What remains when two neutron stars collide?

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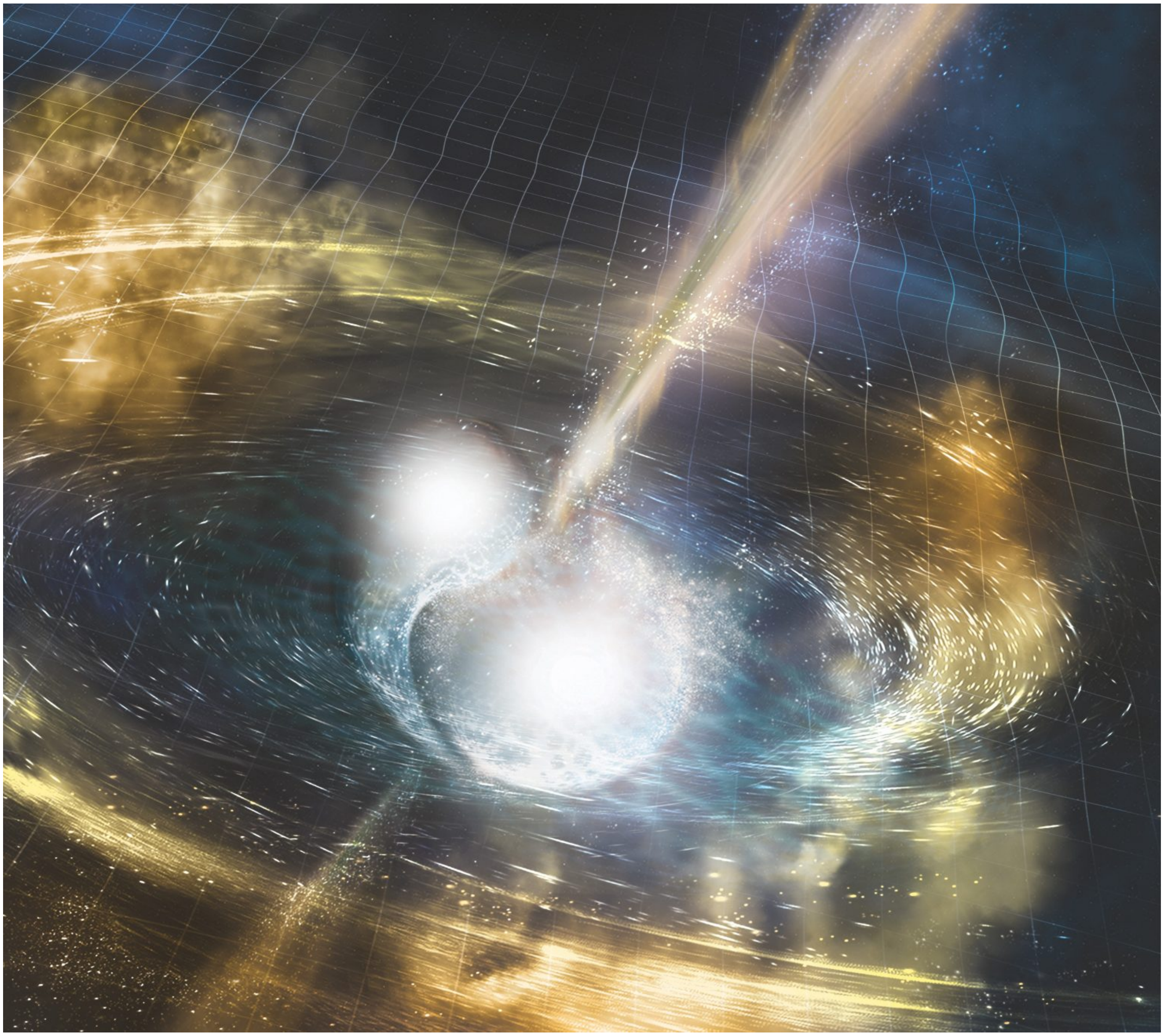

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Distinguished Professor Susan M. Scott and Dr Karl Wette from the Australian National University examine what remains when two neutron stars collide in this exciting gravitational astrophysics focus

Our Universe is now 13.7 billion years old. Many processes have evolved slowly over its existence; for example, our Sun will burn for about 10 billion years over its working life before entering retirement as a white dwarf star. At the opposite end of the scale, the Universe is also home to a myriad of short-lived events, which may radiate enormous amounts of energy in an instant. These are the astronomical transients.

A new class of astronomical transient

On 14th September 2015, a new class of astronomical transients was first discovered, gravitational wave transients. Throw a stone into a pool of water and watch the ripples radiate away from where it hits the surface. Likewise, gravitational waves carry the history of energetic events from the distant Universe.

Two black holes, tens of times heavier than the Sun, had collided to form an even heavier black hole and radiated – for a split second – more energy than all the observable stars combined.

A miniscule bit of that energy, in the form of gravitational waves, travelled the Universe for some 1.3 billion years, before being captured by the U.S.-based Laser Interferometer Gravitational-wave Observatory (LIGO).

Pleasingly, this discovery [(1)] arrived in time to commemorate 100 years since Albert Einstein presented his new general theory of relativity, which first predicted the existence of gravitational waves. Indeed, the precise shape of the waves was exactly as expected by Einstein's theory. Black holes are, by their very nature, impossible to see, and gravitational waves are the only way to confirm that black holes really exist. Black holes are usually born from collapsed stars after a colossal explosion known as a supernova.

From this discovery, we now know that a pair of stars can both explode, forming two black holes, without being blown away from each other, which helps us to understand how all stars are born, live, and die. Gravitational waves have opened an entirely new window into the Universe.

Gravitational wave transients

A network of gravitational wave observatories is now in operation: LIGO, the European Virgo detector in Italy, and the Japanese Kamioka Gravitational Wave Detector (KAGRA). To date, the network has detected more than 90 gravitational wave events from pairs of colliding stars. Most of these stars were black holes, but some were neutron stars: extremely dense, compact stars, weighing about the same as the Sun, but squashed down to the size of inner London.

As the two stars orbit each other, the radiation of gravitational waves causes the orbit to shrink, and the two stars to orbit faster and faster, radiate even more gravitational waves, and spiral closer and closer together. Inevitably, the two stars collide. The runaway orbit generates gravitational waves, which oscillate at higher and higher frequencies, producing a distinctive "chirp" signal.

Colliding stars are one class of gravitational wave transient, but many others haven't been detected as yet. For example, a supernova may itself produce a burst of gravitational waves. Rapidly spinning neutron stars occasionally get hiccups; these so- called "glitches" may also be detectable as gravitational wave transients.

The collision of neutron stars: The gravitational wave transient seen around the world

On 17th August 2017, LIGO and Virgo witnessed the gravitational wave signal from a remarkable event: the collision of two neutron stars some 130 million years ago. [(2)] A couple of seconds after the event, a burst of gamma rays was detected, followed by an optical counterpart, flares of infrared and ultraviolet radiation, and longer-lived X-rays and radio waves.

Around 70 telescopes imaged the event worldwide, covering the entire electromagnetic spectrum. Long-held hypotheses were confirmed from this one event; for example, colliding neutron stars are associated with short gamma-ray bursts and are the Universe's production factories for heavy metals such as gold, platinum and uranium.

But what was the remnant?

A key question, however, is still unanswered: what happened after the neutron stars collided? The most likely answer is that the debris collapsed to form a new black hole. It's possible, though, that part of the debris reformed into a newborn neutron star. Like all newborns, this neutron star would have been very fragile and may have quickly collapsed to form a black hole.

But perhaps it survived and thrived as a young, energetic neutron star. If a fraction of that youthful energy was converted into gravitational waves, we would have a unique opportunity to observe a neutron star very early in its life.

At the Australian National University Centre for Gravitational Astrophysics, we are developing new data analysis algorithms to detect the gravitational wave signature of a young remnant neutron star. A key challenge is that the wave frequency will be high and rapidly changing; this implies a vast number of distinct signal shapes.

Our new algorithm [(3)] tracks the rapid variations in signal frequency over time using a piecewise fit; each piece of the signal is then described by a few parameters. Our technique complements other approaches to this same problem [(4)], and we plan to apply it to data from LIGO and Virgo in the near future.

Young neutron stars provide an unparalleled opportunity to study physics at the utmost extremes of matter, energy, and gravity. Curiosity-driven research is essential to furthering our fundamental understanding of the Universe and is often a key driver of applied science and technology.

There is the potential for many profound and exciting discoveries as we continue to observe the gravitational wave transients of the Universe.

References

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