How crashing neutron stars killed off some of our best ideas about what 'dark energy' is

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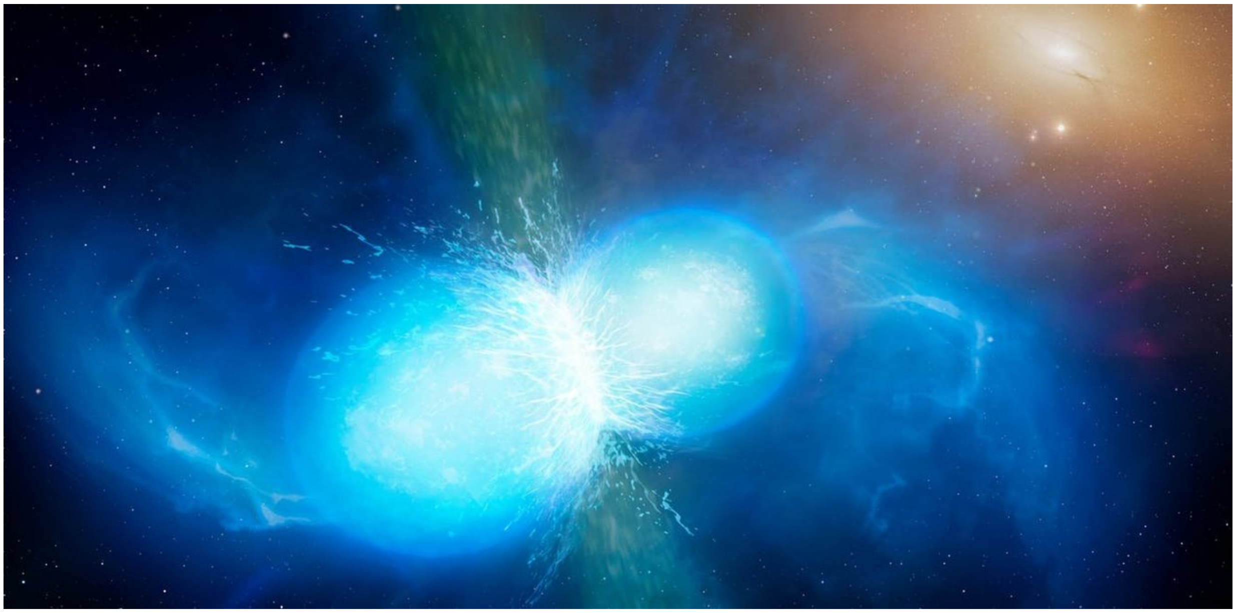

Artist s impression of merging neutron stars. Credit: University of Warwick/Mark Garlick, CC BY-SA

There was much excitement when scientists witnessed the violent collision of two ultra-dense, massive stars more than 100m light years from the Earth earlier this year. Not only did they catch the resulting gravitational waves – ripples in the fabric of spacetime – they also saw a practically instantaneous flash of light. This is exciting in itself and was the first direct evidence for a merger of neutron stars.

But from a cosmologist's perspective, the photo-finish of the gravitational waves and the flash of light has at a stroke demolished years of research into a completely unrelated problem: why is the expansion of the universe accelerating?

It turns out that space and time are actually mutable, pliable, flexible and wiggly, rather than constant, fixed or immovable. This has been known since Einstein published his theory of general relativity, which explains how gravity warps spacetime. The subtle effects that this mutability causes need to be accounted for even in the GPS that makes your sat nav and iPhone work.

One prediction of Einstein's theory was that it should be possible for spacetime to have waves in it, like the surface of the sea. These would be visible if one could, for example, smash together two black holes. This prediction was dramatically seen in the first detection of gravitational waves by the LIGO experiment in 2015. The discovery opened up a whole new way to probe the cosmos, and was awarded the Nobel Prize for physics.

The new detection of gravitational waves from the merger of neutron stars also has profound implications for our understanding of the universe. However for the cosmologists it was the flash of light 1.7 seconds after the gravitational waves that was the more intriguing observation.

The cosmic speed camera

The 1.7 second time delay is important because it means that the gravitational waves and the light waves had been travelling at almost *exactly* the same speed. In fact these are two of the most closely matched observed speeds ever: the two only differed by one part in 10m billion.

To put this into context if the speed cameras on the road could measure speed differences this finely you would get a ticket for going 30.0000000000000001mph in a 30mph zone.

Compared to the best measurements cosmologists were hoping for in the future this is a factor of a million billion times better. Factoring in that the electromagnetic waves may have taken a bit of time to escape from the turmoil of a neutron star collision, for all intents and purposes the speed difference is zero.

Galaxy cluster SDSS – what's pushing it apart at an accelerated rate? Credit: ESA, NASA, K. Sharon (Tel Aviv University) and E. Ofek (Caltech)

Cosmology is in a bit of a pickle. We have a great model that can explain the evolution of the universe from a fraction of a second before the big bang, until now approximately 14 billion years later. The problem is that in order to explain all the observations, a mysterious energy called "dark energy" must be added to the models. Dark energy is a huge problem, it accounts for about 70% of all the energy the universe, and we have absolutely no idea what it is.

Dark energy is *like* an anti-gravitational effect that is pushing the universe apart and causing its expansion to accelerate. So to explain dark energy, cosmologists have attempted to change or replace Einstein's theory to see if a new theory of spacetime could finally explain the effects of dark energy.

One way that cosmologists tried to do this was by changing the speed in which gravitational waves and light travelled. There were many different theories that had this component – each with a peculiar name like quartic and quintic galileons, vector-tensor theories, generalised proca theories, bigravity theories and so forth. Without data any of the theories could have been correct, and there were many people hopeful that they could be the next Einstein or Newton.

Where are we now?

But now in a single observation from a single neutron star merger a wide variety of these have now been consigned to cosmological dustbin in a flurry of papers (here, here, here, here, here and here). So no new Einstein yet.

In the absence of compelling data, it is still possible that we can update Einstein so we can account for dark energy. But the wiggles from the gravitational wave data has left very little wriggle room.

All the theories that have survived the pruning are much simpler than those that were allowed before; and the simplest theory, and the frontrunner, is that dark energy is the energy of empty space, and just happens to have the value we observe.

Another explanation that has survived is that it's a Higgs-like field. The now famous Higgs boson is a manifestation of a "Higgs field" – the first "scalar field" observed in nature. This is a field that has a value at every point in spacetime, but no direction. An analogy would be a pressure map on a weather forecast (values everywhere but no direction). A wind map, on the other hand, isn't a scalar field as it has speed and overall direction. Apart from Higgs, all particles in nature are associated with "quantum fields" that aren't scalar. But like the Higgs, dark energy could be an exception: a ubiquitous scalar field pushing the universe apart in every direction.

Thankfully we won't have to wait long before new telescopes will test the remaining theories and a big piece of the cosmological puzzle will be completed.

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