

Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Never assume anything, or everything.*

Nicolaus Copernicus is commonly acknowledged for establishing the heliocentric model of the solar system – and indeed the general principle that the Earth is not only not the centre of the Universe, but that it does not occupy any kind of central or privileged position.

There's no doubt Copernicus was a polymath and a jolly-clever fellow, but did it all really start with him? For example, there was Aristarchus of Samos who lived around 300 BC. No writings by Aristarchus remain, his proposal is described by Aristotle – who relayed that Aristarchus thought the Sun that the centre around which the Earth orbited and indeed that the fixed background stars might well themselves be other suns, their fixed position being the result of the great distance from us – which made them immune to any effects of parallax.

Nonetheless, Aristarchus who died around 230 BC had just proposed a few interesting ideas. This thinking was soon eclipsed (small astronomy joke there) by Claudius Ptolemy who died around 170 AD and who not only proposed a geocentric model of the universe, but also provided charts and tables to enable the prediction of the future movements of the planets, the Sun and the Moon. The geocentric model was more intuitive than evidence-based, but the predictive charts worked, for the most part, and they were later modified and improved further by others – all of which seemed to bolster the idea that the geocentric model must be correct.

The predictive charts, and the geocentric model itself, were built upon a deeply-embedded belief that everything in the Universe moved in perfect circles. In fact, the puzzling behaviour of many of the planets, which occasionally do a little loop-the-loop in the course of the west-to-east progression against the background stars, was explained by epicycles. Under the Ptolemaic model, for the most part, the planets progress around a big perfect circle – called their deferent, but at certain points they would depart that circle to follow an epicycle – essentially a smaller circle attached to that the larger circle, like a wheel within a wheel. The physical nature of these epicycles was never explained – but an explanation hardly seemed necessary when the Ptolemaic model of deferents, epicycles and equants did a reasonable, if not perfect job, of predicting the motion of things in the sky – something that no-one else had really managed before.

Nonetheless, if one was willing to look beyond the patchy success of the Ptolemaic model, one could begin forming doubts about a geocentric idea. Firstly, while the Sun has an apparent daily rotation around the Earth, it also has an annual cyclic shifting of its position against the stars of the Zodiac constellations. Well, of course, you can never actually see the background stars while the Sun is in the sky, but once the Sun has set is not hard to tell that the Sun sets against a slightly different backdrop each night.

There's also something puzzling about the path the Sun takes across the sky. Although the Sun generally rises in the east and sets in the west, that path shifts over the course of a year. So, in midsummer the Sun rides high in the sky and six months later it rides low and then it takes another six months to shift back to its mid-summer path again, which is why we have an annual cycle of four seasons. While a casual observer might shrug all this off as just

being the way things are, a conscientious observer would note that this annual cycle exactly aligns with the annual shift of the Sun against the Zodiac constellations. Coincidence?

There's further pause for thought in the realisation that the paths of the planets also shift up and down on an annual basis. So, in a nutshell, everything apart from the background stars seems to have some degree of independent motion, but nonetheless, everything seems driven to follow the background stars approximately daily rotation and despite the independent motions of the Sun, the Moon and the planets, they all show this same annual shifting of their paths from high in the sky, to low in the sky, and back again.

It's hardly surprising then that several early thinkers had suggested that the overarching daily rotation of the sky might actually be the result of the Earth rotating – and the movement of the Sun and the planets represented a local system which operated quite independently from the background stars. Indian astronomers as far back as 800 BC had suggested this. Islamic astronomers, who were active around the time the Ptolemaic model was becoming embedded in European thought, were quite comfortable disputing the model – most agreeing it was much more likely that the Earth was rotating, with some further hypothesising the local system of Sun and planets could well be a heliocentric system. However, no-one was able to come up with a mathematical model that could effectively challenge Ptolemy's model of planetary motion.

To be fair to Ptolemy and others, the idea that the Earth could be in a state of steady and seemingly-perpetual rotation was a little problematic. It's only our modern understanding of gravity that lets us appreciate that we are held to the surface of one of many celestial bodies due to our planet's gravity-generating mass. In the absence of that knowledge, it's understandable that people assumed we must occupy some kind of privileged ground state above which the universe extends. Also, it's only our modern understanding of the physics of motion that lets us appreciate we can stand on a rapidly-spinning object without feeling anything – as long as that spin stays at the same rate. And it's only our modern understanding of space that lets us appreciate that the Earth can spin rapidly and constantly without needing additional energy to maintain that spin, because it hangs in a vacuum and experiences minimal friction.

In fact, the links that arose between geocentrism and religion are partly the result of needing to explain motion in the cosmos. Although Claudius Ptolemy was no Christian – he had invoked the concept of the prime mover in his cosmology. The prime mover was essentially the outmost sphere of the various shell-like spheres that surrounded Earth – the first holding the Moon, then Mercury, then Venus, then the Sun – after which followed Mars, Jupiter and Saturn and then another sphere holding the background stars. Beyond that was the outermost sphere of the *prime mover* – an amorphous, poorly defined region which was nonetheless posited as the ultimate driver of all motion observed in the Universe – indeed it was the ultimate cause of all downstream causes and effects that took place in the Universe. For example: Why do we get of the bed in the morning? Because the sun comes up, Why does the sun come up? Because of the prime mover.

With such quasi-physics embedded within mediaeval cosmology, the church naturally assigned the role of the prime mover to God – who the scriptures had already situated up in the heavens and above all things. Hence, any challenge to the concept of geocentrism

became heresy – invoking a standard exit clause to the first commandment, meaning it was punishable by death – and often a fairly grisly death.

Presumably to avoid any such complications, Copernicus arranged for the posthumous publication of his book *On the Revolutions of the Heavenly Spheres* in 1543, being the same year in which he died. Not so lucky was Giordano Bruno who was burned at the stake in 1600 after voicing the view that not only did the Earth orbit the Sun, but it was likely that other planets orbited other stars and could well harbour other life.

A few years after that, Galileo began reporting some hard core observations collected through his telescope – showing that Jupiter had moons in 1609 and that Venus had phases in 1610. The first observation of Jupiter's moons demonstrated that not everything out there orbited the Earth, while the observation of Venus having phases clearly demonstrated that Venus orbited the Sun. Galileo was up before the Inquisition in 1615 and had to spend the rest of his life (over 20 years) under house arrest

Tycho Brahe, who was dead by 1601 had already deduced that the five visible planets orbited the Sun, although he had remained convinced that the Sun still orbited the Earth – with all the other planets in tow. But while Galileo had collected a few optical observations, Tycho had detailed documents of astronomical data about the changing positions of the stars and the planets over time, a data set that he let Johannes Kepler look at. Using Tycho's data, Kepler produced the *Astronomia Nova* in 1610 – which described Mars orbit as firstly an ellipse – and secondly an orbit in which did not move at a constant velocity, instead speeding up near periapsis and slowing down near apoapsis..

It was the confirmation that an orbit could be an ellipse that really floated the Copernican model – Copernicus had himself assumed orbits were perfect circles and had hence been obliged to rely on epicycles in building a model of a heliocentric model. Kepler's model made the whole thing so much easier, since a heliocentric model built of elliptical orbits worked brilliantly, without needing to appeal to bizarre concepts like epicycles. For this reason, it quickly became settled that the Earth was not the centre of the solar system or of the Universe and Kepler never had to explain himself to the Inquisition.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy www.cheapastro.com. Cheap Astronomy offers an educational website where we always avoid going around and around in circles. No ads, no profit, just good science. Bye.