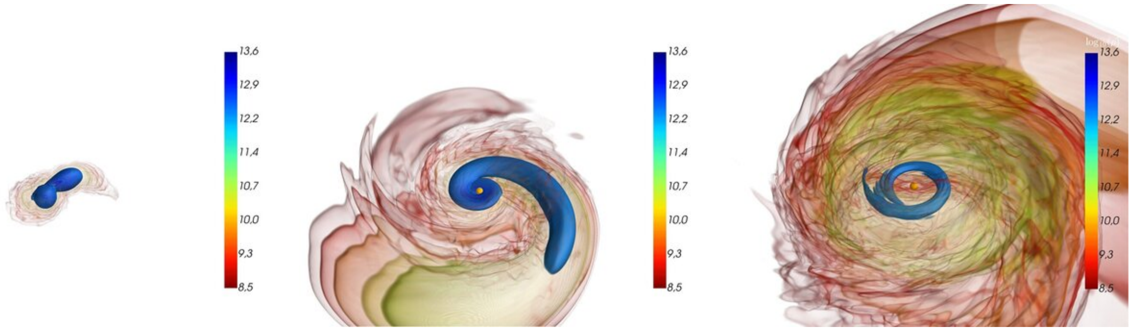
PHYS.ORG

# Unequal neutron-star mergers create unique 'bang' in simulations

August 3 2020, by Gail McCormick



Through a series of simulations, an international team of researchers has determined that some mergers of neutron stars produce radiation that should be detectible from Earth. When neutron stars of unequal mass merge, the smaller star is ripped apart by tidal forces from its massive companion (left). Most of the smaller partner's mass falls onto the massive star, causing it to collapse and to form a black hole (middle). But some of the material is ejected into space; the rest falls back to form a massive accretion disk around the black hole (right). Credit: Adapted from figure 4 in "Accretion-induced prompt black hole formation in asymmetric neutron star mergers, dynamical ejecta and kilonova signals." Bernuzzi et al., Monthly Notices of the Royal Astronomical Society.

When two neutron stars slam together, the result is sometimes a black hole that swallows all but the gravitational evidence of the collision. However, in a series of simulations, an international team of researchers including a Penn State scientist determined that these typically quiet—at least in terms of radiation we can detect on Earth—collisions can sometimes be far noisier.

"When two incredibly dense collapsed neutron stars combine to form a black hole, strong gravitational waves emerge from the impact," said David Radice, assistant professor of physics and of astronomy and astrophysics at Penn State and a member of the research team. "We can now pick up these waves using detectors like LIGO in the United States and Virgo in Italy. A black hole typically swallows any other radiation that could have come out of the merger that we would be able to detect on Earth, but through our simulations, we found that this may not always be the case."

The research team found that when the masses of the two colliding neutron stars are different enough, the larger companion tears the smaller apart. This causes a slower merger that allows an electromagnetic "bang" to escape. Astronomers should be able to detect this electromagnetic signal, and the simulations provide signatures of these noisy collisions that astronomers could look for from Earth.

The research team, which includes members of the international collaboration CoRe (Computational Relativity), describe their findings in a paper appearing online in the *Monthly Notices of the Royal Astronomical Society*.

"Recently, LIGO announced the discovery of a merger event in which the two stars have possibly very different masses," said Radice. "The main consequence in this scenario is that we expect this very characteristic electromagnetic counterpart to the gravititational wave signal."

After reporting the first detection of a neutron-star merger in 2017, in 2019, the LIGO team reported the second, which they named

GW190425. The result of the 2017 collision was about what astronomers expected, with a total mass of about 2.7 times the mass of our sun and each of the two neutron stars about equal in mass. But GW190425 was much heavier, with a combined mass of around 3.5 solar masses and the ratio of the two participants more unequal—possibly as high as 2 to 1.

"While a 2 to 1 difference in mass may not seem like a large difference, only a small range of masses is possible for neutron stars," said Radice.

Neutron stars can exist only in a narrow range of masses between about 1.2 and 3 times the mass of our sun. Lighter stellar remnants don't collapse to form neutron stars and instead form white dwarfs, while heavier objects collapse directly to form black holes. When the difference between the merging stars gets as large as in GW190425, scientists suspected that the merger could be messier—and louder in electromagnetic radiation. Astronomers had detected no such signal from GW190425's location, but coverage of that area of the sky by conventional telescopes that day wasn't good enough to rule it out.

To understand the phenomenon of unequal neutron stars colliding, and to predict signatures of such collisions that astronomers could look for, the research team ran a series of simulations using Pittsburgh Supercomputing Center's Bridges platform and the San Diego Supercomputer Center's Comet platform—both in the National Science Foundation's XSEDE network of supercomputing centers and computers—and other supercomputers.

The researchers found that as the two simulated neutron stars spiraled in toward each other, the gravity of the larger star tore its partner apart. That meant that the smaller neutron star didn't hit its more massive companion all at once. The initial dump of the smaller star's matter turned the larger into a black hole. But the rest of its matter was too far away for the black hole to capture immediately. Instead, the slower rain of matter into the black hole created a flash of electromagnetic radiation.

The research team hopes that the simulated signature they found can help astronomers using a combination of gravitational-wave detectors and conventional telescopes to detect the paired signals that would herald the breakup of a smaller neutron star merging with a larger.

The simulations required an unusual combination of computing speed, massive amounts of memory, and flexibility in moving data between memory and computation. The team used about 500 computing cores, running for weeks at a time, over about 20 separate instances. The many physical quantities that had to be accounted for in each calculation required about 100 times as much memory as a typical astrophysical simulation.

"There is a lot of uncertainty surrounding the properties of neutron stars," said Radice. "In order to understand them, we have to simulate many possible models to see which ones are compatible with astronomical observations. A single simulation of one model would not tell us much; we need to perform a large number of fairly computationally intensive simulations. We need a combination of high capacity and high capability that only machines like Bridges can offer. This work would not have been possible without access to such national supercomputing resources."

**More information:** Sebastiano Bernuzzi et al. Accretion-induced prompt black hole formation in asymmetric neutron star mergers, dynamical ejecta and kilonova signals, *Monthly Notices of the Royal Astronomical Society* (2020). DOI: 10.1093/mnras/staa1860

Provided by Pennsylvania State University

Citation: Unequal neutron-star mergers create unique 'bang' in simulations (2020, August 3) retrieved 11 May 2024 from https://phys.org/news/2020-08-unequal-neutron-star-mergers-unique-simulations.html