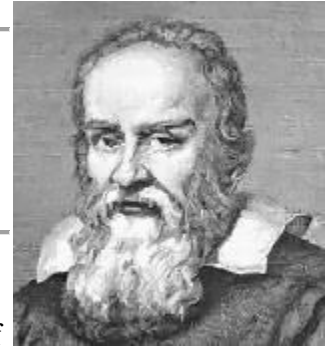


The Beginning of Modern Science

E pur si muove -- And yet it moves.

Galileo Galilei, *sotto voce* after his trial and coerced confession.



One thing that happened during the [Renaissance](#) that was of great importance for the later character of modern philosophy was the birth of modern science. This may not have been a coincidence. It is noteworthy that the confidence of [Johannes Kepler](#) in the mathematical nature of the universe was [Platonic](#) in inspiration, derived from the revival of Plato by Renaissance scholars and ultimately from the Platonism of [Mistra](#) in [Romania](#). It is thus reasonable to think that this enabled Kepler and Galileo to break through Aristotelian conceptions of [induction](#) and found the new, modern mathematical physics.

Even as in the Middle Ages philosophy was often thought of as the "handmaiden of theology," modern philosophers have often thought of their discipline as little more than the "handmaiden of science." Even for those who haven't thought that, the shadow of science, its spectacular success and its influence on modern life and history, has been hard to ignore.

For a long time, philosophers as diverse as [David Hume](#), [Karl Marx](#), and Edmund Husserl have seen the value of their work in the claim that they were making philosophy "scientific." Those claims should have ended with [Immanuel Kant](#) (1724-1804), who for the first time clearly provided a distinction between the issues that science could deal with and those that it couldn't, but since Kant's theory could not be demonstrated the same way as a scientific theory, the spell of science, even if it is only through pseudo-science, continues.

The word "science" itself is simply the Latin word for knowledge: *scientia*. Until the 1840's what we now call science was "natural philosophy," so that even Isaac Newton's great book on motion and gravity, published in 1687, was *The Mathematical Principles of Natural Philosophy* (*Principia Mathematica Philosophiae Naturalis*). Newton was, to himself and his contemporaries, a "philosopher." In a letter to the English chemist Joseph Priestley written in 1800, Thomas Jefferson lists the "sciences" that interest him as, "botany, chemistry, zoology, anatomy, surgery, medicine, natural philosophy [this probably means physics], agriculture, mathematics, astronomy, geography, politics, commerce, history, ethics, law, arts, fine arts." The list begins on familiar enough terms, but we hardly think of history, ethics, or the fine arts as "sciences" any more. Jefferson simply uses the term to mean "disciplines of knowledge."



Something new was happening in natural philosophy, however, and it was called the *nova scientia*, the "new" knowledge. It began with Mikolaj Kopernik (1473-1543), whose Polish name was Latinized to *Nicolaus Copernicus*. To ancient and mediaeval astronomers the only acceptable theory about the universe came to be that of *geocentrism*,

that the Earth is the center of the universe, with the sun, moon, planets, and stars moving around it. But astronomers needed to explain a couple of things: why Mercury and Venus never moved very far away from the sun -- they are only visible a short time after sunset or before sunrise -- and why Mars, Jupiter, and Saturn sometimes stop and move backwards for a while (*retrograde motion*) before resuming their forward motion. Believing that the heavens were perfect, everyone wanted motion there to be regular, uniform, and circular. The system of explaining the motion of the heavenly bodies using uniform and circular orbits was perfected by **Claudius Ptolemy**, who lived in Egypt probably during the reign of the Emperor Marcus Aurelius (161-180). His book, still known by its Arabic title, the *Almagest* (from Greek *Tò Mégiston*, "The Greatest"), explains that the planets are fixed to small circular orbits (epicycles) which themselves are fixed to the main orbits. With the epicycles moving one way and the main orbits the other, the right combination of orbits and speeds can reproduce the motion of the planets as we see them. The only problem is that the system is complicated. It takes something like 27 orbits and epicycles to explain the motion of five planets, the sun, and the moon. This is called the *Ptolemaic* system of astronomy.

Copernicus noticed that it would make things a lot simpler (Ockham's Razor) if the sun were the center of motion rather than the earth. The peculiarities of Mercury and Venus, not explained by Ptolemy, now are explained by the circumstance that the entire orbits of Mercury and Venus are *inside* the Earth's orbit. They cannot get around *behind* the Earth to be seen in the night sky. The motion of Mars and the other planets is explained by the circumstance that the inner planets move faster than the outer ones. Mars does not move backwards; it is simply overtaken and *passed* by the Earth, which makes it *look*, against the background, as though Mars is moving backwards. Similarly, although it *looks* like the stars move once around the Earth every day, Copernicus figured that it was just the Earth that was spinning, not the stars. This was the *Copernican Revolution*.

Now this all seems obvious. But in Copernicus's day the weight of the evidence was against him. The only evidence he had was that his system was simpler. Against him was the prevailing theory of motion. Mediaeval physics believed that motion was caused by an "[impetus](#)." Things are naturally at rest. An impetus makes something move; but then it runs out, leaving the object to slow down and stop. Something that continues moving therefore has to keep being pushed, and pushing is something you can feel. (This was even an argument for the existence of God, since something very big -- like God -- had to be pushing to keep the heavens going.) So if the Earth is moving, why don't we feel it? Copernicus could not answer that question. Neither was there an obvious way out of what was actually a brilliant prediction: If the stars did not move, then they could be different distances from the earth; and as the earth moved in its orbit, the nearer stars should appear to move back and forth against more distant stars. This is called "stellar parallax," but unfortunately stellar parallax is so small that it was not observed until 1838. So, at the time, supporters of Copernicus could only contend, lamely, that the stars must *all* be so distant that their parallax could not be detected. Yeah, sure. In fact, the absence of parallax had been used since the Greeks as more evidence that the Earth was not moving.

It is common now in many venues for people to say that heliocentric astronomy was rejected by the Greeks and ignored in the Middle Ages just because of the human arrogance that wanted the Earth to be the center of the universe -- we *belong* in the center of things. There were certainly

some people who thought that way, but it is hard to imagine that *all* Greeks, or *all* Mediaevals, were so foolish. They weren't. The little morality tale we are given of Mediaeval ignorance and anthropocentrism overlooks the problem that there was no *evidence* of heliocentrism in Ancient or Mediaeval science, that Copernicus himself did not supply any evidence, and that it was the Ancient and Mediaeval understanding of the *physics* that was dead *against* the Earth moving. Usually these treatments don't even mention the physics. The only evidence that Stephen Hawking mentions *against* Ptolemaic astronomy (in his *A Brief History of Time*) at the end of the Middle Ages is that the Moon, moving on an epicycle, would move away from and towards us in a way that would dramatically change its apparent size. Unfortunately, Copernicus *retained* an epicycle for the motions of the Moon, which means that this problem with Ptolemaic astronomy is equally a problem for Copernican astronomy. Only [Johannes Kepler](#) (1571-1630) would fix things by replacing epicycles with elliptical orbits. That Copernicus supplied no compelling evidence for this theory led [Thomas Kuhn](#) to think that Copernicanism won out only because of social, not evidentiary, factors. But then Copernicanism did not triumph until Galileo, and the evidentiary situation with Galileo was much different than it had been with Copernicus.

Copernicus was also worried about getting in trouble with the Church. The Protestant Reformation had started in 1517, and the Catholic Church was not in any mood to have any more of its doctrines, even about astronomy, questioned. So Copernicus did not let his book be published until he lay dying.

The answers, the evidence, and the trouble for Copernicus's system came with **Galileo Galilei** (1564-1642). Galileo is important and famous for three things:

1. Most importantly he applied *mathematics* to motion. This was the real beginning of modern science. There is no math in Aristotle's *Physics*. There is nothing but math in modern physics books. Galileo made the change. It is inconceivable now that science could be done any other way. Aristotle had said, simply based on reason, that if one object is heavier than another, it will fall faster. Galileo tried that out (though it had already been done by [John Philoponus](#) in the 6th century) and discovered that Aristotle was wrong. Aerodynamics aside, everything falls at the same rate. But then Galileo determined *what that rate was* by rolling balls down an inclined plane (not by dropping them off the Leaning Tower of Pisa, which is the legend). This required him to distinguish between velocity (e.g. meters per second) and acceleration (change in velocity, e.g. meters per second per second). Gravity produced an acceleration -- 9.8 meters per second per second. Instantly Galileo had an answer for Copernicus: simple velocity is *not* felt, only acceleration is. So the earth can be moving without our feeling it. Also, velocity does not change until a force changes it. That is the idea of *inertia*, which then replaced the old idea of an impetus. All this theory was ultimately perfected by Isaac Newton (1642-1727).
2. With the objections to Copernicus's theory removed, the case was completed with positive evidence. Around 1609 it was discovered in the Netherlands that putting two lenses (which had been used since the 13th century as eye glasses) together made distant objects look close. Galileo heard about this and himself produced the first astronomical quality telescope. With his telescope he saw several things: a) the Moon had mountains

and valleys. This upset the ancient notion that the heavens, the Moon included, were completely unlike the Earth. b) the Planets all showed disks and were not points of light like stars. c) Jupiter had four moons. This upset the argument, which had been used against Copernicus, that there could only be one center of motion in the universe. Now there were three (the Sun, Earth, and Jupiter). d) There were many more stars in the sky than could be seen with the eye; and the Milky Way, which always was just a glow, was itself composed of stars. And finally e) Venus went through phases like the Moon. That vindicated Copernicus, for in the Ptolemaic system Venus, moving back and forth at the same distance between the Earth and the Sun, would only go from crescent to crescent. It would mostly have its dark side turned to us. With Copernicus, however, Venus goes around on the other side of the Sun and so, in the distance, would show us a small full face. As it comes around the Sun towards the Earth (in the evening sky), we would see it turn into a crescent as the disk grows larger. Those are the phases, from small full to large crescent, that Galileo saw. So that he could claim priority to this discovery, before actually announcing it, Galileo concealed his claim in an anagram that unscrambled to *Cynthiae figuras aemulatur mater amorum*, "The forms of Cynthia [the moon], the mother of loves imitates." The only argument that could be used against Galileo for all these discoveries was that the telescope must be creating illusions. In fact it was not well understood why a telescope worked. Some people looked at stars and saw two instead of one. That seemed to prove that the telescope was unreliable. Soon it was simply accepted that many stars are double. They still are.

3. With his evidence and his arguments, Galileo was ready to prove the case for Copernican astronomy. He had the support of the greatest living astronomer, Johannes Kepler, but not the Catholic Church. He had been warned once to watch it, but then a friend of his (Maffeo Barberini) became [Pope](#) Urban VIII (1623-1644). The Pope agreed that Galileo could write about *both* Ptolemaic and Copernican systems, setting out the arguments for each. Galileo wrote *A Dialogue on the Two Principal Systems of the World* (1632). Unfortunately, the representative of the Ptolemaic system in the dialogue was made to appear foolish, and the Pope thought it was a caricature of himself. Galileo was led before the Inquisition, "shown the instruments of torture," and invited to recant. He did, but was kept under house arrest for the rest of his life. Nevertheless, it was too late. No serious astronomer could ever be a geocentrist again, and the only discredit fell against the Church. As Galileo left his trial, he is supposed to have muttered, *E pur si muove* -- "And yet it moves."

Some think less of Galileo because he recanted his beliefs, while [Socrates](#) was willing to *die* for his. Well, there has been no more civilized example of a death penalty than when Socrates got to sit around, talk to his friends, calmly drink the hemlock, and lie down to a peaceful death -- the "sweet shafts," the [agana belea](#), of Apollo's silent arrows. Galileo was threatened with torture. No one can be faulted for saying anything under those circumstances.

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