Gravitational waves offer glimpse into the past – but will we ever catch ripples from the Big Bang?

18 February 2016, by Andrew King, University Of Leicester

Credit: NASA/Flickr, CC BY-SA

Einstein was right – changes in gravity do spread as waves through space. The LIGO experiment detected such waves from a collision between two black holes with masses of about 36 and 29 times that of the sun (described as 36 and 29 "solar masses"). But the merger of these 65 solar masses in total created a remnant of just 62 – so what happened to the other three? These were used to power the burst of gravitational waves, in a spectacular demonstration of Einstein's famous formula, $E=Mc^2$, where mass and energy are equivalent.

This is only the beginning. Now that we know how to measure gravitational waves, we can use experiments like LIGO to learn about events in the cosmos that we have never been able to see before, such as mergers of supermassive black holes in the early universe. But how far back can we go? What about "primordial" gravitational waves from the birth of the universe itself – will LIGO's discovery help us catch those?

Looking back in time

Although the masses involved in this event are large by stellar standards, they are dwarfed by the supermassive black holes that astronomers believe are present at the centre of almost every galaxy. Our own galaxy, the Milky Way, hosts a hole of about 4m sun masses, detected through the motions of stars orbiting it. Even this is fairly insignificant compared with the holes of up to tens of billions of sun masses thought to be at the centre of the largest galaxies.

There are many things astronomers want to know about these supermassive black holes. We currently see them through the vast amounts of electromagnetic radiation, like visible light and X-rays, produced as gas falls into them. We know that this process helps them grow but it is nevertheless mysterious – most of the gas in galaxies moves too fast or is too far away for the black holes to capture it. So how could they get so big?

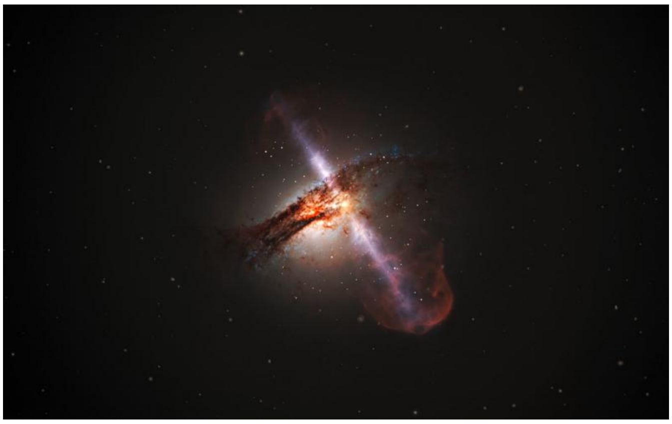

Illustration of galaxy with jets from a supermassive black hole. ESA/Hubble, CC BY-SA

It could be that collisions between these supermassive holes helped to grow them, especially when they were relatively young and had not yet gained much gas. However, a collision between two supermassive black holes can probably only happen if the two galaxies hosting them collide and merge too. This is an inherently rare event in the nearby universe, as galaxies are far away from each other. But it must have been much more common soon after the universe was born in the Big Bang, when galaxies were much closer together.

So detecting gravitational waves from such collisions means looking back in time – observing the most distant galaxies. Light from these galaxies set off on its journey to us only a relatively short time after the Big Bang. This could give us direct clues about how important these events were in growing supermassive black holes early in their lives. This is relevant to our own existence – the electromagnetic radiation thrown out as black holes grow has had a major effect on shaping the galaxies in which stars and planets, including our own, live peaceful lives.

To make such observations will require detectors with sizes far larger than the 4km arms of LIGO. The proposed eLISA experiment will put three satellites into orbit as an equilateral triangle with sides longer than the distance from the Earth to the moon.

The problem with primordial waves

But even supermassive black hole collisions are not the ultimate goal. The Big Bang, and particularly the epoch of very rapid expansion dubbed inflation – which many experts believe took place very soon after – must have involved enormous masses moving with almost light speed. This means that they must have produced powerful gravitational waves. However, the most powerful signal comes from masses whose size is comparable to the scale of the universe itself. Since gravitational radiation has a typical wavelength larger than the masses emitting it, the "wavelength" of this radiation is itself similar to the entire size of the universe. So LIGO, or any other experiment that is smaller than the universe, will not be able to detect it.

Detecting these waves must probably be done indirectly by observing their effects on cosmic microwave background radiation (CMB) – the radiation left over from the Big Bang.

When light waves vibrate in a certain direction, we say that the light has a specific polarisation. If gravitational waves were present at the time when the CMB was born, they should leave behind a unique swirly pattern –- a curling in the polarisation of the light –- dubbed "B modes". A result based on B modes was claimed a few years ago, but it turned out the signal had just been caused by cosmic dust. This is just one of the many competing effects that can distort the CMB polarisation, showing just how hard it will be to detect the true signal.

The stakes are incredibly high. A positive result could give evidence for the popular inflation theory, and offer explanations for several puzzling features of the universe, such as why the distribution of matter is so homogeneous. Although finding such a signal is an enormous challenge, so was the direct detection of gravitational waves when first proposed half a century ago.

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