Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Analemmas and the equation of time.*

This is not, as you may be expecting, a cheap attempt at a Dr Who episode. There really is an equation of time – and to make some kind of sense of it, it's helpful to first describe what an analemma is.

1. *The location of the Sun in the sky shifts back and forth over the course of a year.*

As you are aware, any place south of the tropic of Capricorn and any place north of the Tropic of Cancer tends to get cold for a quarter of the year, get hot for another – and in the other two quarters it's either getting colder or it's getting hotter.

This is mostly about the tilt of the Earth's axis. Even if you stand on the Earth's equator, the Sun rarely moves directly overhead – well, except for just two days in the year, being the equinoxes. Around January, the Sun follows a track to the south – so you know that anyone in the Southern Hemisphere is enjoying mid-Summer, while around June – the Sun follows a track to the north, meaning it will be the Northern Hemisphere's mid-Summer.

When we talk about the Sun following a track, this is just an apparent motion – mostly resulting from the Earth's rotation – making the Sun appear to the follow a line from east to west that we call the ecliptic. So it's the ecliptic that is shifting towards the north up to June – then coming across the equator around September and shifting to the South up until December.

But the Sun's apparent position in the sky is not just about the Earth's rotation. If you stopped the Earth's spinning, the Sun would still show an apparent motion – although from west to east as a result of the Earth orbiting the Sun. The Sun would appear to take six months to cross the sky and then night would fall for six months, until finally it rose again in the west.

2. *This is the complex bit*

Anyway, the point of all this is to say that if you set up a camera on the equator to take a photo of the Sun's position at noon over an entire year – you would end up with a photo showing an upright figure of 8.

The shape traced out by the changing position of the Sun, measured at exactly the same time each day over the course of a year, is called the analemma. There's a picture of an analemma in the show notes – and you can immediately see that it's a very asymmetrical-looking figure of 8.

This is because of a third factor that influences the apparent movement of the Sun in the sky. Not only is the Earth moving in an orbit around the Sun and not only is it tilted on its axis – it's also the case that the Earth's orbit is not a perfect circle, but an ellipse.

If we go back to that imaginary scenario where you stop the Earth spinning and take a photo of the Sun's position at noon each day – you will find the little Sun disks are spread apart around January, but bunched up much closer together for the rest of the year. This is because around January, the Earth is at the periapsis of its orbit where it approaches its closest point to the Sun – and is hence moving faster, than when it is moving out towards apoapsis – being the most distant point in its orbit from the Sun.

Because the Earth is moving faster around January, the apparent west-to-east shift of the Sun is more pronounced around January – so the southern loop of the figure 8 in your analemma is much more pronounced – remembering that its tip represents the December solstice.

Got all that?

3. *The complex bit explained again and with less words.*

If Earth had a perfectly circular orbit, if it didn't have an axial tilt, your analemma would just be a dot in the sky. But because of the axial tilt, the analemma is actually a figure of 8 – and because the Earth's orbit is an ellipse, the figure of 8 is all skewed – with the southern loop much bigger because that is when the Earth is moving much faster in its orbit than other times in the year.

4. *Photographing analemmas*

Actually, it's a substantial technical challenge to take a year long photo of an analemma. Some of the best known examples are by – well, let's just say this Greek chap named Anthony, who has taken a series of analemmas over different ancient Greek temples – and in doing so he also demonstrates how an analemma can tilt when the camera takes a shot at a different time of day. So, for example, while an analemma at noon is upright, it's leaning over to the east in the morning and leaning over to the west in the afternoon – see the show notes. It's just a reflection of the fact that the Sun is towards the east in the morning – and towards the west in the afternoon.

5. *Analemmas on other planets*

Now, assuming a planet has any degree of axial tilt, the eccentricity of the ellipse of that planet's orbit determines the degree of skewing of a figure of 8 analemma. Eccentricity is generally measured as a decimal fraction – where 0.0 is a perfect circle, 0.5 is a very eccentric ellipse and 1.0 is an open parabola where the ends never meet.

Earth's orbit is relatively close to circular with an eccentricity of only 0.01. For a planet with a slightly more eccentric orbit, like Saturn with an eccentricity of 0.05, the small loop of its figure of 8 analemma is even more shrunken – and from Mars with an eccentricity of 0.09, the little loop has disappeared altogether so that a Mars analemma is just a tear drop shape where the pointy bit of the teardrop represents where the second loop might be on a less eccentric planet. Links to Mars' and other extraterrestrial analemmas are in the show notes.

Anyway, this all brings me to the equation of time.

6. *The Equation of Time*

Way before there were cameras, people had sun dials – or could even just put a stick in the ground. If you marked where the tip of the stick's shadow was at noon each day, over the full year – this will trace out an analemma on the ground.

Whether or not early sun dial users fully understood orbital eccentricities and obliquities – they certainly appreciated there was a problem with trying to measure time with a sundial given all this variability – albeit a predictable variability – of the position of the shadow on different days throughout the year.

But really all you have to do is to map out your analemma over a year – and then just draw a straight line through the middle of it and call that mean time. Then every day of the year you just adjust the apparent time the sun dial shadow points to - by the known variance from mean time for that particular day. As it happens, the biggest extremes are around the 3rd of November when you need to subtract 16 and a half minutes from your local apparent sun dial time – and on the 12th of February you have to add 14 minutes and six seconds.

It's all these adjustments that can be calculated by what's known as the equation of time. The actual equation has a lot of trigonometry and stuff, but the outcome tells you how much you have to adjust your apparent time as shown by the shadow of the sticky-out bit of a sun dial – referred to by its ancient Greek name gnomon (spelt gnomon). Oh – and guess what the ancient Greeks called a sundial's base. Yep, an analemma.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where it is over six weeks now since we ordered that Galileoscope. No ads, no profit, just good science. Bye.