Gravitational Waves from Neutron Stars

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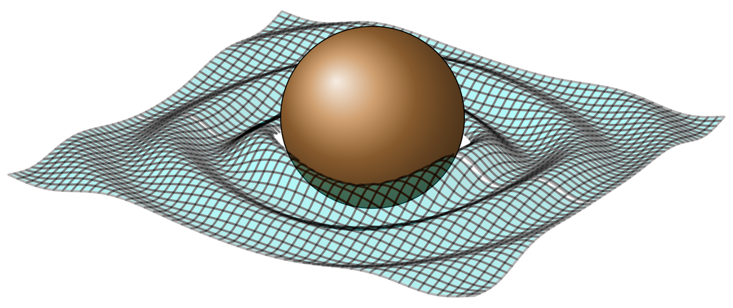
I: What is a *gravitational wave*?

In 1916 Einstein formulated his theory of gravity, general relativity. Like all good theories it made several important predictions. Only one of these predictions has not been experimentally tested: *gravitational waves*.
Einstein unified the ideas of space and time into a single object which we call *spacetime*. Spacetime is a dynamic object that can interact with matter. We can picture this by imagining a stretched rubber sheet on which we place heavy weights, this creates wells in the sheet. In this picture the rubber sheet is spacetime while the weights are large masses e.g. stars, black holes.

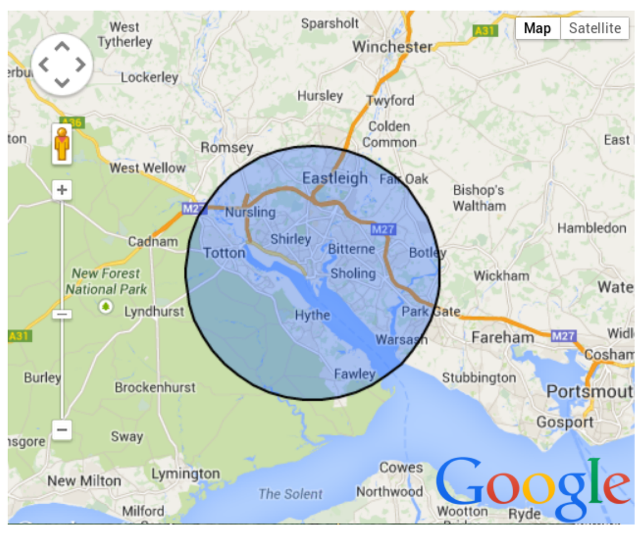
"Spacetime tells matter how to move; matter tells spacetime how to curve." - *J. Wheeler*

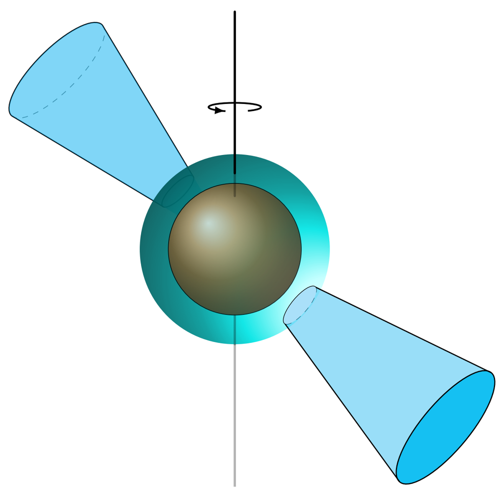


When a large non-symmetric mass rotates, it causes the spacetime to ripple as illustrated in the figure on the left. These ripples are gravitational waves. There is strong evidence that they exist, but they have not yet been directly observed.

II: What is a *neutron star*?

Stars like our sun are in an equilibrium between the outward force from burning nuclear fuel and collapse due to their own gravity. When they run out of fuel they collapse and some form a neutron star. They have a mass about that of our sun, but have a radius of about 10km, this makes them extremely dense. This is like compressing the sun into a sphere roughly the size of Southampton.

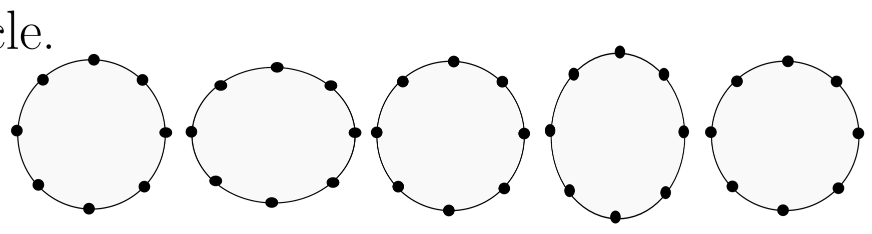




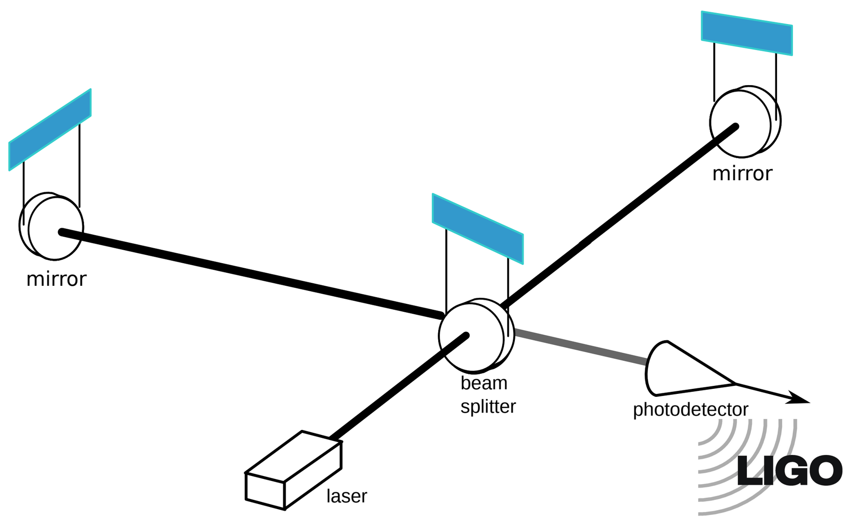
We see some neutron stars as pulses of electromagnetic light. This is caused by radiation streaming out in thin beams which flash over the earth like the beams from a lighthouse, illustrated on the left. Because of their extreme densities, if neutron stars are misshapen the gravitational waves they emit may be measurable on earth.

III: Searching for gravitational waves

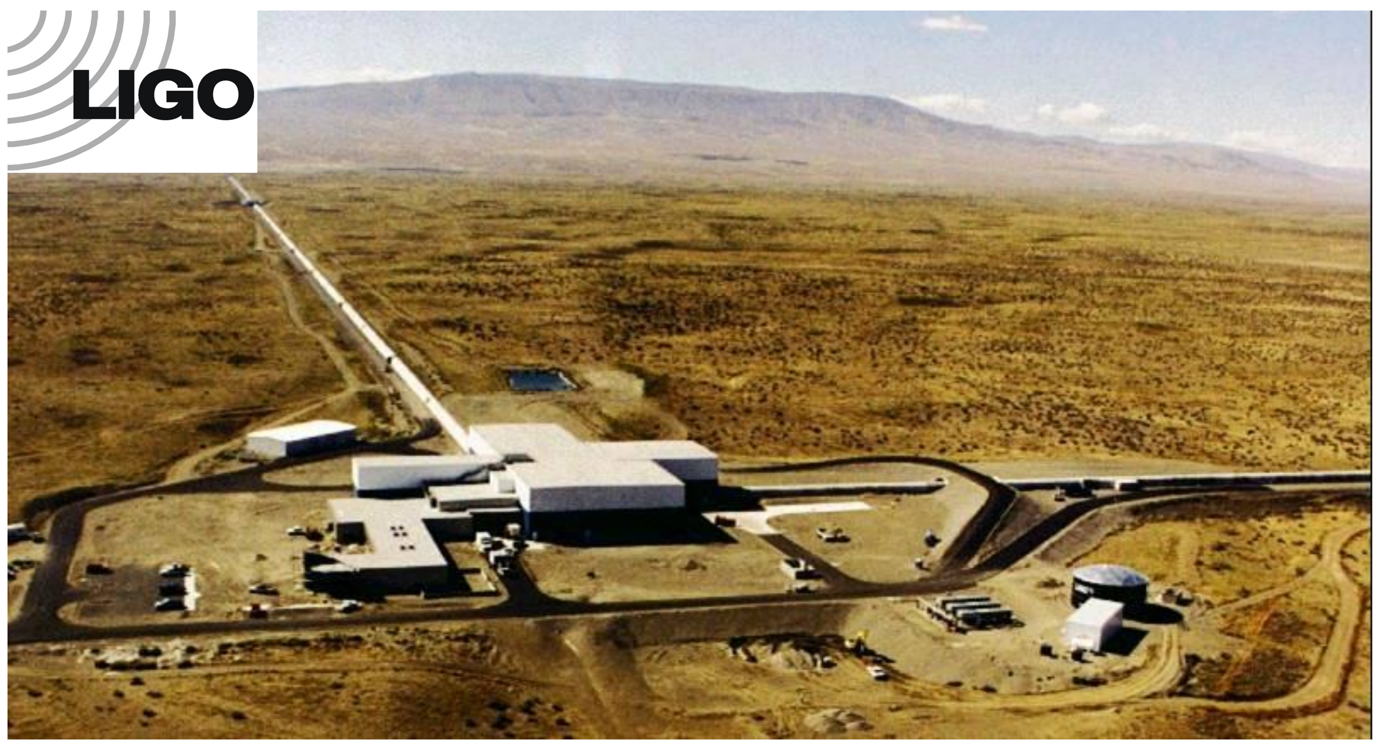
A gravitational wave will periodically stretch and squeeze space in the two directions perpendicular to its direction of travel. In the figure below we show this effect on a circle.



To detect gravitational waves we can use a laser interferometer. These split a laser beam and send it off in two different directions; both beams are then bounced off a mirror and return to the start. Both beams should have travelled the same distance and so should return at the same time. However, if a gravitational wave passed through during the experiment, they will not both return at the same time.



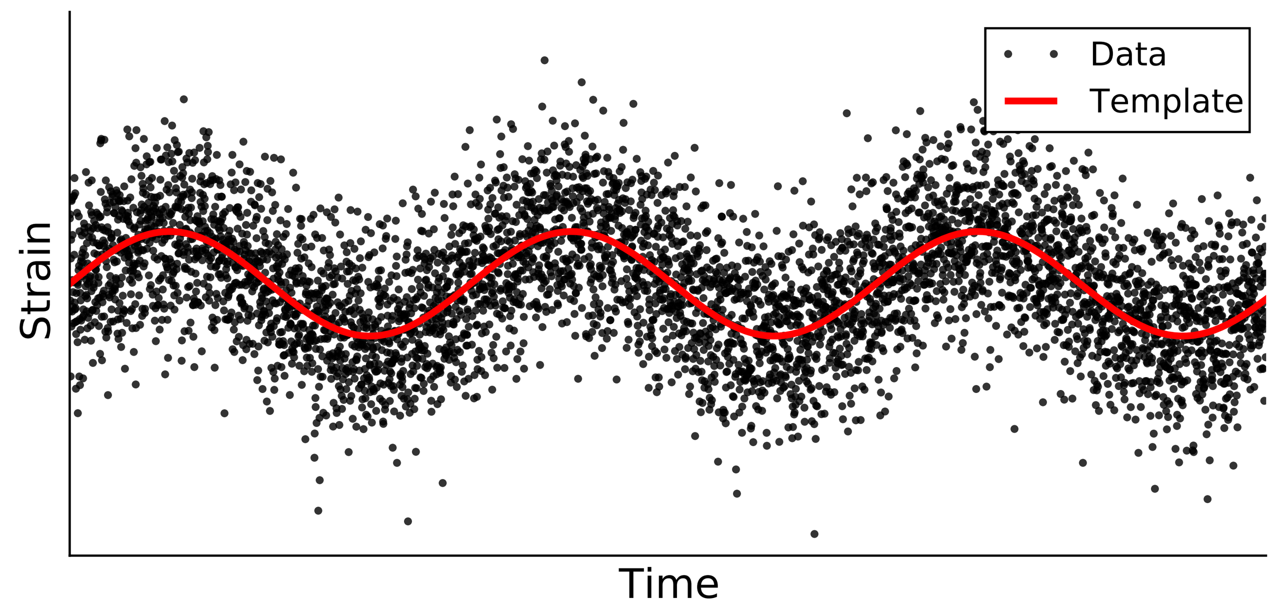
The problem is that the difference between the two beams is tiny. To put it in perspective, it's like trying to measure if a human being has grown by a single atom. We have built enormous interferometers in the hope of measuring gravitational waves, for example here is one of the 4 km long LIGO detectors:



You can find out more about this project at: www.bit.do/LIGO

IV: Searching for signals from neutron stars

The signals we are searching for will be hidden in the *detector noise* from seismic activity. To find them, we make an educated guess for what the signal will look like and compare it to the data, like in the graph on the right. Using the correct guess is crucial to finding the signal. Unfortunately it is possible that real gravitational wave signals will contain *other noise* from the neutron star itself. This neutron star noise may look just like the detector noise, this makes it hard to find the signal. I am trying to test how bad this effect will be and develop methods to improve our chances of detection.



V: Gravitational waves astronomy

Aside from testing Einstein's general relativity, gravitational waves will allow us to explore the universe in a new way. Traditional astronomy observes electromagnetic radiation from distant objects. This means we can only observe the outside of hot, light emitting objects. With gravitational wave astronomy we may be able to observe more of the difficult to explore areas of physics such as black holes, neutron stars, and maybe even the big bang.

VI: Conclusions

Scientists from around the world are trying to detect gravitational waves. Finding these is crucial evidence for Einstein's theory of gravity, general relativity. Here in the gravity group of Southampton, we are helping by modelling neutron stars. We use these models to predict what the signals may look like. I am interested in finding out what happens when the signals include noise from the neutron star.