Biographical Encyclopedia of Astronomers

Kepler, Johannes

Born Weil der Stadt, (Baden-Württemberg, Germany), 27 December 1571

Died Regensburg, (Bavaria, Germany), 15 November 1630

Johannes Kepler revolutionized astronomy and physics even more than Nicolaus Copernicus, in that he broke with the principle of uniform circular motion for celestial bodies, which Copernicus had tried to uphold. His reasoning was physical, but he created a rigorous mathematical model of planetary kinematics. Although best remembered today for his "three laws of planetary motion," Kepler made contributions to science that were much broader than this simple mnemonic suggests, and his discoveries were hard-won

His father, Heinrich Kepler, was a soldier who later abandoned the family; his mother, Katharina Guldenmann, was the daughter of the *Burgemeister* (mayor) of Eltingen, a village near Weil der Stadt. The family's means were modest. As a scholarship student at the University of Tübingen (1589–1594), Kepler was educated in a rigorous curriculum established by Protestant reformers during the previous half-century, which helped develop his understanding of the roles of astronomy and mathematics. Kepler's own confession was Lutheran, with Calvinist leanings. At Tübingen, he fell under the particular influence of the instructor Michael Mästlin, a convinced follower of Copernicus who was to remain Kepler's mentor in astronomy for many years. From this time at least, Kepler was a Copernican He planned a career in academia, but when a teaching position in mathematics became available at a seminary in Graz in 1594, Kepler's instructors recommended him for the post as the strongest of their candidates. It was in Graz that he developed his first original ideas in astronomy, which he published in the *Mysterium Cosmographicum* in 1596. This work expands upon the worldview that forms the basis of much of his future theoretical work by proposing a structure of the planetary system based on geometrical regularity. The particular model of the heavens that it lays out determines both the number of planets and their sequential distances from the Sun by nesting the five classical regular solids within the (notional) spheres encompassing the planetary orbits. Kepler, i. e.g., created a model with a cube inscribed within the sphere representing the orbit of Saturn, a sphere inscribed within this to represent the orbit of Jupiter, a tetrahedron inscribed within this, and a sphere inscribed within the tetrahedron to represent the orbit of Mars, and so forth. By this structure, the proportional distances of the planets from the Sun (as then known from the Copernican model) were approximately represented.

During his tenure in Graz, Kepler was engaged to a twice-married heiress, Barbara Müller, whom he married in 1597. They had three children who survived childhood, but one died in 1611, and Barbara followed a few months later. Kepler married Susanna Reuttinger in Linz in 1613. Three of their six children survived

The *Mysterium*, which was Kepler's first book, and his correspondence with Tycho Brahe (as well as his inadvertent involvement in Brahe's priority dispute with Nicholaus Bär [Raimarus

Ursus] over the non-Copernican planetary theory according to which the planets orbit the Sun, which in turn orbits the Earth) led Brahe, the preeminent European astronomer, to invite Kepler to join him in Prague at the court of the Holy Roman Emperor Rudolph II in 1600, as one of several mathematical assistants. Kepler, who had greater ambitions for modeling the Universe, was assigned the carefully circumscribed task of determining the parameters of the orbit of Mars from Brahe's meticulous observations

A few days after Brahe's death in 1601, Rudolph appointed Kepler Imperial Mathematician; he was to be Brahe's successor. This position, at a comparatively early age, brought him European eminence. Several more major works followed during Rudolph's reign, including the *Astronomiae Pars Optica* in 1604, and the *Astronomia Nova*, based on his work on the orbit of Mars, in 1609. Rudolph was deposed and replaced on the throne by his brother in 1612, and the remainder of Kepler's life was unsettled

The *Astronomia Nova*, unique among astronomical works to this date in that it is not only a treatise, but also a personal history of scientific discovery subtly reworked to convince the reader of the inevitability of its conclusions, creates a wholly new and revolutionary model of planetary kinematics. The book presents the first two of what (since at least the time of Joseph de Lalande, in the late 18th century) have been known as Kepler's "three laws of planetary motion." These two are: (1) that planets move in elliptical orbits with the Sun at a focus and (2) that a line connecting a planet with the Sun will sweep over equal areas in equal periods of time. The first law, in particular, demolished the Western (including the Arabic) tradition of planetary models derived from combinations of circular motion Kepler actually discovered the second law of motion first and used it as an aid to calculation. Because the ellipticity of Mars' orbit is very small, Kepler's discovery rested both upon Brahe's extremely precise (nontelescopic) observations and Kepler's own confidence in their accuracy. Another noteworthy aspect of the book is that Kepler attempts to derive the kinematics of planetary motion from physical principles based in part on William Gilbert's discovery that the Earth itself is a magnet. This line of reasoning required that the Sun be at one focus of the planetary orbits. In the Copernican system, though the Sun was at the center in a general sense, it was not actually at the mathematical center of the orbits; Kepler thereby forced classical astronomy to confront the physical consequences of the Copernican revolution. One cannot, however, draw a direct line from Kepler's theorizing to the planetary dynamics that were developed later in the 17th century, by Isaac Newton in particular.

Kepler's account of his model was persuasive for a number of technically proficient astronomers, but the practical difficulties of using it to calculate planetary positions were considerable. It was some time before his discoveries were widely applied in practice. In particular, the theory required the solution of what has become known as Kepler's equation or Kepler's problem, the best solution to which, if only as a mathematical problem rather than a practical one, has occupied a number of mathematicians over the centuries (and, in different contexts, at least as far back as the 9th century). For much of the 17th century, astronomers who chose to apply Kepler's elliptical theory to the determination of planetary positions used an approximation method developed by Ismaël Boulliau

Kepler had a tremendous capacity for work (especially notable when one considers how much computation had to be done by hand), and several more books on astronomy followed, of which the most important were the *Epitome Astronomiae Copernicanae* (1618), a general textbook on astronomy that has not yet received much examination by historians, and the *Harmonice Mundi* (1619), within which is what we now call Kepler's third law, that the square of a planet's period is proportional to the cube of its mean distance from the Sun.

The long-delayed *Tabulae Rudolphinae*, published in 1627, were a kind of culmination of Kepler's astronomical work. They provided the basis for the calculation of ephemerides with greatly increased accuracy

Kepler expended much energy between 1615 and 1621 in the ultimately successful defense of his mother, who had been accused of witchcraft. The last decade of his life was troubled by vicissitudes attending to the Thirty Years' War, which broke out in 1618.

Kepler's last work, the *Somnium*, published posthumously in 1634, is an imaginative account of a visit to the Moon and a consideration of its inhabitants. Its speculations derive from his understanding of astronomy and physics, and it is now considered one of the earliest works of science fiction

Kepler worked on and made significant contributions to fields of knowledge other than astronomy, including optics, mathematics (in the geometry of solids, close packing, tiling, and logarithms), meteorology, and, though it has long ceased to be a scientific subject, astrology. His *Dioptrice* of 1611 laid out the theory of the refracting telescope, introducing a system of two convex lenses, later known as the Keplerian telescope. What became the Kepler conjecture on close packing, which was finally proven in 1998, is more closely related to work done by Thomas Harriot, and contrary to some recent accounts, Kepler and Harriot did not discuss the subject. He attempted, without success, to discover the law of refraction, whose successful formulation is now often attributed to Willebrord Snel, who had studied Kepler's writings on optics. Harriot, with whom he did indeed correspond on this topic, had earlier discovered the law but declined to reveal it to Kepler or anyone else. Among the discoveries set forth in the *Astronomiae Pars Optica*, which explores aspects of optics related to astronomical observation, is that the image projected onto the retina by the lens of the eye is inverted, leading to the realization that the process of vision is more complex than the simple receipt of the image

Kepler was not primarily an observational astronomer, but rather a theoretician. Nonetheless, throughout his work, from his earliest model onward, his theories are conceived in very concrete or geometric models, rather than in abstract algebraic constructs. Indeed, even in his work on the mathematics of regular solids, one can easily picture Kepler physically constructing models to ease his efforts at visualization. This may partly explain why, though a prominent streak of neo-Platonism runs through his thought, notably in his belief in a Universe founded on archetypes, a case can be made that, in his philosophy, Kepler was what we now term a "realist."

Many historians and other writers have described, with varying degrees of subtlety, a Kepler who had a dual personality: a forward-looking modern rational scientist on the one hand and a mystic and obscurantist who looked backward to the Middle Ages on the other This portrait, still sometimes presented to the public, has been superseded by the research of more recent historians, who see much of Kepler's thought as having greater unity and consistency, its important theoretical innovations arising from the same milieu as the less familiar or more easily disparaged ideas, such as his improvements (as Kepler conceived them) to astrology. This greater appreciation of the depth and unity of his thought does not, however, completely place Kepler's contributions within the broader history of astronomy, because even his contemporaries, and many of those who advanced the study of astronomy in the following decades, were perplexed by his dynamic and harmonic theories and stymied by the complexity of the mathematical methods required to apply his astronomical discoveries in practice.

Regardless of this puzzle, it is clear that although Kepler, like Copernicus, worked within long-standing traditions, his contributions to the kinematics of astronomy were radically new, and they gave to the revolution that Copernicus had started an impetus that helped drive both astronomy and physics forward to the creation of classical dynamical physics later in the 17th century.

Adam Jared Apt

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