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.

A lot of Einstein's material is articulated through thought experiments which, while not actually evidence, are at least compelling interesting. An early one, that allegedly led him on the road to relativity, was imagining himself standing in front of a big clock – like Big Ben say.

You look at the clock and it says ten past two and you realise your eyes are receiving information transmitted from a light beam reflected off the face of the clock – you hop aboard that beam of light and move away from the clock. So you are riding this beam of light carrying the particular information that says it's ten past two – and as long as you keep moving with that beam of light that's all the clock will ever appear to say. It's as though, if you could fly at the speed of light (which you can't), time would appear to freeze to zero.

So you might reasonably deduce that the apparent rate of time, is not a universal constant, but depends upon the frame of reference of the observer. It's not a test, but it's a nice thought experiment and you can sort of see how special relativity falls out of such thinking – well along with some maths and some extreme cleverness.

In this podcast we'll just cover the so-called 'classic tests' which delivered the first round of evidence for relativity – and which were possible with the technologies of the early 20th century. These include an explanation of Mercury's orbit, a demonstration of gravitational lensing during a solar eclipse and a demonstration of the red shifting of light when emitted from a gravity well. As you will see, it takes astronomy to really test Einstein.

Einstein's paper on special relativity in 1905 came out with no experimental evidence – but did make reference to the 1887 Michelson-Morley experiment which had showed light speed to be constant regardless of the frame of reference from which you measured it. Although the experiment was not direct evidence of special relativity, Einstein did offer his theory as an explanation of the otherwise puzzling Michelson-Morley outcome.

The 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. Einstein's explanation for this, was that the light beam going forward was just moving at its normal speed through a continuum where lengths were shorter and the clocks were slower – but the speed of light was constant.

Einstein's paper on general relativity, published in 1915, again included no experimental evidence, but this time offered a solution to a long standing astronomy problem, the precession of Mercury's orbit.

Kepler's laws of planetary motion has it that a planet of negligible mass should orbit a perfectly spheroidal Sun in a neat, eternal elliptical orbit. However, this is only an rough approximation of reality – since a planet's orbit is influenced by other factors than just the Sun's gravity – notably other massive planets, which can perturb its orbit.

But Mercury's orbit was a puzzle. Astronomers found the precession of its orbit could only be partly explained by the influence of the other planets and the fact that the Sun is not a perfect sphere. There was still an unaccountable component of 45 arc seconds per century in Mercury's observed precession.

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

Einstein also proposed two new tests for the theory of general relativity which were 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 be out of position due to gravitational-lensing resulting from the Sun's huge mass warping space-time.

Interestingly, Isaac Newton had himself proposed that gravity would have such an effect on light since Newton – clever chap that he was – had already proposed that light might be made up of particles, or corpuscles (as he called them).

Nonetheless, Einstein predicted, by general relativity, that the degree of light bending would be twice that predicted by Newton's law of gravity. Newton realised that gravity might 'slow' something down (what Einstein would better represent as time dilation). However, the additional effect of space warpage did not occur to Newton – so he had only predicted half of the full light-bending effect.

An expedition in 1919, including the astronomer Arthur Eddington, observed a solar eclipse from the island of Principe to see if Einstein was right – and indeed observed that stars had shifted out of position much as predicted by general relativity.

Much of Einstein's person of the 20$^{th}$ century, and all-round genius status, can be attributed to Arthur Eddington. It wasn't until 1920, following the publication of Eddington's paper on the Principe expedition, that relativity and Albert Einstein became headline news. Eddington followed up his paper with a series of public lectures and books – and was also the person who when confronted with the notion that only three people really understood relativity paused sardonically before replying that he was trying to think 'who the third person might be'.

The other test of general relativity proposed by Einstein was that a light beam projected upwards from a gravity well 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 longer – meaning its kind of stretched out, with its wave peaks occurring more infrequently – or to put it another way, it's redder.

The first attempt to measure gravitation red-shift on Earth was in 1925, but a conclusive, reliable measurement was not possible until 1959 – when a shift was detected between the bottom and top of a faculty building at Harvard.

So there you go – if you want to be a famous Nobel prize winning genius think up a new theory, propose ways that it can be tested objectively – and get yourself a good publicist.

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.