Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Superluminal motion.*

It is a fundamental principle of Einstein's relativity physics that nothing can move than light - but there are various ways to kind of, sort of move faster than light - and this podcast is about those various ways.

Here we'll just stick to directly measurable examples of superluminal motion - although it turns out most of them are either optical illusions, or they kind of, sort of exceed light speed in a way that doesn't conflict with relativity physics. Relativity physics specifically requires that nothing can move or transmit information faster than the speed of light in a vacuum. The 'in a vacuum' point is important here. Light speed varies significantly through glass, water and other refractive media. However, relativity physics is built upon the principle that the speed of light in a vacuum is always constant – and this value c is then used as a constant within the mathematics of relativity.

So, here's a few legitimately measurable examples of superluminal, or at least apparent superluminal, motion.

*1. Cause and effect illusions*
Imagine you arrange a line of light bulbs which are independently triggered. It's easy enough to make them fire off in sequence - first one, then two, then three - and you can keep reducing the time delay between each one firing until you have a situation where bulb 2 fires off after bulb 1 in less time than light would need to travel the distance between bulbs 1 and 2. It's really just a trick - there is no causal connection between the bulbs firing - but it looks as though a sequence of actions (first one, then two, then three) moved faster than light across the row of bulbs – kind of like a Mexican wave in a crowd. This illusion is an example of *apparent* superluminal motion.

It's been proposed that a superluminal Mexican wave of synchrotron radiation might emanate from different point sources on a rapidly rotating neutron star within an intense magnetic field - producing a light boom, which is like a sonic boom but with light rather than sound waves. The light boom itself is still just light moving at the speed of light, but it's been amplified by the addition of separate light pulses. This makes it look as though light pulses produced later in time have somehow caught up with the first pulse - which means they must have moved faster than light. But in fact all the separate light pulses were at the same time from different and causally unconnected point sources on the rotating neutron star.

*2. Making light faster than light*
You can produce an apparent superluminal motion of light itself by manipulating its wavelength. If we consider a photon as a wave packet, that wave packet can be stretched out linearly so that components of the waveform within that packet can move faster than the speed of the whole packet – which means that those parts of the waveform are travelling faster than light.

Indeed you could argue that the leading edge of the wave from - when it's stretched out – will arrive at its destination faster than the packet as a whole, which again means it's moving faster than light.

Now, the physical nature of 'the leading edge of a wave packet' is not really clear. After all, the whole wave packet is equivalent to one photon. In any case, it is generally agreed that the leading edge of a stretched out wave packet is unable carry any significant information on its own - indeed, in being stretched-out and attenuated, it may become indistinguishable from background noise.

If you are keen on the technical details, you can make phase velocity or group velocity faster than c (the speed of light in a vacuum) - but not signal velocity – which is essentially the velocity of the information being carried by the wave packet. In any case, since the photon, as a complete unit, is not moving faster than light in a vacuum, relativity physics is not violated.

*3. Getting a kick out of gain media*
You can generate the apparent superluminal motion of light through a 'gain medium' – which will be some sort of transparent molecular matrix. When the leading edge of a light pulse hits the edge of a gain medium this stimulates the emission of a new pulse of light at the far end of the gain medium. It’s as though the light pulse has hit one end of a Newton's Cradle making a new pulse is project out from the other end. As a consequence light appears to jump this gap superluminally, but in fact it's a whole new light pulse emerging at the other end – which is still, just like the first pulse, moving at light speed. And if you are wondering, a Newton’s Cradle is a line of suspended metal balls – where... it’s easily found in Wikipedia.

*4. The relativistic jet illusion*
We've covered this before in Episode 93 about *Jets*, but it is one of the best known examples of apparent superluminal motion in astronomy, so what the heck. If an active galaxy, like M87, is pushing out a jet of superheated plasma moving at close to the speed of light - and the jet is roughly aligned with your line of sight from Earth - you can be fooled into thinking its contents are moving faster than light.

So, if that jet is 5,000 light years long, a photon emitted by a particle of jet material near the start of the jet is going to take 5,000 years to reach you. But meanwhile, the particle of jet material continues moving towards you nearly as fast as that photon. So, when that particle emits another photon, near the tip of the jet - that second photon will reach your eye in much less than 5,000 years after the first photon – all of which will give you the impression that the particle has crossed 5,000 light years in much less than 5,000 years – that is, it's moved faster than light. But the whole thing is just an optical illusion and relativity physics remains intact.

*5. Unknowable superluminal motion*
Lastly, it is entirely possible that objects beyond the horizon of the observable universe are moving away from our position faster than the speed of light - as a consequence of the universe's cumulative expansion, which makes distant galaxies appear to move away faster than close galaxies. But since light from hypothetical objects beyond the observable horizon will never reach Earth, their existence is simply unknowable - and does not represent a violation of relativity physics.

*Conclusion - why relativity says no.*
The requirement in relativity physics that you can't move faster than light in a vacuum is more than just an arbitrary rule. In fact, it may be all about the issue of information transfer and of fundamental causality.

So, let’s go back to the standard relativity clock story. You’re standing in front of a Big Ben and it strikes twelve. If you fly over to the other side of London faster than the speed of sound and announce to everyone that it’s 12 o'clock, you'll get some people rolling their eyes since they already know the clock had struck twelve because they could see it in optical light – which gets there well ahead of the sound of the chime.

But if you repeat the same experiment - and this time move faster than light - then not only do you surprise people with your news that it's 12 o'clock but when you look back at the clock you see that it's only just now striking twelve – because the light carrying that information has just arrived at your location. And so you discover that by moving faster than light, not only do you move faster than information can move - but in fact you move backwards in time.

Now, there are various problems with that story and in any case it's impossible. To explain:

Where you run into real problems is if - back in London, you somewhat maliciously decide to return back in time to your original location and then trip yourself up so that you can't do what you just did. Or if you're really feeling nasty you could go way back a hundred years in time and kill your grandparents - which a) isn't very nice and b) violates not only relativity theory, but causality and indeed reality as we know it.

So, once again - relativity says no.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website encouraging everyone to be nice to their grandparents. No ads, no profit, just good science. Bye.