Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Kepler's laws of planetary motion.*

Seeing how it's 2009, the International Year of Astronomy, it's worth focusing (small astronomy joke there) on the sequence of events that led up to modern astronomy.

Galileo did indeed start mucking about with telescopes in 1609. But, by then Nicolaus Copernicus had already been dead for over 60 years, Tycho Brahe had died eight years earlier in 1601, possibly from untreated prostate hypertrophy and Kepler, still living, had proclaimed his laws of planetary motion four years earlier in 1605.

It was Copernicus who had proposed that the often baffling and strange oscillations of the planets' movement in the sky could be easily explained if Earth, along with all those other wandering planetary bodies, collectively orbited the Sun.

Copernicus also suggested that Earth and the other planets orbited the Sun in circular orbits. He had no easy way of telling that those orbits were generally slightly eccentric ellipses (notwithstanding that circles are also ellipses, but with an eccentricity of zero).

Then Tycho Brahe the great data collector entered the scene. Even though he was a strong advocate of the Ptolomeic model that positioned the Earth at the centre of the universe. Tycho was an honest scientist who presented his recorded data unencumbered by any preconceptions. It was these data points, particularly those of the orbit of Mars, that then allowed Johannes Kepler to establish his three planetary laws of motion.

1. *The orbit of every planet is an ellipse with the Sun at a focus.*

Tycho Brahe's data was accurate enough to demonstrate that the planets did undoubtedly orbit the Sun, although their orbits were not perfectly circular. But given that a circle is just an ellipse with a focus situated equidistant from all points on the circle, the law holds anyway. In all important respects, the focus of any kind of ellipse is still its centre – even if that centre may not be equidistant from all points on the ellipse.

In any case, all Kepler was really doing here was stating a self-evident truth from Tycho's data. An explanation as to why planets orbited, let alone orbited in an ellipse, was not available to him.

It wasn't until Newton came along with the Principia in 1687 – and his laws of motion and universal gravitation, that a mathematical explanation of planetary motion was established – drawing on the concept of an invisible, though quantifiable, force called gravity.

Arguably, it wasn't until Einstein came along with general relativity in 1916, that a physical explanation was established – whereby the supposed invisible force of gravity is really just a consequence of massive objects warping the geometry of space-time – such that the Sun creates a gravity well and the planets move under their own inertia around and around the sides of that well. Take the Sun away and the planets would keep on moving at the same velocity they move at now – except they would move off in straight lines.

2. *A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.*

Here we are just talking about the Sun being the focus of an ellipse and again it's easier to understand what's going on by looking at a circle as a special type of ellipse. On a circular clock face the big hand sweeps out an equal area when ticking from 12 to 3 o'clock as when it ticks from 6 to 9 o'clock.

If you then imagine a clock made out of an eccentric ellipse – the big hand will have to move faster at the 'close-in' periapsis of the ellipse in order to sweep out the same area as it does when it's ticking near the 'further-out' apoapsis of the ellipse.

And again, this is just Kepler reporting a self-evident truth from the data – and the main implication of the second law is that planets move faster in their orbits at periapsis than they do at apoapsis – unless of course the orbit is a perfect circle, in which case it will maintain a constant velocity all the way around.

For examples of the second law in action, Mercury – with the most eccentric orbit of all the planets – moves at 59 kilometres a second at periapsis and only 39 kilometres a second at apoapsis. Venus, with the least eccentric (that is closest to circular) orbit, is moving at 35.3 kilometres a second at periapsis and only a slightly different 34.8 kilometres a second at apoapsis.

Looking at this through Einstein's eyes, where we talk about the Sun creating a gravity well in space-time, well that's an almost conical structure – well, conical in a 4 dimensional spacey-timey sort of way. If you cut a cone straight across you get a circle, while if you cut it at an angle you get an eccentric ellipse. So it's as though planets with an eccentric orbit are moving at an inclined angle on the gravity well – although from our normal three dimensional perspective on space everything still looks like its just moving around in the same flat orbital plane. I don't know quite what that all means, but it's fun trying to visualise the hyperspatial geometry involved.

3. *The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit.*

Got all that? The major axis of an ellipse is a bisecting line drawn across the most stretched out part of the ellipse – although for a circle this is just its diameter. The semi-major axis is exactly half that of the major axis – which in the case of a circle, is the radius – but in the case of an eccentric ellipse it's best just to say the semi-major axis. The orbital period is just the time it takes a planet to do a complete orbit of the Sun.

So what we are really saying here is that the further away a planet is from the Sun, the longer it's going to take to complete one orbit – which is a bit of no-brainer, but here Kepler defined the exact mathematical relationship between those two parameters. For example, if a planet is four times further from the Sun than Earth, then its orbital period will be eight times as long – since eight squared equals four cubed. The apparent harmony and universality of the relationship must have been a dramatic, even spooky, finding at that time.

When Newton came along he overlaid this relationship with a consideration of forces – notably a centripetal force which pulls the planet in towards the Sun – counteracting the centrifugal force which would otherwise see the planet flung away like a sling shot.

For Newton the centripetal force was the force of gravity – while for Einstein it was the curved surface of space-time that holds the planets in orbit, kind of like the banked curve of a race track – except in a 4 dimensional spacey-timey sort of way.

Kepler's third law works fine in an ideal universe where you have one planet orbiting one sun, seemingly eternally. In the real universe, there are a whole bunch of factors that will perturb or decay an orbit over time. For example, the effects of other planets, the solar wind and even relativistic effects leading to an otherwise unaccountable orbital precession of any planet – although most noticeably for Mercury in our solar system. All these factors make the universe a much more complicated place than Kepler might have imagined, but hey – for the 17th century, he was doing good science.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where department store telescopes are actually kind of OK. No ads, no profit, just good science. Bye.