

## Historical astronomy

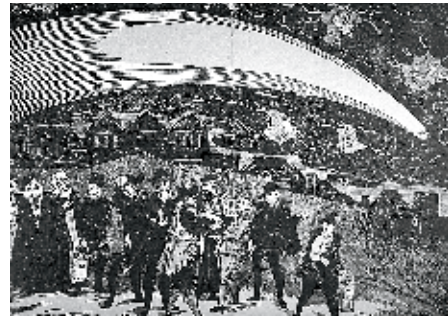
# How Johannes Kepler revolutionized astronomy

This 17th-century German astronomer explained planetary orbits, discovered light's inverse-square law, and wrote the first modern book on optics. **by Daniel Hudon**

Johannes Kepler was one of the key figures of the Scientific Revolution. True, he is not as well-known as Galileo or the reclusive genius, Isaac Newton, who built on Kepler's work. But Kepler — Germany's mathematical genius — was a major player in astronomy's history and set the stage for many subsequent important discoveries.

### Great discoveries

By describing the process of human vision, Kepler wrote the first modern book of optics, *Astronomiae Pars Optica*. He discovered the inverse square law of light — the foundation for measuring all modern stellar and galactic distances. His thoughts on the shapes of snowflakes



**The Great Comet of 1577** spread its tail across the sky. This event was an early memory of Kepler's. When he was 5, his mother took him to view the comet when it shone at its brightest.

Woodcut by Jiri Daschitzky, 1577

resulted in the first book on crystallography, *De nive sexangula*.

After Galileo's telescopic discoveries in 1610, Kepler described how the revolutionary new instrument worked. He also introduced improvements, including one that increased the field of view. His design came into wide use by the middle of the 17th century.

We know Kepler mostly for his three planetary laws, which he derived after a Herculean battle with the data of the great Danish naked-eye observer, Tycho Brahe. Kepler linked physics and astronomy by establishing the idea that the planets had to move due to unseen forces. He thus founded celestial mechanics and opened the door for Newton's work on gravitation.

### Personal history

Kepler was born December 27, 1571 — 28 years after the death of Copernicus

< *Astronomia Nova*, published in 1609, details Johannes Kepler's work on Mars' orbit. Kepler based his work on the observations Danish astronomer Tycho Brahe had collected over 20 years. Linda Hall Library of Science, Engineering, and Technology

and 7 years after Galileo's birth — in Weil der Stadt, a small, mostly Catholic town on the edge of the Black Forest in southern Germany. Despite being the oldest of four children (three siblings died in infancy), Kepler was always an underdog. His first chore in life was to overcome an unhappy childhood that was plagued by illnesses both real and imaginary.

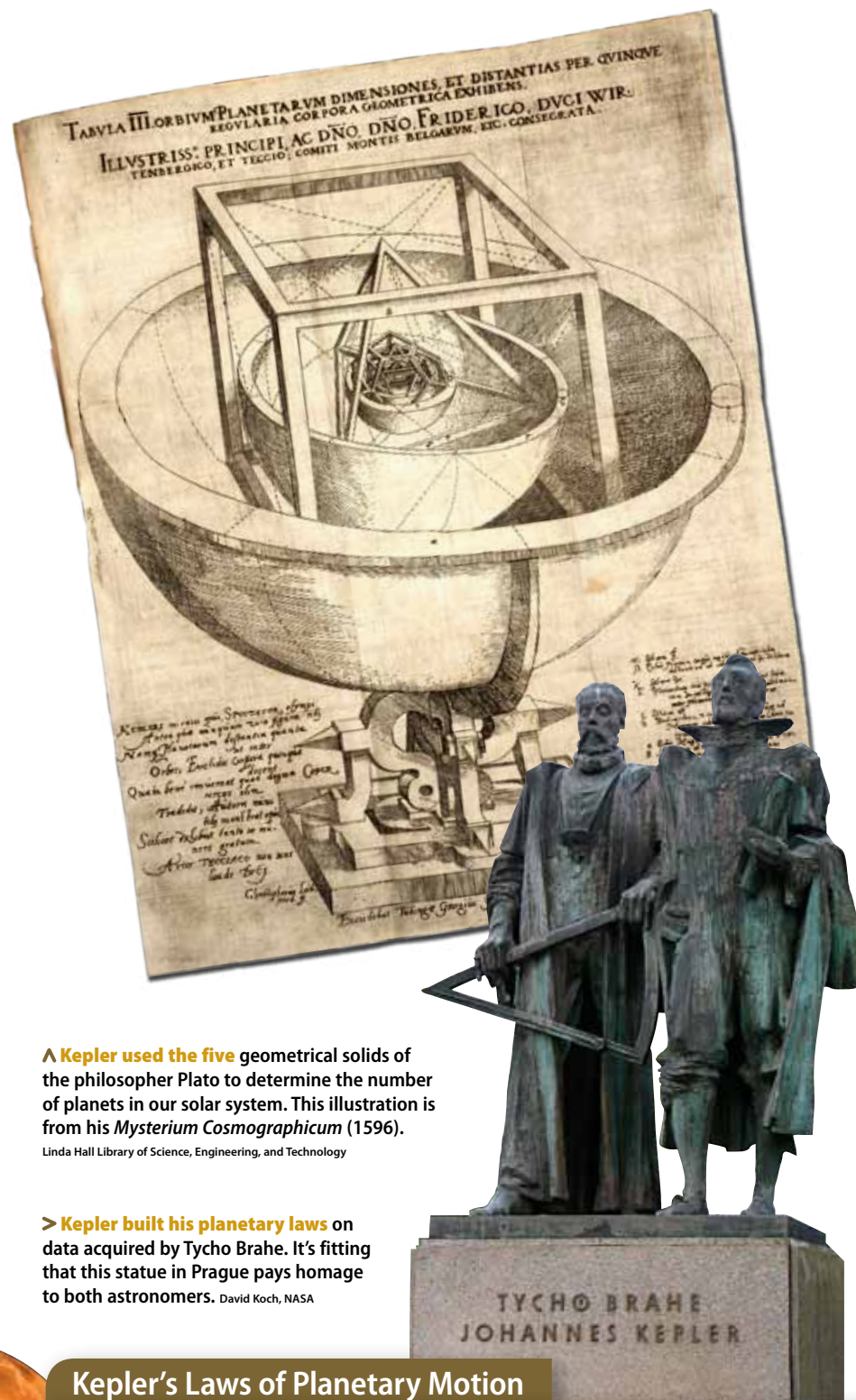
An early bout with smallpox left Kepler with defective vision — one reason he eventually pursued theoretical rather than observational astronomy. One notably happy event occurred when he was 5. Kepler's mother took him to a hilltop to view the Great Comet of 1577, whose tail arched across the entire sky.

Kepler's first job was as a math teacher in Graz, Austria. It was there that he embarked on his lifelong quest for harmony. In a flight of mathematical mysticism, he tried to link the known planets to Plato's five geometrical solids (the cube, tetrahedron, octahedron, icosahedron, and dodecahedron). By nesting each geometrical solid between the orbits of the planets, he thought he had the basis for the known number of the planets. He was so pleased with this idea, he wrote it up as a sort of "theory of everything" called *Cosmographicum Mysterium* ("The Cosmic Mystery").

The book impressed the most impressive astronomer of the day, Tycho Brahe, and the two men began what quickly became a tempestuous collaboration. Brahe had accumulated 20 years of precise observations and needed someone with Kepler's mathematical prowess to make sense of it. Kepler promised he could solve the orbit of Mars within 8 days. Mars was particularly difficult because the observations varied from Tycho's calculations more than any of the planets. Instead, the task took nearly 8



Johannes Kepler produced the three laws of planetary motion, the first detailed observation of a supernova, and an accurate star and planetary position catalog. Copy of anonymous 1610 portrait



▲ Kepler used the five geometrical solids of the philosopher Plato to determine the number of planets in our solar system. This illustration is from his *Mysterium Cosmographicum* (1596).

Linda Hall Library of Science, Engineering, and Technology

> Kepler built his planetary laws on data acquired by Tycho Brahe. It's fitting that this statue in Prague pays homage to both astronomers. David Koch, NASA

years and more than 900 pages of calculations before he wrapped it up.

To harmonize observations with calculations, Kepler first determined Earth's motion as a planet. Think of understanding the motion of an airplane circling an airport as seen from another airplane, and you have some sense of the enormity of his task. "I have spent so much pains on it," he wrote a friend, "that I could have died 10 times."

By insisting that his theoretical orbits agreed to within the errors of Brahe's data, Kepler created one of the linchpins of the scientific method. In the process, he swept the astronomical house free of its clutter of circles and epicycles and gave the world two of his three laws of planetary motion: Planets orbit the Sun in ellipses, and a line drawn from the Sun to the planet sweeps out equal areas in equal times. The wheels of the Scientific Revolution were turning, and the ancient notion of uniform circular motion, which even Copernicus held onto, was abandoned for good.

### Kepler's nova

In October 1604, a brilliant new star blazed forth in the evening sky. Kepler observed the star and wrote about it in his 1606 work, *De Stella Nova*. As he observed the star, he noted it did not show any parallax.

Parallax is an apparent shift seen as an object is viewed from two locations. A nearby object shows a large parallax, while a distant object shows small parallax. He concluded the object lay within the sphere of the fixed stars.

This conclusion put Kepler at odds with the church. Indeed, how could such a phenomenon occur if the heavens were immutable? Such a "new star" showed the sky does, indeed, change.

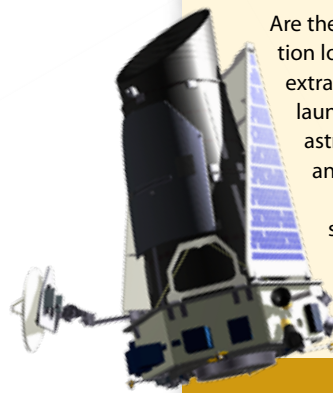
### Triumph through adversity

Working while suffering religious persecution and financial hardship, Kepler was part mystic and part modern scientist.

Despite constant battles with illness and fever, and tragedies that claimed the lives of his first wife and several of his children, Kepler kept up his quest for harmony. In 1618, his spirit soared when

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### Kepler searches for Earths



NASA's Kepler mission flies the first spacecraft designed to find Earth-sized planets. It measures the light-drop when a planet crosses in front of its host star. The craft will survey 100,000 stars.

Jon Lomberg, NASA

Are there other Earths? This question looms large in the search for extrasolar planets. With the launch of the Kepler Mission, astronomers hope to know the answers soon.

This dedicated space telescope will monitor the brightnesses of 100,000 nearby stars, searching for planetary transits. A transit occurs when a planet passes in front of its host star, causing its light to dim. Johannes Kepler first predicted such an event for Mercury and Venus almost 400 years ago.

But the transit method has challenges. Viewed from Earth, planets have only a small

chance of crossing in front of their host stars. During a transit, earthlike planets will cause the host stars' brightnesses to dip by only  $1/10,000$ . Of course, such a dip could be caused by a star spot or the star's own brightness variation. So astronomers must monitor stars precisely for several years to catch recurring transits.

The Kepler Mission's main instrument is a 37.4-inch (0.95 meter) photometer that has a particularly large field of view — 105 square degrees. That area is equivalent to two "scoops" of the Big Dipper. If other Earths are common, then Kepler will detect hundreds.

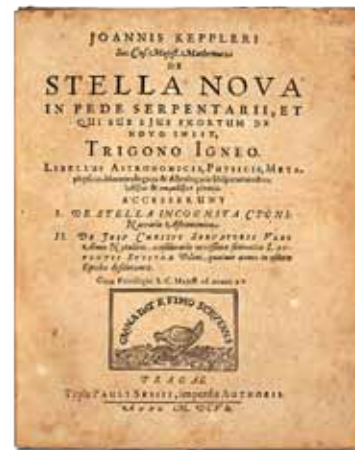
Johannes Kepler's last work, *Somnium* ("The Dream") was a pioneering science fiction novel about a man's voyage to the Moon. Finding Earths will be like a dream come true for many. — D. H.

he discovered the third of his planetary laws while revising his book, *The Harmony of the World*. He considered this law — that the cube of a planet's distance is proportional to the square of its orbital period — one of his greatest achievements. It now forms the basis of the solar system's structure.

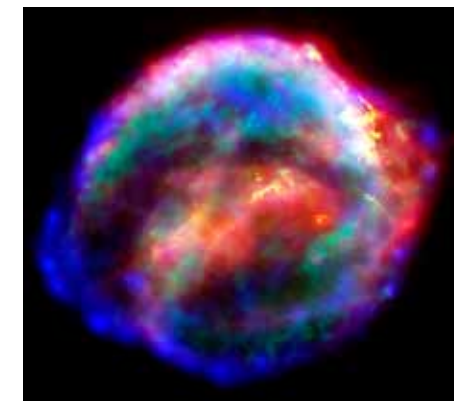
In 1627, he completed *The Rudolphine Tables*, a culmination of his life's work, by combining Brahe's data with his planetary laws. The tables remained astrono-



Kepler plotted the position of "his" nova (marked by an "N" near bottom-center) accurately against the stars of the constellation Ophiuchus. Linda Hall Library of Science, Engineering, and Technology



Kepler's *De Stella Nova*, published in 1606, described a "new star" (what astronomers now call a supernova) he observed in October 1604. Linda Hall Library of Science, Engineering, and Technology



The supernova remnant from the "new star" Kepler observed in 1604 continues to expand today. Three of NASA's space-based observatories — Hubble, Spitzer, and Chandra — collaborated to make this image. NASA/ESA/R. Sankrit and W. Blair (Johns Hopkins University)

my's most accurate resource for decades. Astronomers used them to predict the first observed transits of Mercury and Venus in 1631 and 1639, respectively. Observations of these events helped solidify acceptance of the heliocentric model and Kepler's laws.

Kepler rarely called attention to his accomplishments — he was the first scientist to advocate freely sharing data — and wanted nothing more than to devote his life to philosophical speculation. But

time and again he was forced to take to the roads to flee religious turmoil brought on by the Counter Reformation or to seek secure employment. He died of a fever November 15, 1630, while searching for another job. Though his grave was lost in the Thirty Years War, the epitaph he wrote for himself remains:

*I measured the skies, now the shadows I measure,  
Skybound was the mind, earthbound the body rests.* ☾

### Kepler's Laws of Planetary Motion

- 1 Planets orbit the Sun in elliptical orbits with the Sun at one focus. (This law destroyed the notion of circular orbits.)
- 2 A line drawn from a planet to the Sun sweeps out equal areas in equal times. (This law shows why planets [and other objects, like comets] move faster when they lie closer to the Sun than when farther away.)
- 3 The square of a planet's orbital period,  $P$ , is proportional to the cube of its semi-major axis (solar distance),  $a$ . If the period is in Earth years and the semi-major axis is in astronomical units, then  $P^2 = a^3$ . (Astronomers use this law to determine an extrasolar planet's distance from its host star. All they need to know is its period.) — D. H.