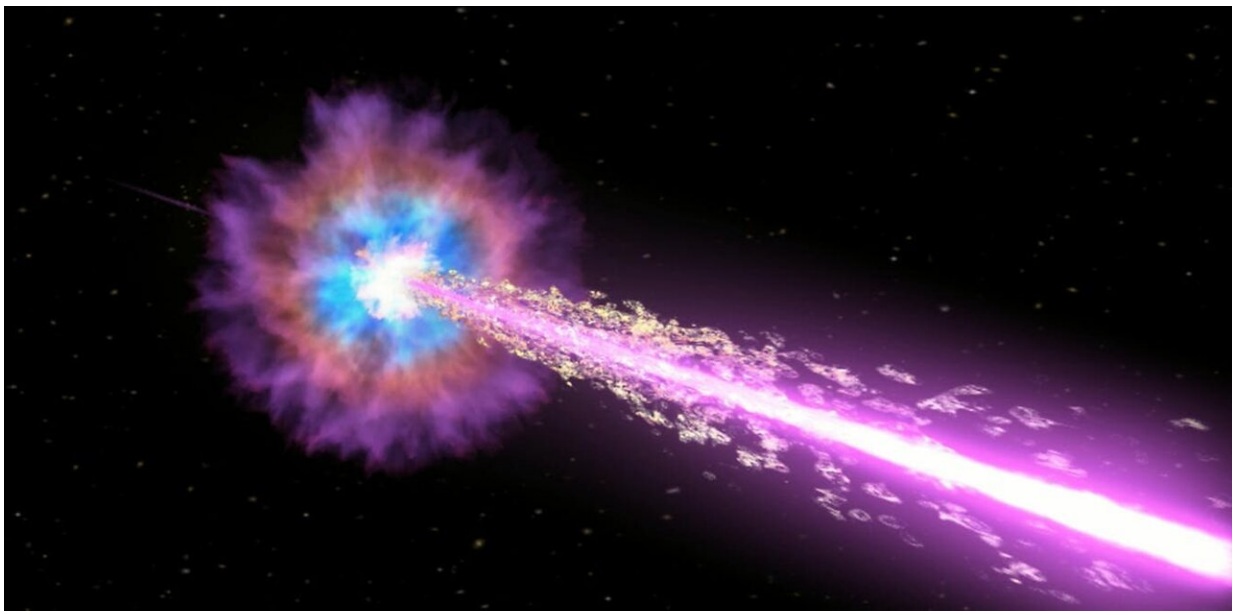
The universe's biggest explosions made elements we are composed of, but there's another mystery source out there

June 1 2024, by Robert Brose



Credit: NASA/Swift/Cruz deWilde

After its "birth" in the Big Bang, the universe consisted mainly of hydrogen and a few helium atoms. These are the lightest elements in the periodic table. More-or-less all elements heavier than helium were produced in the 13.8 billion years between the Big Bang and the present day.

Stars have produced many of these heavier elements through the process of nuclear fusion. However, this only makes elements as heavy as iron. The creation of any heavier elements would consume energy instead of releasing it.

In order to explain the presence of these heavier elements today, it's necessary to find phenomena that can produce them. One type of event that fits the bill is a gamma-ray burst (GRB)—the most powerful class of explosion in the universe. These can erupt at a quintillion (10 followed by 18 zeros) times the luminosity of our sun, and are thought to be caused by several types of events.

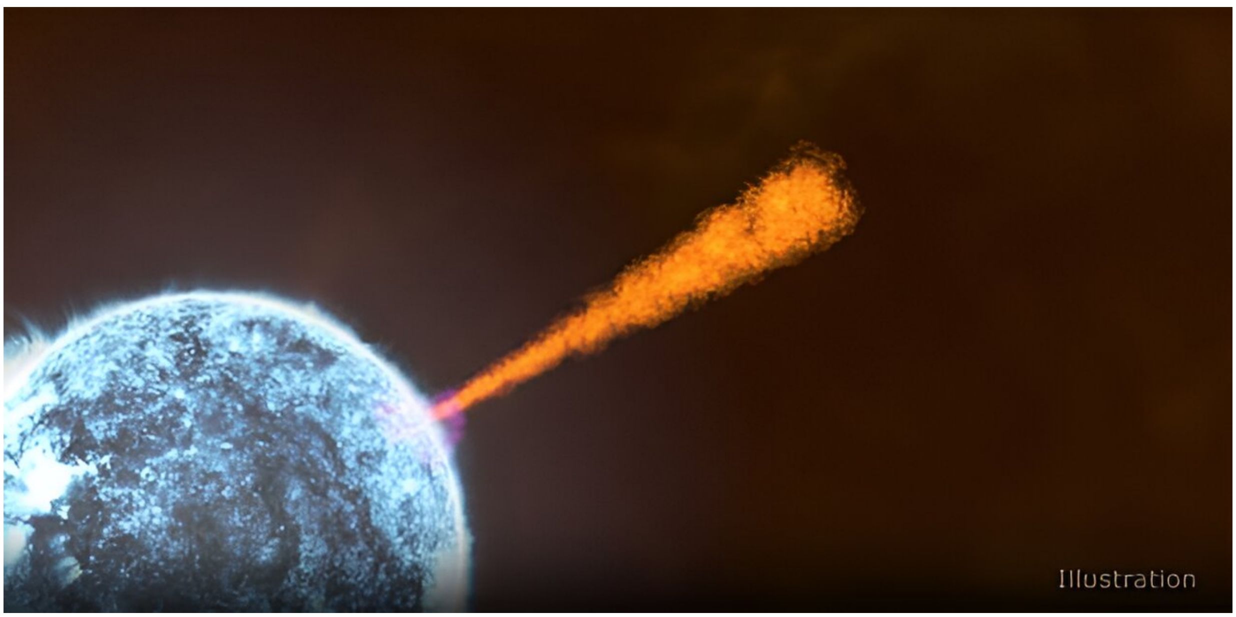
GRBs can be subdivided into two categories: long bursts and short bursts. Long GRBs are associated with the deaths of massive and fast-rotating stars. According to this theory, the fast rotation beams material ejected during the collapse of a massive star into narrow jets that move at extremely fast speeds.

The short bursts last only a few seconds. They are thought to be caused by the collision of two neutron stars—compact and dense "dead" stars. In August 2017, an important event helped support this theory. Ligo and Virgo, two gravitational wave detectors in the US, discovered a signal that seemed to be coming from two neutron stars moving in for a collision.

A few seconds later, a short gamma-ray burst, known as GRB 100817A, was detected coming from the same direction in the sky. For a few weeks, virtually every telescope on the planet was pointing at this event in an unprecedented effort to study its aftermath.

The observations revealed a kilonova at the location of GRB 170817A. A kilonova is a fainter cousin of a supernova explosion. More interestingly, there was evidence that many heavy elements were produced during the explosion. The authors of a study in *Nature* that analyzed the explosion showed that this kilonova seemed to produce two different categories of debris, or ejecta. One was composed primarily of light elements, while another consisted of heavy elements.

We've already mentioned that nuclear fusion can only feasibly produce elements as heavy as iron in the periodic table. But there's another process which could explain how the kilonova was able to produce even heavier ones.



A jet of particles pierces a star as it collapses into a black hole. Credit: NASA Goddard Space Flight Center

Rapid neutron-capture process, or r-process, is where the nuclei (or cores) of heavier elements such as iron capture many neutron particles in a short time. They then rapidly grow in mass, yielding much heavier elements. For r-process to work, however, you need the right conditions:

high density, high temperature, and a large number of available free neutrons. Gamma ray bursts happen to provide these necessary conditions.

However, mergers of two neutron stars, like the one that caused the kilonova GRB 170817A, are very rare events. In fact, they may be so rare as to make them an unlikely source for the abundant heavy elements we have in the universe. But what of long GRBs?

A recent study investigated one long gamma ray burst in particular, GRB 221009. This has been dubbed the BOAT—the brightest of all time. This GRB was picked up as a pulse of intense radiation sweeping through the solar system on October 9 2022.

The BOAT sparked a similar astronomical observation campaign as the kilonova. This GRB was 10 times more energetic than the previous record holder, and so close to us that its influence on the Earth's atmosphere was measurable on the ground and comparable to a major solar storm.

Among the telescopes studying the aftermath of the BOAT was the James Webb Space Telescope (JWST). It observed the GRB about six months after it exploded, so as not to be blinded by the afterglow of the initial burst. The data JWST collected showed that, despite the event's extraordinary brightness, it was caused by a merely average supernova explosion.

In fact, previous observations of other long GRBs indicated that there is no correlation between the brightness of the GRB and the size of the supernova explosion associated with it. The BOAT seems no exception.

The JWST team also inferred the number of heavy elements produced during the BOAT explosion. They found no indication of elements produced by the r-process. This is surprising as, theoretically, the brightness of a long GRB is thought to be associated with the conditions in its core, most likely a black hole. For very bright events –- especially one as extreme as the BOAT –- the conditions should be right for the r-process to occur.

These findings suggest that gamma ray bursts may not be the hoped-for crucial source of the universe's heavy elements. Instead, there must be a source or sources still out there.

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