the possibility that Venus' phases could support a Tychonic view); because the mechanical objections had not yet been answered and the physics of a moving Earth had not yet been articulated; and because the theological objections had not yet been refuted. Thus, Galileo conceived a work on the system of the world in which all aspects of the question would be discussed. This synthesis of Galileo's astronomy, physics, and methodology was not published until his *Dialogue on the Two Chief World Systems* (Florence, 1632).

This particular delay was due to the fact that the theological aspect of the question got Galileo into trouble with the Inquisition, acquiring a life of its own that drastically changed his life. As it became known that Galileo was convinced that the new telescopic evidence rendered the geokinetic theory a serious contender for real physical truth, he came increasingly under attack from conservative philosophers and clergymen. They argued that Galileo was a heretic because he believed in the Earth's motion and the Earth's motion contradicted Scripture. Although Galileo was aware of the potentially explosive nature of this issue, he felt he could not remain silent and decided to refute the biblical argument against Copernicus. To avoid scandalous publicity, he wrote his criticism in the form of long private letters, in December 1613 to his disciple Benedetto Castelli and in spring 1615 to the dowager Grand Duchess Christina

Galileo's letters circulated widely, and the conservatives became even more upset. Thus, in February 1615, a Dominican friar filed a written complaint against Galileo with the Inquisition in Rome. An investigation was launched that lasted about a year. As part of this inquiry, a committee of Inquisition consultants reported that the key Copernican theses were absurd and false in natural philosophy and heretical in theology. The Inquisition also interrogated other witnesses. Galileo himself was not summoned or interrogated, partly because the key witnesses

exonerated him and partly because Galileo's letters had not been published, whereas his published writings contained neither a categorical assertion of Copernicanism nor a denial of the scientific authority of Scripture.

However, in December 1615, Galileo went to Rome of his own accord to defend his views. He was able to speak to many influential Church officials and was received in a friendly manner; he may be credited with having prevented the worst, insofar as the Inquisition did not issue a formal condemnation of Copernicanism as heresy. Instead, two milder consequences followed. In February 1616, Galileo himself received a private warning from Cardinal Robert Bellarmine (in the name of the Inquisition) forbidding him from holding or defending the truth of the Earth's motion. Galileo agreed to comply. And in March, the Congregation of the Index (the cardinals in charge of book censorship) published a decree which, without mentioning Galileo, declared that the Earth's motion was physically false and contradicted Scripture, that a 1615 book supporting the Earth's motion as physically true and compatible with Scripture was condemned and permanently banned, and that Copernicus's 1543 book was banned until appropriately revised. Published in 1620, these revisions amounted to rewording or deleting a dozen passages suggesting that the Earth's motion was or could be physically true, so as to convey the impression that it was merely a convenient hypothesis for making mathematical calculations and observational predictions.

For the next several years, Galileo kept quiet about the forbidden topic, until 1623 when Cardinal Maffeo Barberini became Pope Urban VIII. Since Barberini was an old admirer and patron, Galileo felt freer and decided to write the book on the system of the world conceived earlier, adapting its form to the new restrictions. Galileo wrote the book in the form of a dialogue among three characters engaged in a critical discussion of the cosmological, astronomical, physical, and philosophical arguments, but determined to avoid the biblical or theological ones. This *Dialogue* was published in 1632, and its key thesis is that the arguments favoring the geokinetic theory are stronger than those favoring the geostatic view, and in that sense, Copernicanism is more probable than geostaticism. When formulated thus, the thesis is successfully established. In the process, Galileo managed to incorporate into the discussion the new telescopic discoveries, his conclusions about the physics of moving bodies, a geokinetic explanation of the tides, and various methodological reflections. From the viewpoint of ecclesiastic restrictions, Galileo must have felt that the book did not "hold" the theory of the Earth's motion, because it was not claiming that the geokinetic arguments were conclusive; that it was not "defending" the geokinetic theory, because it was merely a critical examination of the arguments on both sides; and that it was a hypothetical discussion, because the Earth's motion was being presented as a hypothesis postulated to explain observed phenomena.

However, Galileo's enemies complained that the book did not treat the Earth's motion as a hypothesis but as a real possibility, and that it defended the Earth's motion. These features allegedly amounted to transgressions of Bellarmine's warning and the Index's decree. And there was a third charge: that the book violated a special injunction issued personally to Galileo in 1616 prohibiting him from discussing the Earth's motion in any way whatsoever; a document describing this special injunction had been found in the file of the earlier Inquisition

proceedings. Thus, Galileo was summoned to Rome to stand trial, which, after various delays, began in April 1633

At the first hearing, Galileo was asked about the *Dialogue* and the events of 1616. He admitted receiving from Bellarmine the warning that the Earth's motion could not be held or defended, but only discussed hypothetically. He denied receiving a special injunction not to discuss the topic in any way whatsoever, and in his defense he introduced a certificate he had obtained from Bellarmine in 1616 that only mentioned the prohibition to hold or defend. Galileo also claimed that the book did not defend the Earth's motion, but rather suggested that the favorable arguments were inconclusive, and so did not violate Bellarmine's warning

The special injunction surprised Galileo as much as Bellarmine's certificate surprised the inquisitors. Thus, it took three weeks before they decided on the next step. The inquisitors opted for some out-of-court plea bargaining: They would not press the most serious charge (violation of the special injunction), but Galileo would have to plead guilty to a lesser charge (unintentional transgression of the warning not to defend Copernicanism).

Galileo requested a few days to devise a dignified way of pleading guilty to the lesser charge. Thus, at later hearings, he stated that the first deposition had prompted him to reread his book; he was surprised to find that it gave readers the impression that the author was defending the Earth's motion, even though this had not been his intention. He attributed his error to wanting to appear clever by making the weaker side look stronger. He was sorry and ready to make amends

The trial ended on June 22, 1633, with a sentence harsher than Galileo had been led to believe. The verdict found him guilty of a category of heresy intermediate between the most and the least serious, called "vehement suspicion of heresy"; the objectionable beliefs were the cosmological thesis that the Earth moves and the methodological principle that the Bible is not a scientific authority. The *Dialogue* was banned. He was condemned to house arrest for the rest of his life. And he was forced to recite a humiliating "abjuration."

One of the ironic results of this condemnation was that, to keep his sanity, Galileo went back to his earlier research on motion, organized his notes, and five years later published his most important contribution to physics, *The Two New Sciences*. Without the tragedy of the trial, he might never have done it.

Maurice A. Finocchiaro

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