Johannes Kepler, Doug Hayhoe, August 2022

Kepler was the "man who revolutionized astronomy," as a recent biography of him is titled. He was also the first person to integrate modern science and Christianity, in his views on nature.

The Scientific Revolution came when people realized that science must be based on careful observations, accurate mathematics, and testable theories. Copernicus, Galileo, and Newton are well-known names of that period. But another person's work was also key: Johannes Kepler (1571-1630). When Newton said, "if I have seen further [than others], it is by standing on the shoulders of giants," he was referring to Galileo and Kepler (Figure 1).

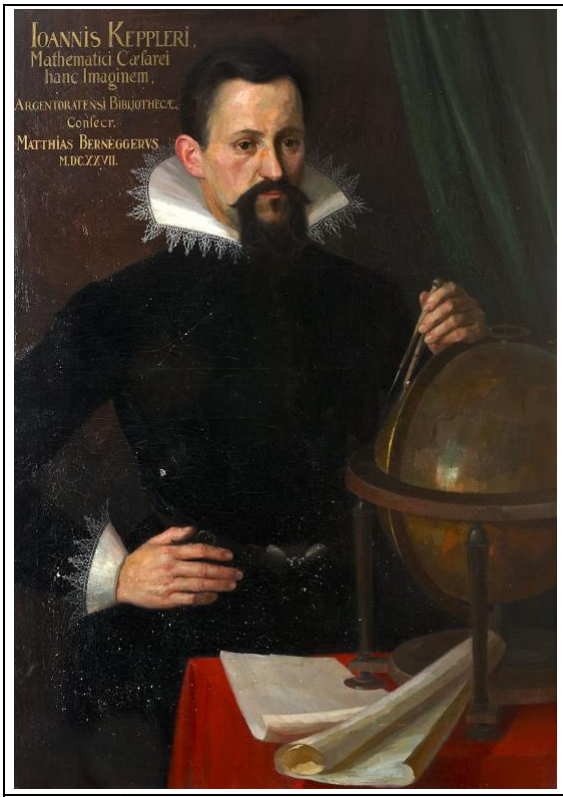

Figure 1 Portrait of Kepler by an unknown artist in 1620 (Wikipedia, public domain)

Physics was my first love. In high school, I was introduced to it. In university, I slogged my way through it. Some of my physics instructors were good, some mediocre, and some downright scary! So, when it was my turn to teach it, I was ready to try something new.

I was fortunate that a new curriculum had just been developed at Harvard, the *Project Physics Course*. Instead of emphasizing problems and equations, it focused on historical personalities and their hands-on investigations. It began with Galileo and the study of motion, a common topic in physics courses. But before going on to Newton and force, it looked at Copernicus and Kepler, and their discoveries in astronomy. Understanding this step was critical, it emphasized, to fully appreciate Newton's work on gravity.

Kepler's science

Copernicus was the famous Polish astronomer who rejected the geocentric view of the solar system, which had been taught since the days of the Greeks, and adopted the heliocentric view, that planets orbit the Sun, not Earth. He still went with the Greek idea of the circle as the perfect form, however. To make circular orbits fit the data, he used a complicated system of epicycles.

When Kepler came along, half a century later, he accepted Copernicus's heliocentric model, but had doubts about its complexity. By then, he had access to key astronomical data that Copernicus didn't have. The well-known astronomer, Tycho Brahe, had made new naked eye observations of planetary positions that were incredibly accurate. (The telescope had not yet been invented.)

Kepler took this data and plotted it to see how he could make it fit a circular orbit. The orbit of Mars was his nemesis. When he fitted it to a circle, there was always a tiny error in one angle, only eight minutes of arc (a fourth of the moon's diameter), but it was significant for Kepler. He had worked with Tycho and knew he didn't make mistakes like that.

What did Kepler do? On the basis of this one discrepancy, he gave up the idea of using circles to explain the motion of planets, a tradition that was two thousand years old, and postulated that the planet Mars's true motion was that of an ellipse. He soon realized that all the planets, as well as comets, travel around the Sun in elliptical orbits, not circular ones. He later wrote, "these eight minutes alone have prepared the way for reshaping the whole of astronomy."

I remember as a teacher asking my high school students to plot Mars's orbit on a poster board (Figure 2). For each point on the orbit of Mars (M), they used two sightings from Earth (E) taken a Martian year apart (687 days). Mars would be back at the same point in its orbit. By intersecting the two observation lines drawn from Earth, they could fix its position. (Mars was in the same position again, but Earth would not quite have completed two Earth years.) The students tried to fit a circle to all the points they found this way. It was fun watching them slowly realize it wouldn't work. Following Kepler, they finally rejected the circle and tried fitting the points to an ellipse. If they were careful, they found it worked!

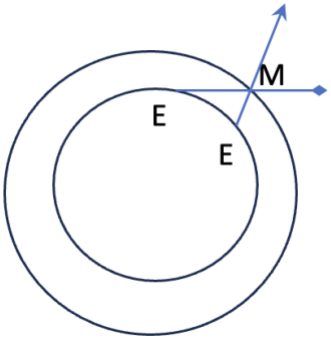

Figure 2 Finding a point on the orbit of Mars (M) with paired observations from Earth (E)

Kepler's first law, therefore, is that all planets travel in an elliptical orbit with the Sun at one focus (Figure 3). Kepler went on to formulate a second law, that when the planets are closer to the Sun, they move faster. In fact, their speed is such that a line from the planet to the sun, "sweeps out equal areas in equal times" (Figure 4). For a simulation of this, see here.

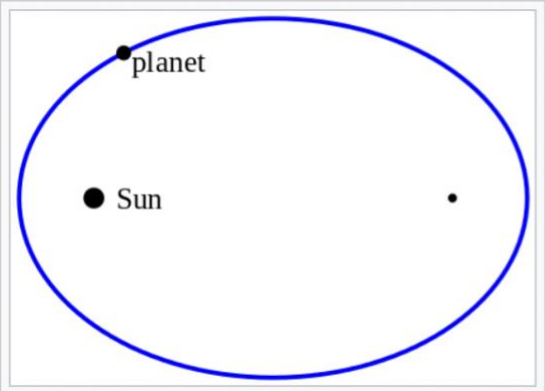

Figure 3 The first law: planets travel in ellipses with the Sun at one focus

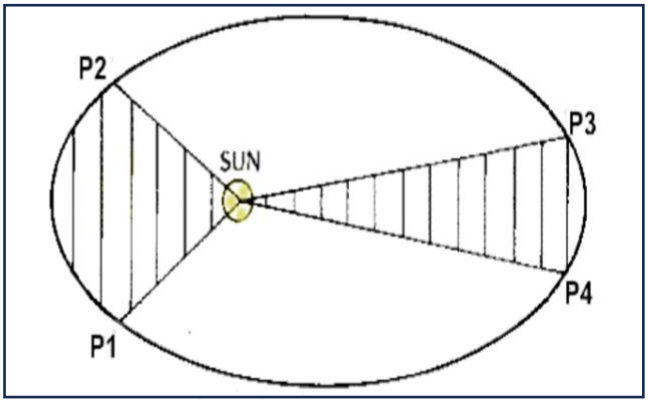

Figure 4 The second law: planets sweep out equal areas in equal times. (The planet takes the same time to travel P1-P2 as P3-P4. Shaded areas are equal.)

But Kepler wasn't done. He had noticed that planets farther from the Sun, move slower. Of course, a planet five times farther from the Sun than Earth, like Jupiter, will have an orbit five times as big, and therefore take five times as long to orbit the Sun, if it is moving at the same speed as Earth. Jupiter, however, takes twelve years to go around the Sun, not five! So, it is moving less than half the speed of Earth. Kepler made the amazing deduction, never thought of before, that the Sun is exerting a force on the planets, which gets smaller with distance. He even provided an exact formula describing how the Sun's gravity decreases with distance. Kepler's third law became the basis of Isaac Newton's "universal law of gravitation," the most important law ever discovered. Gravity holds the universe together, comets, planets, stars, and galaxies!

Kepler's faith

Project Physics helped students focus on the personalities and life of the scientists, not just their discoveries. Both Kepler in Germany and Galileo in Italy were Christians. They lived during the Protestant Reformation and Catholic Counter-Reformation. Kepler was Protestant while Galileo was Catholic. But for both, their faith in Scripture as God's authority was very important. I've commented on Galileo in my essay "God's Two Books." Here I'll only talk about Kepler.

Kepler's fascination with God's universe began early. When he was five his mother took him outside to see a spectacular comet. And when he was nine, his father showed him an eclipse of the moon. It was no accident, then, that he later became interested in astronomy. I remember my own fascination with nature when my mother hauled us out of our beds in the middle of the night to see a lunar eclipse!

Although he tended to over promote his own discoveries, as his biographer, David Love, points out, Kepler never become too proud to give God the glory. When he was writing out his third law, he wrote: "Sun, moon, and planets glorify Him in your ineffable language! … Thou, my soul, praise thy Creator! It is by Him and in Him that all exists." (Morris Kline, p. 39). If you're familiar with the New Testament, you'll recognize Colossians 1:17 here.

Kepler not only appreciated the order in the universe, he also recognized that in creating us in His image, God gave us the ability to understand His universe. "The laws [of the universe] lie within the power of understanding of the human mind; God wanted us to perceive them when He created us in His image in order that we may take part in His own thoughts" (Gerald Holton, pp. 340). It's interesting to contrast this with Einstein's views three centuries later. *He* said, "The most incomprehensible thing about the universe is that it is comprehensible" (Steve Adams). Einstein was amazed that we humans could actually understand the universe. Kepler wasn't.

Many astronomers and other scientists have let their discoveries and fame become the focus of their attention, rather than nature itself. Kepler was aware of this danger, and once wrote that "astronomers as priests of God to the book of nature, ought to keep in their minds not the glory of their own intellect, but the glory of God above all else" (Hooykaas, p. 105). What a warning!

Conclusion

In some ways, Kepler still remained enmeshed in the Pythagorean traditions of the Greeks. For he tried to explain the positions of the six known planets by fitting their orbits around the five regular solids (tetrahedron, cube, octahedron, dodecahedron, icosahedron). Nevertheless, he was the first modern astronomer. He broke through the Greek legacy of circles that even Copernicus adhered to, and formulated equations for the motions of heavenly bodies that we still use today.

Kepler saw no conflict between science and Scripture. He felt that he could serve God equally well through the study of His works as through that of His Word. For although he had originally wanted to be a minister, he came to realize that his calling was to be an astronomer. His hope in his publications was that "[people's] belief in the creation of the world be fortified through this … and that [God's] inexhaustible wisdom shine forth daily more brightly" **(**Gerald Holton).

Credits

Caspar, Max, *Kepler* (Dover reprint, 1993).

Holton, Gerald, "Johannes Kepler's Universe: Its Physics and Metaphysics," *American Journal of Physics* Vol. 24, No. 5, pp. 340-351.

Hooykaas, Reijer, *Religion and the Rise of Modern Science* (Scottish Academic Press, 1972), p. 105.

Johannes Kepler, Wikipedia, https://en.wikipedia.org/wiki/Johannes_Kepler

Kline, Morris, *Mathematics: The Loss of Certainty* (Oxford UP, 1980), p. 39.

Love, David K. *Kepler and the Universe: How One Man Revolutionized Astronomy* (Prometheus, 2015).

Rutherford, F. James, Holton, Gerald et al.(ed), *Project Physics Course*: Text and Handbook: Unit 2, Motion in the Heavens (1970). This is available online at https://fep.if.usp.br/~profis/arquivo/projetos/HARVARD/Ingles/motioninheavensp00fjam.pdf