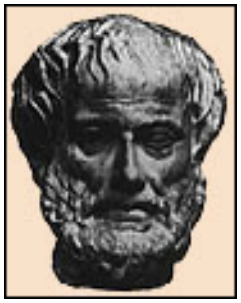
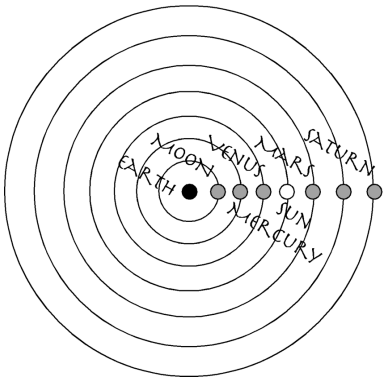
PhyzGuide: The History of Gravity

How celestial mechanics was brought down to Earth, part 1

ARISTOTLE: CRYSTALLINE SPHERES AND NATURAL PLACES



The natural philosophers and mathematicians of ancient Greece determined that the Earth was spherical, the moon was a distance of 60 Earth radii from the Earth, and the sun was much farther from the Earth than the moon was. They discovered planets as wanderers through otherwise fixed background stars. Such findings were triumphs of the geometry and astronomical observations they valued and worked to perfect. The foremost Greek scientist was Aristotle. Aristotle was educated by Plato (who was taught by Socrates); Aristotle subsequently taught Alexander the Great (arguably the most successful conqueror the world has ever known). In Plato's Academy, Artistotle was taught that the circle and the sphere were nature's most perfect shapes in two and three dimensions. So it is little surprise that Aristotle's model of the universe relied heavily on circles and spheres. The Aristotelian system placed Earth at the center; common sense and general observations dictated as much. The moon, the sun, and the planets were embedded in crystalline spheres that revolved around the central Earth. (The bodies had to be embedded in the moving spheres because in Aristotle's view, objects moved only when in contact with a moving agent; the spheres had to be crystalline because the inner spheres did not block views of the outer bodies.) While this model is far from the one we now accept, it does agree with simple observations.

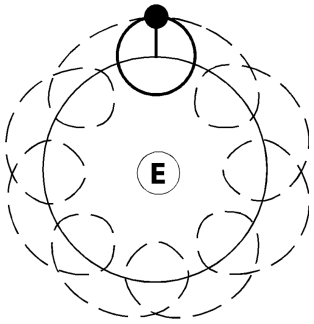


The Greek mathematician Aristarchus postulated that the sun was the center of the universe and that Earth revolved around it. His reasoning came from his calculation that the sun was much larger than Earth and the lesser body should orbit the greater. Some of the peripheral arguments in Aristarchus' model were flawed and his ideas were rejected by the great mathematician/scientist of the era, Archimedes. Motions of Earth-bound objects were explained by Aristotle's "natural places" model (see "The History of Physics") as described in his *Physics*. There is no record of any ancient Greek theory suggesting a connection between the motions of heavenly bodies and Earthly bodies. Aristotle's *Physics* became the textbook for physical scientists for nearly 2000 years. Until the time of Galileo, scholarly work in physics involved writing commentary to add to, or sit beside *Physics*; no attempt was made to replace it.

PTOLEMY: PRACTICAL PROBLEMS AND THE EPICYCLE SOLUTION

By the second century CE, it became apparent that the mathematical models of the universe based on simple spherical perfection were flawed. Observations of Mars showed that the red planet traveled across the sky, backed up for a while, then proceeded forward in its orbit. This *retrograde* motion could not be accounted for in Aristotle's model. And the accurate positions of stars needed by the increasing number of maritime merchants throughout the Mediterranean could not be produced from the crystalline spheres model. In Alexandria, Egypt, a scholar developed the successor to Aristotle's model. Claudius Ptolemy retained the ideas of geocentrism, and planetary orbits following perfect circles in his model.

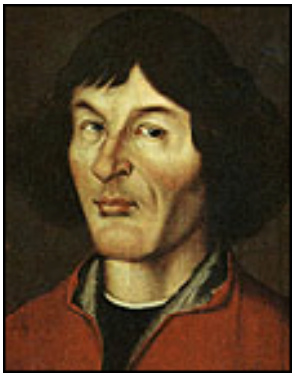
But he offered a few new twists. Earth was still at the center of all motion. But now planets revolved on small circles called *epicycles* while the centers of the epicycles themselves revolved on larger circles called *deferents*. It was the deferents that were concentric to Earth. Ptolemy's epicycles were more complicated than Aristotle's crystalline spheres, but they also accounted for Mars' retrograde motion and offered better predictions of the positions of stars. Ptolemy's model was part of his compendium of star charts and planetary data called the *Almagest* (which translates as *Greatest)*. Ptolemy's *Almagest* was considered the authoritative work in astronomy for the next 1300 years.



COPERNICUS: THE REBIRTH OF HELIOCENTRISM

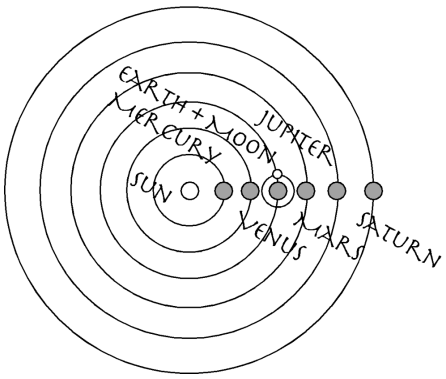
More than a thousand years pass in our story of gravity before anything significant happens. During this time, often referred to as The Dark Ages, scholars devoted themselves to rigorous proofs of God's existence or to fruitless efforts to explain the natural world in terms of theological teachings. Religion dominated culture and society; it was the time of the Crusades and the Inquisition. While advances in technology were made in the pursuit of better weaponry and devices of torture, pure science languished.

In the 14th century, however, William of Ockham gave birth to an interesting philosophical tenet. Ockham suggested that if two theories explain a phenomenon equally well, the simpler theory is the one that should be retained. In other words, simpler models are to be preferred over unnecessarily complicated ones. This principal, known as *Ockham's Razor*, is one of the lights by which the course of science has been steered ever since.



In 1543, a Polish monk on his deathbed allowed the publication of a book he authored some twenty years earlier. The monk was Nicholas Copernicus and the book was *On the Revolution of Heavenly Orbs*. The book detailed Copernicus' well-developed heliocentric (sun-centered) model of the universe. (While Copernicus must have been aware of Aristarchus' ancient heliocentric theory, he made no mention of Aristarchus in *Revolution*.) Copernicus was reluctant to publish his work because he knew it would bring trouble to anyone brave enough to agree with it.

By 1543, the Ptolemaic system had been the model of the universe for centuries. Improved observations of the heavens necessitated adding more and more epicycles to the already unwieldy system. The Copernican model cut through this increasing complexity by placing the sun at the center with the Earth and other planets orbiting it. It was a simpler model that explained the observations equally well. But after centuries of dominance, threads of the geocentric system were woven into the religious and thus political thinking of the day. One theorist, Giordano Bruno, was burned at the stake during the Inquisition for insisting that the universe was infinite and that the Earth orbited the sun.



To be continued....