Hi, this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Testing Einstein*.

Albert Einstein published his paper on special relativity in 1905 and then his killer paper on general relativity in 1915. But it wasn't until 1920 that he became the 20th century's rock star of physics – when a key test of his theories came back positive.

In this podcast we'll cover the so-called 'classic tests' which delivered the first evidence of relativity. As you will see, it takes astronomy to really test Einstein. There's the explanation of Mercury's orbit, a demonstration of gravitational lensing during a solar eclipse and a red shifting of light when emitted from a gravity well. And what the heck, let's do a couple of experimental spacecraft missions too.

Einstein's paper on special relativity in 1905 came out with no references to other works – but he did make reference to a curious phenomena in electromagnetism, which could be attributed to investigations by James Clarke Maxwell and contemporaries - where 'electric currents of the same path and intensity' occurred in situations where a magnet was in motion near a conductor at rest or the magnet was at rest while the conductor was in motion - in either case you got the same outcome. This partly explains why the paper was called *On the electrodynamics of moving bodies*.

The paper also contained a curious statement about 'the unsuccessful attempts to discover any motion of the Earth relatively to the light medium'. I say curious because Einstein later stated he couldn't recall having heard of the 1887 Michelson-Morley experiment prior to writing his 1905 paper.

So, whether Einstein knew about it or not, the 1887 Michelson-Morley experiment is a useful test to show that light speed really is constant regardless of the frame of reference from which you measure it. The Michelson-Morley experiment effectively showed that the Earth's forward velocity in its solar orbit (of 30 kilometres a second) contributed nothing to the speed of a light beam moving ahead of the Earth. This was done by comparing the speed of one beam going forward, with another going sideways. Einstein's explanation for this, was' that light is always propagated in empty space with a definite velocity *c* which is independent of the state of motion of the emitting body'.

Einstein's 1915 paper on general relativity, which is essentially his theory of gravity, offered a solution to a long standing astronomy problem, about the precession of Mercury's orbit. In any elliptical orbit there is a closest-in point called the periapsis and an outermost point called the apoapsis. As Mercury orbits the Sun again and again - that point of apoapsis gradually shifts around the Sun - or in other words, Mercury's orbit precesses.

Astronomers found the precession of Mercury's orbit could be partly explained by the influence of the other planets and the fact that the Sun is not a perfect sphere. However, there was still a tiny but seemingly unaccountable component of 45 arc seconds per century in the precession of Mercury's observed orbit – and indeed we've since found the same tiny effect in every solar sytem planet's orbit – it's just more obvious with Mercury, being the planet closest to the Sun.

Applying general relativity to the problem showed that the warping of space-time near the Sun means an orbiting planet (from the point of reference of a distant observer) spends a bit longer in periapsis (when it's closest to the Sun) due to time dilation – so when it swings out again, towards apoapsis, it's as though the whole orbit has shifted around slightly – or precessed– and by about 45 arc seconds per century in Mercury's case.

In the 1915 paper, Einstein also proposed two other tests for the theory of general relativity which were at least conceivable with the technologies of the day. Firstly, he proposed that, at the time of a solar eclipse, when the Sun is blocked out, it should be possible to observe stars close to the edges of the Sun and these stars should appear slightly out of position due to gravitational-lensing resulting from the Sun's huge mass warping space-time.

The astronomer Arthur Eddington took up the challenge and mounted an expedition to the island of Principe – and made the appropriate observations of a solar eclipse. Following the publication of Eddington's paper on the Principe findings, relativity and Albert Einstein became headline news.

The other test of general relativity proposed by Einstein was that a light beam projected upwards from a gravity well, like a planet, should be red-shifted from the perspective of an observer in a weaker gravity field – such as someone in orbit around the planet. Essentially the light moving out of a gravity well gets stretched because the environment it is moving through (space-time) is itself being stretched by the mass of the planet.

So, from the point of view of an observer in orbit, the light beam's frequency is stretched and lengthened – or to put it another way, it becomes redder.

The first attempt to measure gravitational red-shift was in 1925, but a conclusive, reliable measurement was not possible until 1959 – after Einstein's death – when a shift was reliably detected between the bottom and top of a faculty building at Harvard University.

And then, in the space age, we started flying gravity probes. First, there was the unsophisticated Gravity Probe A launched in 1976 - which, in a single two hour orbit, effectively demonstrated that a clock in orbit - and hence in a weaker gravity field - runs faster than one on the surface of the Earth. This is why GPS satellites today have slow running clocks at launch – so that when they are in orbit they run at the same speed as clocks on Earth.

After that there was the terribly complicated Gravity Probe B, launched in 2004. Now, a spacecraft in orbit is at a constant velocity and is almost in a vacuum. So if you set a gyroscope spinning – like they did in Gravity Probe B – it should just spin without its axis ever shifting - unless of course space-time is curved in the vicinity of a massive object like the Earth – which is just what Einstein would have predicted. And yes - the axes of the gyroscopes on Gravity Probe B did kind of lean into the orbit in a way predicted by Einstein's gravity theory, but not Newtonian gravity.

Gravity B also tried to measure the last of Einstein’s untested predictions - which is frame-dragging - where the rotation of a massive body should drag space-time around in its wake. But since the Earth is only moderately massive, this effect on the gyroscopes was not substantial enough to be reliably differentiated from background noise.

So, the challenge for the 22nd century is to build Gravity Probe C and to put into orbit around a black hole. Now that will be frame-dragging..

Thanks for listening. This is Steve Nerlich from Cheap Astronomy www.cheapastro.com. Cheap Astronomy offers an educational website where you can tour the universe in economy class. No ads, no profit, just good science. Bye.