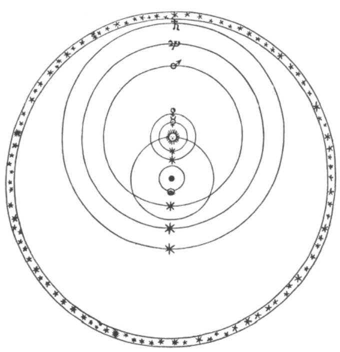
PhyzGuide: The History of Gravity

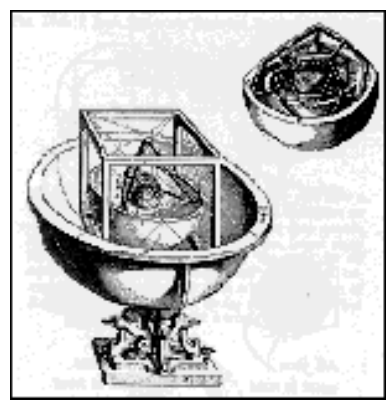
How celestial mechanics was brought down to Earth, part 2

TYCHO: OBSERVATIONAL EXCELLENCE AND A MODEL FOR COMPROMISE

As the furor over the Copernican model grew, a Danish nobleman stepped forward with a model that borrowed from the Ptolemaic and Copernican systems. Tycho Brahe suggested that the Sun revolved around the Earth but that the planets revolved around the Sun. Tycho was an interesting personality. He studied astronomy in secret and against the wishes of his father. He lost part of his nose in a sword duel he had in college to settle a dispute over mathematics. He wore a silver and copper prosthetic over his injury. Anyway, few people other than Tycho believed the Tychonic system. But Tycho was a man of means: he owned the finest observatory in Europe and methodically collected the best planetary data in the solar system. He hoped to use the data to prove the validity of his model. But his skills in mathematics were limited, so he hired the so-called "wandering mathematician," Johannes Kepler of Germany, to perform the needed calculations. Kepler had his own model in mind, however. Kepler's model was heliocentric, but was meticulous in its placement of the planets. Each planet circled in an orbit that would form the equator of a sphere that enclosed a regular solid polygon. It suggested a geometric purity that Kepler felt his God would have built into the universe. Tycho sensed that Kepler had plans of his own; the Dane kept his data away from his hired mathematician for the better part of two years. However, Tycho failed to heed "nature's call" during one of his famous banquets. The resulting rupture of his bladder led to Tycho's untimely death. His dying words to Kepler were, "Let me not seem to have lived in vain." The Dane's family refused, however, to give Tycho's planetary data to Kepler for analysis.

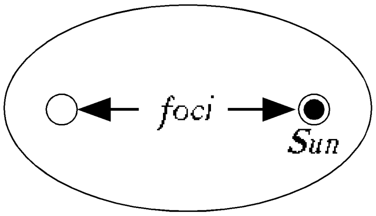


KEPLER: THE TRIUMPH OF EMPIRICAL ANALYSIS

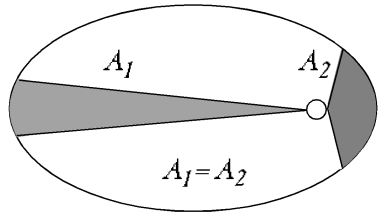


Kepler was a manic depressive whose life was filled with tragedy. He was conceived out of wedlock, abandoned by his father, and his mother was accused of witchcraft (a crime for which his aunt was burned at the stake). He suffered poor vision and ill health throughout his life. He traveled throughout Europe collecting old debts and casting astrological charts to earn money to support his large family and pay the debts of his parents. But he also pursued his academic interest in astronomy. He sought to find evidence accurate enough to demonstrate the validity of his geometric model of the Copernican system. On January 1, 1600, the "wandering mathematician" moved to Prague to work for Tycho Brahe.

Kepler and Brahe did not get along at all, but each needed the other, so they maintained a cold, professional relationship. When Tycho died and his estate refused to give Kepler the planetary data he needed, Kepler stole the information. In the subsequent thirty years and by means of over 900 pages of calculations, Kepler deduced three important findings about planetary orbits. First, Kepler found that planets travel in ellipses (with the sun at one focus) instead of circles. Circular orbits had been assumed since antiquity. Kepler himself required circular orbits for his elaborate, geometric model of the solar system. Yet Brahe's precise and accurate data insisted on ellipses. Given the choice of accepting centuries of scholarship and geometric beauty or accepting the physical evidence, Kepler chose to accept the evidence. Kepler also found that a line connecting the sun to a planet sweeps out equal areas in equal time intervals. Planets travel faster when near the sun and slower when farther from the sun. Lastly, he found a mathematical relationship between the orbital period and orbital radius of any given planet.



Kepler's First Law: Ellipses

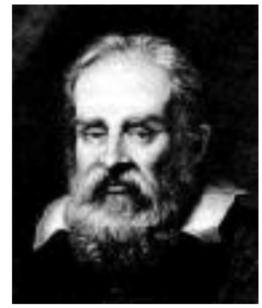


Kepler's Second Law: Equal Areas

$$\frac{R^3}{T^2} = K$$

Kepler's Third Law: Harmony Between Radius and Period

GALILEO: THE COLLAPSE OF ARISTOTLE'S WORLD VIEW



While Kepler was constructing a new model of the heavens, Galileo Galilei was destroying the old one. Galileo devised experiments to determine the nature of falling bodies. His findings led him to reject Aristotle's "natural places" model. Through insightful demonstrations and reasoning, he conceived the modern idea of inertia. Specifically, he showed that bodies in motion would continue in their motion without the need for continued propulsion.

Critics of Copernicus' heliocentric model argued that the Earth could not be moving because if it were, the ground would move rapidly beneath us if we were to jump. Galileo's new concept of inertia explained that since we were already moving prior to jumping, we would move along with the Earth while we were airborne.

Galileo also made some of the first astronomical observations using a telescope. He observed moons orbiting Jupiter—a clear contradiction to the geocentric assertion that all bodies orbited the Earth. He also saw that Venus underwent phases much like those of the moon—a finding inconsistent with the geocentric model but consistent with the heliocentric model.

Galileo summarized his findings in something of a story format in a book called *Dialogue on the Great World Systems*. Scholarly texts of the time were written exclusively in Latin, the language of the learned. Galileo wrote his *Dialogue* in Italian so that all his countrymen could read it. He dedicated the book to the Pope, a man who had been a childhood friend of Galileo's. The Church reacted badly to Galileo's book. They saw it as yet another attack on their authority. The geocentric model had become a tenet of the Roman Catholic faith by this time, and Europe was in the throes of the Reformation and Counter-Reformation. Galileo was tried for heresy. Upon being shown the instruments of torture used on heretics, he recanted his support for the heliocentric model. Nevertheless, he was found guilty and placed under house arrest in his home near Florence until his death in 1642. Legend has it that as he was being led away from the proceedings, he was heard to say, "Eppur, si muove" (Nevertheless, it [the Earth] moves).

Meanwhile in the world of science, Galileo's verification of the heliocentric model was accepted as the landmark achievement it was. The geocentric model was completely abandoned. In recent years, the Catholic Church has officially forgiven Galileo and admitted the possibility of an error on its part.

NEWTON: THE UNIFICATION OF HEAVEN AND EARTH

Isaac Newton was born the year Galileo died. As a physicist, he inherited the findings of the Ancients, Copernicus, Brahe, Kepler, Galileo, and others. But he added a crucial insight that evaded his predecessors. Newton deduced that the same force that pulls the apple to the Earth is the force that binds the moon in its orbit around the Earth.

Before Newton, no one thought that Earthly gravity extended into the heavens. Or that solar gravity bound the planets to their orbits of the sun. Uniting the heavenly to the Earthly was as much a revolution as abandoning the geocentric model in favor of the heliocentric model. Newton used knowledge of geometry, algebra, his own laws of motion, and Kepler's findings to determine a law of universal gravitation. The law states that the attraction between any two bodies in the universe is proportional to the product of their masses and inversely proportional to the square of the distance between them: $F_G = GMm/R^2$. He used the law to predict how far the moon deviated from the straight-line path it would take if the Earth weren't pulling on it.

When comparing the prediction of his theory to the actual movement of the moon, he found solid agreement. But there is more to the story of gravity. You will study it in your university course in Modern Physics.