Chapter 9

The Sun at the Center

In This Chapter

- Copernicus put the Sun at the center
- Galileo and Kepler figured things out
- The Sun isn't perfect
- Other solar systems

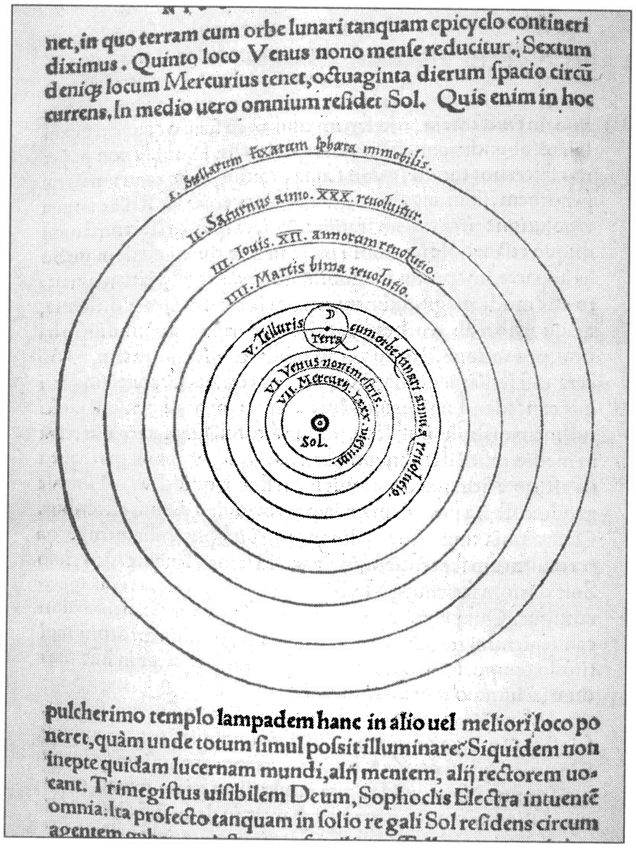
Throw Down Your Ptolemy

More than 2,000 years ago, about 350 B.C.E., the great philosopher and scientist Aristotle advanced a theory of the universe that seemed to make sense, at least to our ordinary senses: We are on a stationary Earth, and the Sun, the Moon, and the planets go around us. About 500 years later, Claudius Ptolemy, who flourished in Alexandria around 140 C.E., modified Aristotle's theory to make it fit better with the details of the observations of the time. In particular, he had to account for the details of the wanderings of the planets in the sky with respect to the stars.

If you watch the sky every night, you can see bright planets like Jupiter or Mars rise and set with the stars. If you watch from night to night, though, you can see that they appear to drift among the stars. For most of the time, they move slightly faster than the stars in their rising and setting; we call such motion prograde. And occasionally, they seem to fall behind the stars in their rising and setting; we call such backward motion retrograde.

Ptolemy tried to reason how the planets could sometimes appear to move backward. He suggested that rather than merely being attached to huge spheres that rotated around Earth, they were on small circles whose centers moved on the big spheres. The main motion on the spheres as they turned were said to be on the deferents. But motion on the small circles, known as epicycles, brought the planets apparently backward for part of the time.

In the early 1500s, Polish canon, physician, and astronomer Nicolaus Copernicus worked out a system of the universe in which the Sun instead of Earth is at the center. He explained retrograde motion as the effect of perspective. As an example, you have been in a car at a stoplight and thought you were going backward as the car next to you drifted forward. The effect in the solar system is the same: We might see Mars seem to drift backward as we pass it as we both orbit the Sun.



net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum deniq; locum Mercurius tenet, octuaginta dierum spacio circū currens. In medio uero omnium residet Sol. Quis enim in hoc

pulcherimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentē omnia. Ita profecto tanquam in solio regali Sol residens circum

The first heliocentric diagram, from Copernicus's book of 1543. Note that the Sun (sol, *in Latin) is at the center.*

(Jay M. Pasachoff)

We have accepted for years that Copernicus's work demoted the Earth from the center of the universe to a peripheral role. Recently, Seattle English professor Dennis

Danielson has realized that a careful historical reading shows that the center of the system was not a desirable place to be. After all, sewage winds up at the center of a system on Earth, and, to Aristotle, "gross matter" settled at a the center of the world. We may be well out of that filthy place.

Solar Scribblings

Anthony Hecht and John Hollander invented a verse form known as the double dactyl, an eight-line poem in which every line has the "da' da da" dactylic form repeated twice. The first line is a nonsense set of syllables, and one line must be a single double-dactylic word. One of their efforts comes to mind here:

Higgledy-piggledy
Nic'laus* Copernicus
Looked at the universe,
Spoke to the throng:

Give up your Ptolemy,
Rise up and follow me,
Heliocentrically
Ptolemy's wrong.

*This is clearly cheating; on the other hand, "Nicky" would have been far, far worse. Lines 5 and 6 are nevertheless inspired.

(Poem by Nancy L. Stark; footnote by John Hollander. From *Jiggery-Pokery*, Copyright 1966, 1983 by Anthony Hecht and John Hollander. Used by permission.)

Galileo on Your Side, Nicky

One of the most brilliant scientists at the turn of the sixteenth century, when Shakespeare was treading the boards and writing his plays, was Galileo Galilei, in what we now call Italy. As we have seen, he turned the newfangled telescope at the sky in 1609. He had come to believe that Copernicus was right, that the Sun was at the center of the solar system. Among his early achievements, he had figured out the precursor of what we now know as the law of inertia, and with it he could understand why some of the supposed arguments against Copernicanism were wrong. For example, Copernicus's opponents asked how birds weren't whisked away by huge winds if the Earth were spinning rapidly in space. Galileo realized that the birds and the air shared in the Earth's rotation and kept going by inertia.

Galileo made his early discoveries in physics while at the University of Pisa. For example, he discovered that a pendulum swings with a constant period no matter how high it swings. Then he moved to the University of Padua, which enjoyed the freedom of the Venetian Republic. He was such a good lecturer that a tall platform and chair were built for him to stand on and sit in to allow students to see him while he lectured. These objects still survive at the University of Padua. He was at that university when he worked on his first telescopes.

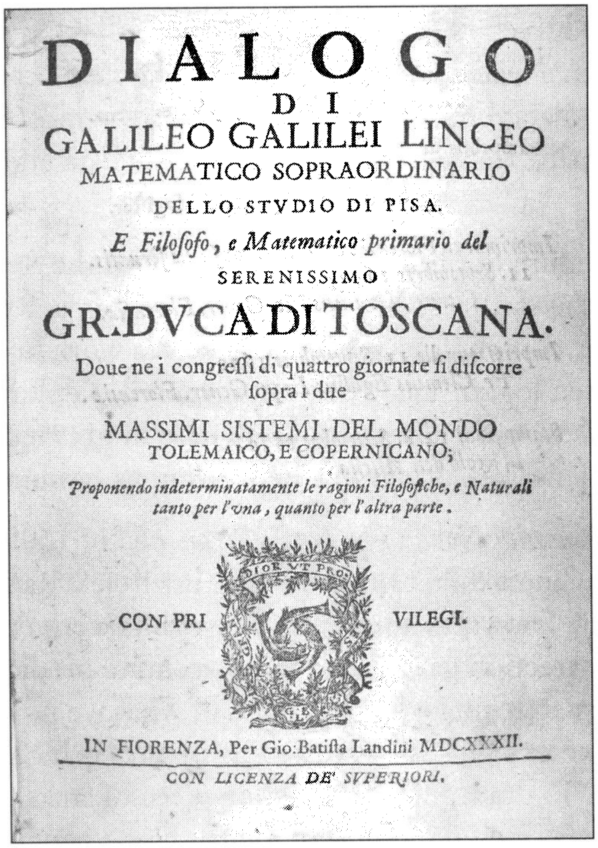
Galileo's telescopic discoveries got him what he thought was a better job: back in Tuscany, in Florence. But Florence was closer to Rome and was under the influence of the Pope and the Inquisition, which was rooting out supposed heresy. In 1616, Galileo was brought before the Inquisition and was even shown the rack and other instruments of torture in order to convince him to withdraw his backing for the heliocentric theory. Rumor has it that as he left the room after abjuring, he muttered "And still it [Earth] moves."

Galileo kept himself clean until 1629, when he couldn't resist anymore. An old friend was then pope. Galileo wrote a book in the form of a discussion among three individuals discussing the theories of how the universe is arranged: *Dialogue Concerning the Two Great World Systems.* It took him three years to arrange permission to publish it, and it came out in 1632. The book was written in the vernacular, common Italian that the general public could understand, instead of the Latin of scholarly works. That fact helped condemn Galileo, especially when the pope realized that at the end of the book, Galileo had placed a foolish argument in the mouth of a character identifiable as the pope.

Galileo was again called before the Inquisition. This time, he didn't get off. He was convicted of disobedience and sentenced to house arrest. Even while restrained, though, he continued to work and wrote important books, including one on optics. He died on Christmas in 1642.

Fun Sun Facts

The story of Galileo and his fight with the Roman Catholic Church was so dramatic that it is still written and sung about. Bertholt Brecht's play *The Life of Galileo,* dating from 1943, is an old standard. In 2002, the opera composer Philip Glass and the librettist and director Mary Zimmermann collaborated with librettist Arnold Weinstein on the opera *Galileo Galilei,* which played in Chicago, New York, and London. It used the theme of Galileo's eventual blindness, ironic in one who saw so far for the first time, to trace out his life, and it included dramatic scenes of Galileo with the Inquisition.


DIALOGO
DI
GALILEO GALILEI LINCEO
MATEMATICO SOPRAORDINARIO
DELLO STVDIO DI PISA.
E Filoſofo, e Matematico primario del
SERENISSIMO
GR. DVCA DI TOSCANA.
Doue ne i congreſſi di quattro giornate ſi diſcorre
ſopra i due
MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;
Proponendo indeterminatamente le ragioni Filoſofiche, e Naturali tanto per l'vna, quanto per l'altra parte.
CON PRI VILEGI.
IN FIORENZA, Per Gio: Batiſta Landini MDCXXXII.
CON LICENZA DE' SVPERIORI.

The title page of Galileo's Dialogo, *the book that got him in his final trouble with the Inquisition when it was published in 1632.*

(Jay M. Pasachoff)

Kepler Controls the Universe

Johannes Kepler was a young mathematician in Germany in 1601 when he wrote to the great astronomer Tycho Brahe, who had just moved to Prague. Tycho had brought with him his meticulously collected data about the positions of the planets, principally Mars, in the sky. Though the telescope had not yet been invented, Tycho had used large sighting instruments to record data of unprecedented accuracy.

Fun Sun Facts

Kepler was one of the greatest mathematicians of all times, and many of his achievements are still in use today. For example, Kepler figured out in 1611 that the way your oranges are displayed on a fruit stand or at the supermarket—with a base row, a second row filling in, and so on—is the most efficient way to pack spheres. When his supposition was finally proved in 1998, the achievement merited headlines. When Kepler got married in 1613, he noticed at the celebration that there was then no efficient way to measure the contents of the wine barrels. Over the next couple of years, he figured out a way to measure the contents of a volume enclosed by rotating a curved shape.

In 1600, Kepler joined Tycho's entourage in Prague. It included a household of dozens, including even a jester. When Tycho died the next year, Kepler wanted to continue work on the data, but the data were among the most valuable property of Tycho's heirs. Eventually, Kepler got his hands on the data and went to work on the orbit of Mars.

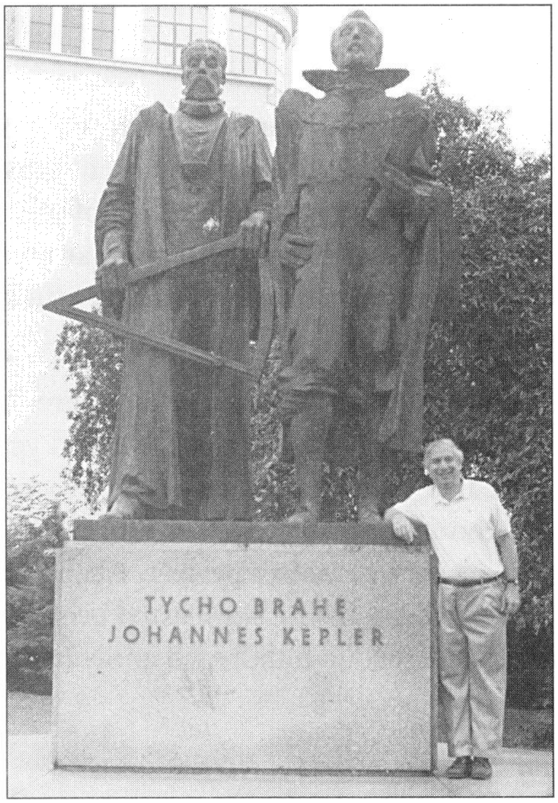
It took him years to figure out how Mars's orbit around the Sun led to the positions of Mars recorded in the sky, including the retrograde loops. Remember that there were no calculators or computers; he had to do all his work by hand. Indeed, almost two decades later, when logarithms were first invented, Kepler was the first to adopt them for scientific calculation. He was as up to date in his methods as possible, but he still had to carry out lengthy calculations in an arduous fashion.

In Kepler's book *Astronomia Nova* (*The New Astronomy*) of 1609, he announced his breakthroughs: The planets didn't orbit the Sun in circles. Rather, they orbited in a type of squashed circle known as an ellipse. The orbits weren't far out of round, but enough so that the correction gave much more accurate predictions for the positions of Mars. Later, clear statements were extracted of what we now call Kepler's Laws of Planetary Motion. Kepler's first law is this: The planets orbit the Sun in ellipses with the Sun at one focus. To draw an ellipse, hold a piece of string with its ends at two different points (the two foci, the plural of focus). Use a pencil to hold the string taut, and move the pencil around. The result is an ellipse. When the two foci are at the same place, the ellipse is the special case that we know as a circle. When the two foci are far apart, the ellipse is very far out of round and matches the orbits of many comets.

Kepler's book of 1609 contains his second law as well: "The line joining the Sun and a planet sweeps out equal areas in equal times." Thus, the long, skinny triangle swept out in a day must have the same area as a short, fat triangle covered in a day at another time of the orbit. As a result, when the planet is relatively close to the Sun, it must move faster in its orbit.

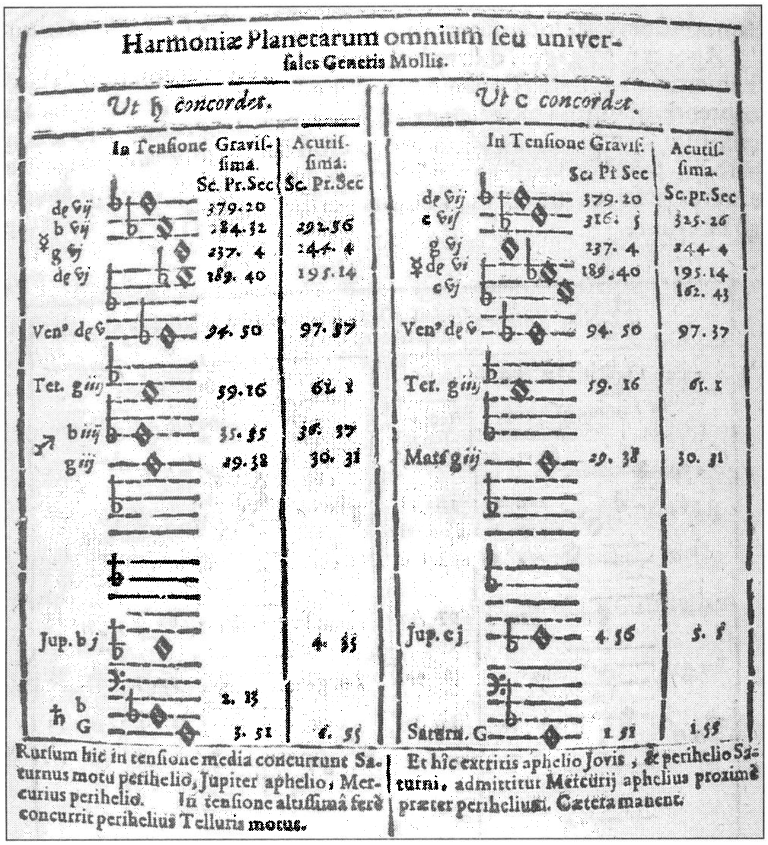
Kepler's third law, which links the period of the orbit (the time it takes to complete it) and the average size of the orbit, didn't come out until his book *Harmony of the World* was published in 1618.

Only with Kepler's laws did we have a clear view of the place of the Sun in the solar system. Kepler's laws are applicable even today in a wide variety of situations. For example, in 2002, observations were reported showing a star that orbits the center of our galaxy in only about 15 years. Given the size of its orbit, which we can measure from Earth only because of advances in optical telescopes, astronomers calculated from Kepler's laws that a giant black hole containing 2.5 million times the mass of the Sun is sitting in our galaxy's center.



The statue in Prague of Johannes Kepler and Tycho Brahe, with the author.

(Deborah Pasachoff)



An excerpt from one of the pages of Kepler's book of 1618, showing the notes to illustrate the harmonies that he thought existed in the orbits of the planets.

(Jay M. Pasachoff)

Imperfection

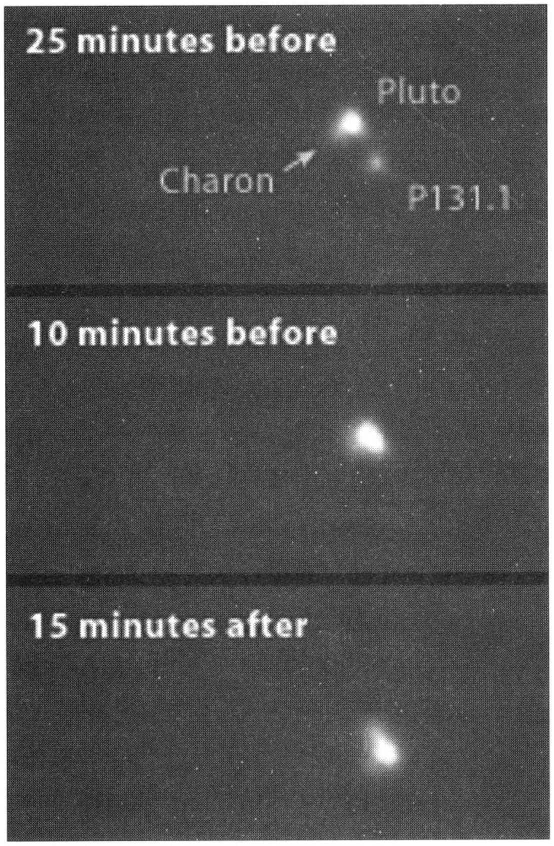
Traditionally, under the ideas of Aristotle and Ptolemy, the universe was a perfect place, at least in the realm of the planets and the stars. In Aristotle's model, the planets and stars orbited on crystalline spheres. The orbits of objects, originally around the Earth, were thought to be perfect circles, and circular motion was thought to be natural. Even Copernicus used circular orbits, although his orbits were around the Sun rather than the Earth.

But Kepler's discovery, announced in 1609, that orbits weren't circular destroyed the idea of circular perfection governing the universe. About a year later, Galileo's work with the new telescope revealed that the surface of the Moon was pockmarked, so it also wasn't perfect. Then, about another year later, the realization that the Sun had sunspots on it showed that its surface wasn't perfect, either. We had to come to terms with a universe that was imperfect—blemishes existed even in the celestial realm. It won't be long before we reach the four-hundredth anniversary of that heady time of scientific discovery.

Dozens and Dozens of Planets

Until 1781, people knew of six planets: Mercury, Venus, Earth, Mars, Jupiter, and Saturn. People were stunned that year when in Bath, England, Hanoverian musician William Herschel discovered the planet soon to be named Uranus. In the 1840s, the world was further excited by the discovery of the planet that was named Neptune. National rivalries came into play. People in England still tend to give credit for the discovery to John Adams, who first predicted its position, while people in France credit Urbain Le Verrier, who soon thereafter predicted its position independently and published the results first, which led to the actual sighting. People in Germany credit Johann Galle, who first actually sighted this eighth planet.

The ninth planet, at least from 1930 to the present, is Pluto. It was discovered by Clyde Tombaugh, then a young astronomer, so until his death in 1997, we were privileged to live at a time when the discoverer of a major planet was still alive. Nowadays, our new, more powerful telescopes are discovering objects not too far from Pluto in size among and beyond similar objects, so perhaps Pluto isn't a major planet after all. It hasn't been officially demoted by the International Astronomical Union, and even the Division of Planetary Sciences of the American Astronomical Society has defended its planethood. But that's all another story.



Pluto, with its moon Charon, about to occult (hide) a star in 2002. I observed the occultation in order to study Pluto's atmosphere, and this image was taken by my team at the University of Hawaii's 2.2-m telescope on Mauna Kea.

(Jay M. Pasachoff)

During the 1990s, a number of planets were found around sunlike stars—that is, distant, ordinary stars that have about the same amount of mass and thus the same brightness as the Sun. Many people are especially excited about planets around such stars because, with our limited knowledge of how life evolves, they seem to have the highest chance of having intelligent, communicating life on them.

The new planets were found by observing the spectral lines from the star and how they shift back and forth over time. The change in wavelength of light (or of any other wave) is known as the Doppler effect, after nineteenth-century physicist Christian Doppler. To make the discoveries, the scientists needed to develop new methods of measuring the Doppler effects in stars to a new level of precision.

The planets can be discovered because each system of objects has a center of mass that follows laws of motion set down in 1687 by Isaac Newton. First, you must know that all the mass of a spherical object acts as though it is at the center of that object. Proving that point took Newton years, and he had to invent calculus to do so. If in a pair of objects, one object is much heavier than the other, the center of mass is closer to the center of that object. So if you consider in our solar system only Jupiter and the Sun, both orbit the center of mass of the pair, but that point is located deep inside the Sun. So the Sun would appear to move back and forth only a little each time Jupiter goes around, while Jupiter swings from 5 A.U. out from the Sun (that is, 5 astronomical units, or 5 times the Earth's average distance from the Sun) around to 5 A.U. out the other side over about a 12-year period (that is, a period of 12 Earth years).

As we discussed in Chapter 1, the first of these planets around sunlike stars was found in 1995 by Swiss astronomer Michel Mayor and his graduate student Dedier Queloz. Their find was soon confirmed by American astronomers Geoff Marcy and Paul Butler, who had collected good data that showed the effect but who hadn't yet analyzed it. After all, since Jupiter takes about 12 years to go around the Sun, who was expecting a planet that went around a sunlike star in only 4 days?

With the 1995 discovery, the floodgates opened, and occasionally teams of scientists have listed as many as a dozen newly discovered planets at a time. Mostly these are individual planets around a given star, but, of course, we are discovering the most massive ones first. As our techniques improve, we will discover less massive ones, though it may be over a decade before our sensitivity improves enough to discover a wimpy planet like Earth. NASA satellites, including the Space Interferometry Mission (SIM) in this decade and the Terrestrial Planet Finder in the next, hold out hope. NASA's Kepler mission and the European Space Agency's Eddington mission, to detect planets transiting stars by a slight dip in a star's brightness, may join SIM in space in the later years of this decade.

Fun Sun Facts

Giordano Bruno was burned at the stake in Rome in 1600 for his heretical belief that there was a multiplicity of worlds, as we mentioned in Chapter 5. It took almost 400 years, but by that anniversary of his death, about 100 worlds were known to be orbiting stars other than the Sun. So Bruno was right, after all.

Fun Sun Facts

Who wouldn't want to get a Nobel Prize? But the rules say that no more than three people at a time can share it. How would you pick three for a prize on new planets? Queloz—who worked with Mayor—was only a student but was there first in the discovery of planets around Sunlike stars, while Marcy and Butler (since joined by Debra Fischer) found more planets than anyone. And planets around a pulsar were discovered even earlier. Somebody deserving will get shut out if and when a prize is given on this topic.

You can always get a list of planets around other stars at www.exoplanets.org, the site that Marcy keeps current. As of this writing, it shows over 100 planets.

The Least You Need to Know

- Copernicus's heliocentric theory eventually supplanted Earth-centered theories.
- Galileo championed Copernicus's theory in the early 1600s.
- Between 1601 and 1618, Kepler figured out the basic laws of orbits.
- Celestial objects like the Sun are not perfect.
- Astronomers are detecting solar systems around stars other than the Sun.