Colliding black holes and gravitational waves

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In 1915 Albert Einstein published a theory which revolutionised our understanding of gravity. His Generalised Theory of Gravitation, often called General Relativity or 'GR' for short, gave us a whole new understanding of what gravity is.

Gravity wasn't a set of invisible strings connecting every object to every other object. Instead we should imagine space as a stretchy material. This material gets pulled and stretched by massive objects, which causes objects to move differently. A good way to picture this is by imagining a marble being rolled across a trampoline, with a bowling ball in the middle.

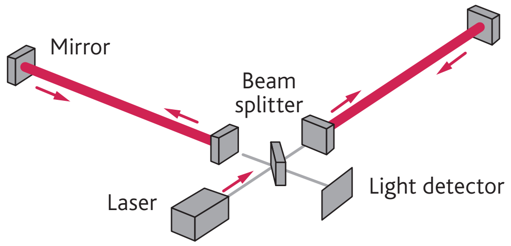
General Relativity made several predictions, some of which have been tested over the last century. So far, GR has passed every test. One prediction was the existence of objects so massive, and yet so small, that nothing – not even light – could escape from them. These objects were later dubbed 'black holes', and are some of the most enigmatic objects in the universe.

Another prediction was that as massive objects moved around, they could cause 'ripples' to spread through the fabric of space, affecting other objects in the universe. The result of these 'gravitational waves' passing through space is to stretch everything in one direction, and squeeze in the opposite. As the wave passes, the effect would switch, and the stretching and squeezing would reverse. This effect would be so small as to be almost (but not quite) undetectable. Evidence has been uncovered for the existence of these waves over the last few decades. Binary pulsars, or pairs of rotating stars, were shown to lose orbital energy by emitting gravitational waves. But direct detection of the waves themselves took longer.

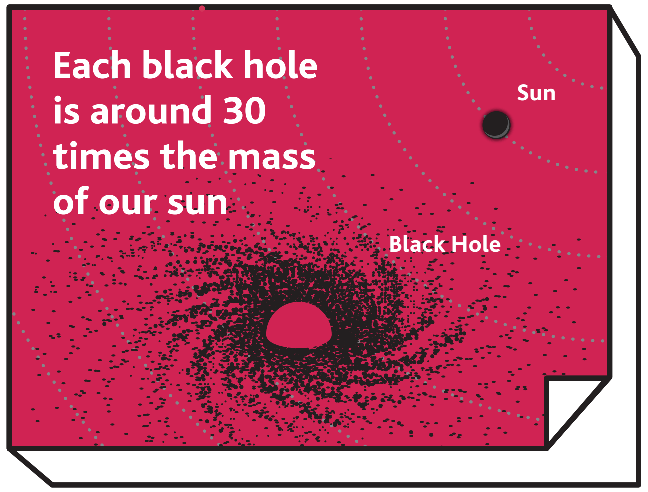
In 1984, the Laser Interferometer Gravitational-Wave Observatory (or LIGO for short) was born, with the aim of directly detecting gravitational waves. Since building the twin LIGO detectors in the US, the international team has continued to grow, and they now work closely with the upcoming Virgo detector in Italy.

Gravitational wave detectors

Modern gravitational wave detectors all work in a similar way: a laser beam is split in two and reflects off mirrors positioned along two arms, arranged in an 'L' shape. A gravitational wave will move the two arms slightly. The real challenge comes from just how small the effect is – even with 'arms' several kilometres long!



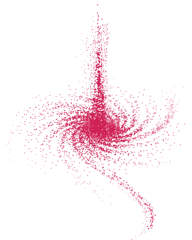
Objects have to be incredibly massive, and moving incredibly fast, for the gravitational waves to be measureable. An extreme example would be two black holes colliding. Even then, the expected signal is very small, with the mirrors predicted to move a thousandth of the diameter of a proton. The technological achievement is staggering. The detectors use vacuum chambers, quadruple pendulums, power-recycling mirrors and ultra-stable lasers (along with many other innovative techniques) to ensure the detectors are stable enough, and accurate enough, to make the detections.


Each black hole is around 30 times the mass of our sun

Previous generations of detectors, including the first LIGO detectors, were not expected to be sensitive enough to detect real signals. In 2015, after a huge overhaul, 'Advanced LIGO' began its first official search for gravitational waves, and was expected to detect something in the first few years. It didn't take long – two colliding black holes were detected on 14 September 2015.

It was possible to determine the properties of the black holes by comparing the observed signal with computer simulations. Each one was around 30 times the mass of our sun, and they emitted gravitational energy in the form of waves as they spiralled towards each other.

They'd probably been there for billions of years, but LIGO witnessed just the final 200 milliseconds of their lives. During this moment, they orbited each other five times and collided at over half the speed of light. The result was a black hole almost as massive as the two combined, radiating gravitational waves. Despite briefly emitting more power than all the stars in all the galaxies in the visible universe, the only measured effect was the movement of two mirrors by a few thousandths of the diameter of a proton.



Advanced LIGO has now detected three mergers of black holes, and there's much more to come. The LIGO detectors are due to be upgraded further over the coming years, and the Advanced Virgo detector is now online as well. There are also detectors being designed and built in Japan, India and even in space one day.

As these detectors become more sensitive we'll be able to see further and further into space, and see more of these events. Detectors will also be able to pinpoint the events' locations in the sky, allowing us to study them with telescopes. And it won't just be black holes. With predicted observations of colliding neutron stars and supernovae, the era of gravitational wave astronomy is just beginning.