How did the odd black holes detected by LIGO form – and can we spot them in the sky?

February 17 2016, by Stephen Smartt, Queen's University Belfast

A needle in a haystack? Pan Starrs telescope is scanning billions of galaxies to find the black holes emitting gravitational waves. CC BY-SA

Great scientific discoveries often raise more questions than they answer.

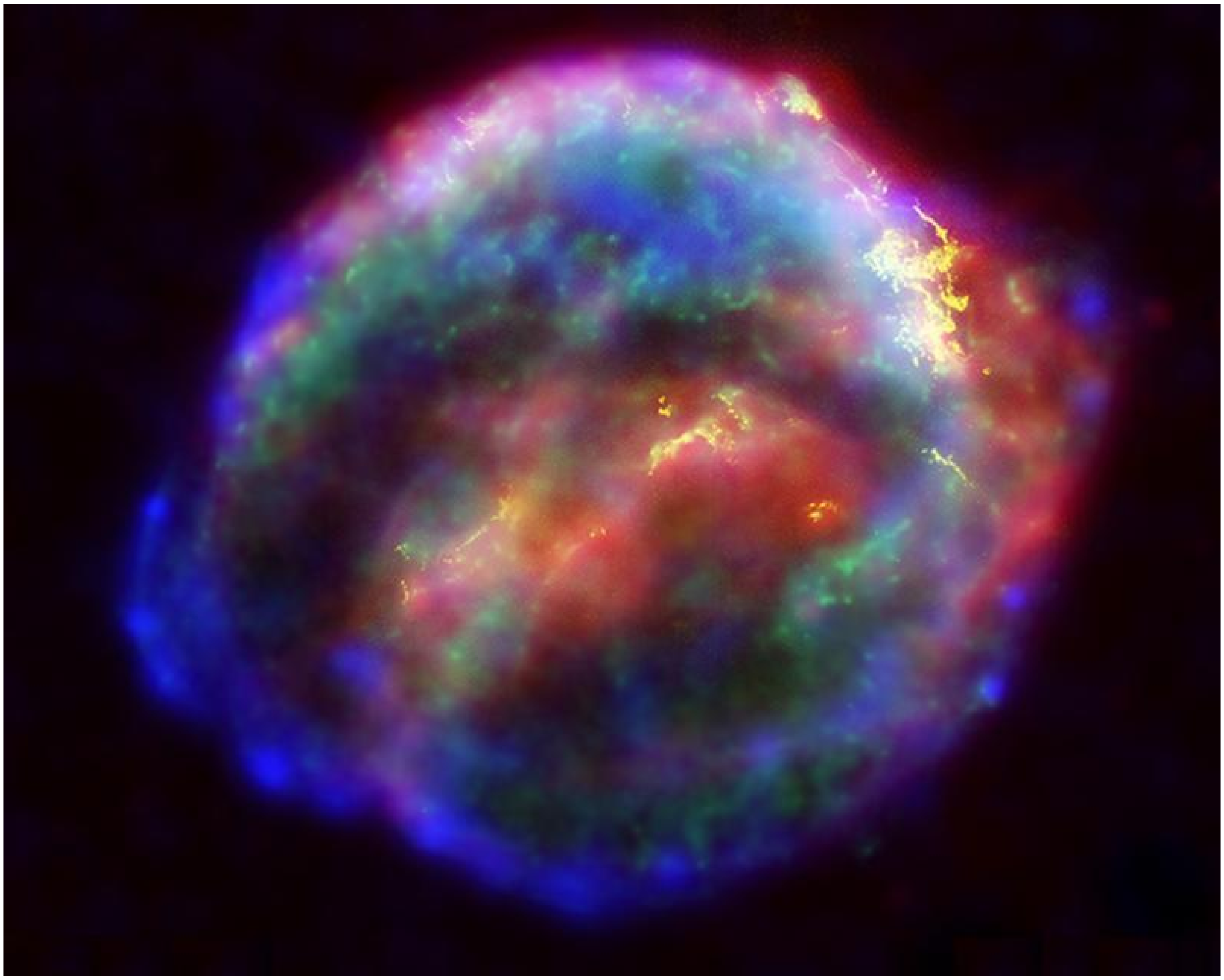
Just days after the announcement that gravitational waves from two merging black holes have been detected, astrophysicists are already pondering what this means for our understanding of stars. New studies are already being released and we can expect a flood of creative ideas in the near future.

One of the most surprising things about the discovery is the huge size of the black holes involved which is challenging our understanding of how they form. So how can we find out more? One way is by pinpointing the black holes on the sky so we can try to study them using regular telescopes.

Massive mystery

LIGO, the observatory that detected the gravitational waves, is a so-called laser interferometer. It estimated that the two merging black holes would have masses of about 36 and 29 times that of the sun respectively (described as 36 and 29 "solar masses"), calculated from the frequency of the gravitational waves. But what's so unusual about these masses?

Black holes form after huge supernovae explosions, which can only be produced by massive stars. The masses of the black holes in our own galaxy can be measured by looking at the speed of stars orbiting a black hole. The most massive black hole in a binary system (a black hole and a companion star orbiting a common centre) in our galaxy is about 10-20 solar masses.



Multi-wavelength compilation image of Kepler’s supernova remnant, SN 1604. Credit: NASA/wikimedia

This is well explained by our knowledge of stars. The biggest stars are born at about 100 solar masses and end up at around only ten solar masses at their endpoints due to stellar winds blowing out material into space. This means they shouldn't be able to produce the kind of huge black holes that LIGO detected. But there are still big uncertainties about the rate at which this occurs and the influence of a star's spin, the existence of a second star orbiting a common centre (binary stars), and its chemical composition.

So how could the black holes detected by LIGO be so massive? Research has already come out that suggests we can explain that by assuming they come from two collapsing massive stars. But the stars that formed them must have had a very different chemical composition to the stars in our own Milky Way, which has a high content of heavy chemical elements like oxygen, sodium, magnesium, silicon, sulphur, iron.

In fact, a paper from the LIGO team and one from two experts on binary stars proposed that they needed to be in small galaxies with very low metal content (we astronomers label all elements heavier than boron a "metal"). That's because, according to atomic physics, low-metal stars lose less mass during their life. So they end up with higher mass than other stars at the end, and form larger black holes.

Sky scanning

The LIGO team could give a rough direction of where on the sky the merger took place, due to the difference in detection time between its two experiments in different parts of the US (0.07 seconds). However this can only be located to about 500 square degrees (an area of 2,000 full moons). Astronomers tried to pinpoint the source by pointing optical, infrared, X-ray and radio telescopes in this area.

However, it wasn't easy. Black hole mergers are not predicted to produce significant electromagnetic radiation such as visible light or X-rays. But there was an intriguing detection of gamma-rays (which are high-energy electromagnetic waves) by the Fermi satellite that lasted just a second and appeared 0.4 seconds after the LIGO signal. However, it is not certain that the two are related, as Fermi can't tell where these gamma rays came from in the sky. The next step is to look for more high-energy emissions coincident in time with future gravitational wave signals to see whether there's a link. There are indeed theories that suggest that two merging holes can produce a gamma-ray burst if they form and merge in a certain way, meaning it is important to keep looking.

We recently scanned the area with the Pan-STARRS telescope and found 56 sources of optical light emissions, but we weren't able to link any of them to the LIGO event. This is not too surprising, it's tough to cover such a large area – including billions of galaxies – fast, deep and with broad wavelength coverage. There are some clever ideas to pick the biggest galaxies using catalogues and focus on observing those. However if these massive black holes have to come from metal-depleted stars, their host galaxies will be small because of where low-metal stars are found. These galaxies are much more numerous than large ones, and there are too many of them to use this method. Also, many of them are too faint to have been catalogued before.

It will definitely not be an easy observation to make, but what is certain is that we will be looking harder than ever. The world's most powerful telescopes on the ground and in space are all joining the hunt. The journey is just starting and the LIGO discovery is truly inspiring.

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