Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Gravitational waves*.

So, in 2016, we discovered gravitational waves using LIGO – the Laser Interferometer Gravitational-Wave Observatory and enough have been said about who did what, when, where and how not to dwell on all that. But, since it did require a 4 kilometre by 4 kilometre interferometer to measure very faint waves from a very distant source, it begs the question as to what gravitational waves would look like up close?

All sorts of massive objects exert gravitation, by stretching warping and shaping the spacetime continuum around them. That gravitation extends outwards to a potentially infinite distance, although it diminishes with distance by the inverse square relation. To produce a gravitational wave you need a sudden change in the position of a massive object – which might be an acceleration, or it might be a jerk, the equivalent of a giant hand slapping on the fabric of space-time.

The elliptical orbit of the Earth round the Sun is a very small example. The Sun's gravity effects the velocity of Earth – and since the Earth's orbit is not a perfect circle, it does not move in its orbit at a constant velocity, but instead speeds up and slows down between periapsis and apoapsis. That accelerating and braking consumes energy – but when we say consumes, of course energy is neither created nor destroyed, just transformed – so what we really mean is that nett energy is lost from the system in the form of exceedingly tiny gravitational waves. That lost energy results in the Earth's orbit around the Sun slowly decaying – although we expect the Sun will turn into red giant long before Earth's orbital decay due to gravitational wave production becomes noticeable.

But, that is a local and fairly humdrum example of gravitational wave production. Imagine two black holes in a close binary orbit with masses of 29 and 36 solar masses. Well, actually you don't have to imagine this, because two such merging objects produced the recently-announced gravitational waves. That black hole binary was roughly in the direction of the Magellenic clouds, though an awful lot further out – indeed, about 1.3 billion light years further out. The 29 and 36 solar masses objects merged, to form a 62 solar mass object, the 'missing' 3 solar masses leaving the system in the form of tsunami-like gravitational waves carrying the energy of 3 solar masses multiplied by the speed of light squared out into the wider Universe. This was, allegedly, a momentary power output exceeding 50 times what is normally put out by all the stars in the observable Universe combined.

Still, the output was a series of waves, not just one giant one. The orbiting black holes were producing gravitational waves of steadily increasing amplitude and frequency long before they actually coalesced together. And even as the black holes did merge – producing the very highest amplitude waves, those huge waves immediately began to decline in amplitude, as they spread outwards in great circles from their source and the inverse square rule kicked in. By the inverse square rule, a stupendous gravitational tsunami can quickly become a ripple after just a billion kilometres or so, let alone a light year, let alone 1.3 billion light years. Indeed after 1.3 billion light years the amplitude of such a wave becomes reduced to about one ten thousandth the width of a proton.

So, to have any chance of seeing a gravitational wave with the human eye, you do need to be pretty close to the source. At very close range to a black hole merger, the passage of the resulting gravitational wave would likely kill you just at the moment you had the chance to see it, as your body was suddenly required to occupy a spacetime, which was being stretched by orders of magnitude, first one way and then the other.

But in reality, the spaghettification of being is such close proximity to the black holes would have killed you already. Once you are at a far enough distance from where the black holes' gravity won't kill you, then the gravitational waves they produce while merging probably won't kill you either.

But can you visually-see a gravitational wave ripple that is small enough *not* to kill you? And, well… probably not. Since the wave is moving outward at the speed of light in an attenuating sphere, there is no perspective from which you can see it before it is already passing you by. In the moment that it does pass you by, one hypothesis has it that your eye geometry would stretch in just the same way as the wave – hence making its passage invisible. And if you tried looking for a receding wave front that had just passed you by – that wouldn't work either. The passage of a gravitational wave doesn't *produce* light, it just influences the continuum through which light moves. So a photon that may be bobbed up and down by the wave, while it's on its way to your eye, would likely have returned to its original trajectory before it reaches your eye.

But even though we might never see gravitational waves, we now have the tools to tell us when they just passed by. This will apparently open up a whole new field of gravitational wave astronomy, which will add to the list of other non-optical methods we now use routinely: gamma ray, infra-red and radio astronomy, as well as exotic approaches like neutrino astronomy – all of which can deliver what we call *multi-messenger* astronomy, a field which can now be supplemented by gravitational waves as well.

Gravitational wave astronomy has some advantages over electromagnetic wave astronomy in that passage of gravitational waves are neither absorbed nor scattered by any masses or charges they may pass by. The obvious disadvantage of gravitational waves is that once attenuated over distance they become difficult to distinguish from what is already a very noisy gravitational background. As described earlier, any objects in non-circular orbits – which unfortunately comprises the vast majority of orbiting objects in the Universe – produce gravitational waves. Hence, we have a huge challenge in distinguishing the output of distant wave sources that have attenuated, from local small scale waves such as those produced by the elliptical orbits of planets – or even just by a car speeding past your local LIGO observatory.

Distant wave sources that are powerful enough to produce detectable gravitational waves are most likely to be compact binaries, like black holes or neutron stars. Or otherwise, supernovae which explode in an asymmetric fashion can produce gravitational waves – and the large majority of supernovae do explode in an asymmetric fashion. There has been some suggestion that gravitational waves might tell us something about the innards of black holes, but that won't be by any sort of direct observation. An event horizon is an event horizon – doesn't matter if you're talking light or gravitational waves… or neutrinos. On the plus side, gravitational waves will tell us more about the sequence of events leading up to the gravitational collapse of a black hole or the events leading up to a binary black hole merger.

To undertake the observation of gravitational waves produced by such point sources we will need arrays of detectors. The 2015 observation, that was announced in early 2016, came from two LIGO observatories, one in Washington state and one in Louisiana. Ideally, you want three, for the most effective triangulation and to better confirm you have captured a true signal rather than just an artefact in the background noise. All that said though, point source observation isn't the most useful thing that gravitational wave astronomy can do.

Wide field of view gravitational wave astronomy has the potential to deliver information about the early Universe, which is also one of the main objectives of neutrino astronomy. Either method has the potential to transmit information about events that happened before *recombination*, the time in which the Universe first became transparent to electromagnetic radiation. In other words, gravitational wave astronomy – or neutrino astronomy – might provide us with an even earlier view of the Universe than we can currently get from the cosmic microwave background.

You might remember all the excitement that arose from the premature announcement of findings from the BICEP-2 experiment, which eventually turned out just to be confusion between background noise and signal. Nonetheless, the signal they *thought* they had, was the hypothesised gravitational wave echoes of early cosmic expansion, which was a stupendous acceleratory event that may have occurred microseconds after the Big Bang.

That was what the excitement around the BICEP-2 announcement was really about. The LIGO announcement was all woop-de-doos we've measured gravitational waves – because otherwise all they could have really announced was finding yet more evidence that black holes merge. When we do eventually get genuine observational evidence of what happened in the 400,000 years preceding the production of the cosmic microwave background – that will be quite a press release.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where spacetime is gnarly dude. No ads, no profit, just good science. Bye.