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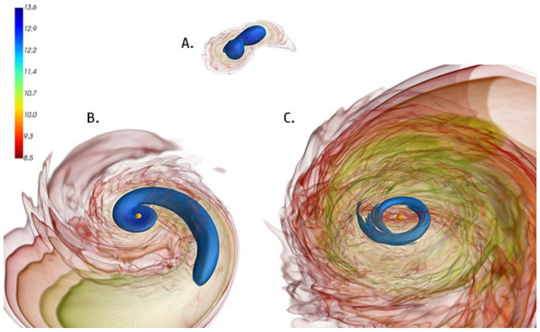
SDSC’s Comet Supercomputer Helps Uncover Noisy Neutron Star Collisions

Simulations reveal a unique ‘bang’ in unequal mergers

It seems strange to talk about “quiet” versus “noisy” collisions when discussing neutron stars, but many such impacts form a black hole that swallows all but the gravitational evidence. A series of simulations using multiple supercomputers, including *Comet* at the San Diego Supercomputer Center (SDSC) at UC San Diego, suggests that when the neutron stars’ masses are different enough, the result is far noisier.

The models predicted an electromagnetic ‘bang,’ which isn’t present when the merging stars’ masses are similar, which may make it easier for astronomers to more easily detect.



A neutron star is ripped apart by tidal forces from its massive companion in an unequal-mass binary neutron star merger (A). Most of the smaller partner’s mass falls onto the massive star, causing it to collapse and to form a black hole (B). But some of the material is ejected into space; the rest falls back to form a massive accretion disk around the black hole (C). Credit: David Radice, Pennsylvania State University

David Radice, a Pennsylvania State University astrophysics assistant professor working as member of the Computational Relativity International Collaboration or CoRe, which includes scientists in the U.S., Germany, Italy, and Brazil, wanted to better understand the phenomenon of unequal neutron stars colliding, and to predict signatures of such collisions that astronomers could look for.

Radice gained access to a number of supercomputers for his research, but the ones most useful to conduct these simulations were *Comet* at SDSC and *Bridges* at the Pittsburgh Supercomputing Center (PSC). Both systems are funded by the National Science Foundation and allocated to researchers via the agency’s Extreme Science and Engineering Discovery Environment (XSEDE) program. The CoRe group recently reported their results in the *Monthly Notices of the Royal Astronomical Society*.

“There is a lot of uncertainty surrounding the properties of neutron stars,” said Radice. “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* and *Comet* can offer. This work would not have been possible without access to such national supercomputing resources.”

Many neutron-star collisions are quiet, at least in terms of radiation that scientists can detect, according to Radice. A strong surge of gravitational waves emerges from the impact – now being sensed by gravity-wave detectors such as the Laser Interferometer Gravitational-Wave Observatory (LIGO), in Hanford, Washington, and Livingston, Louisiana; and Virgo, in Cascina, near Pisa. But precious little else appears. That’s because the incredibly dense collapsed stars combine to form a black hole, which swallows any of the radiation that could have come out of the merger.

But that’s not the only way it can play out. After reporting the first detection of a neutron-star merger in 2017, the LIGO team reported a second detection in 2019, which they named GW190425. The first of these mergers was what astronomers expected, with a total mass of about 2.7 times the mass of our Sun and each of the two neutron stars nearly equal in mass. However, GW190425 was heavier, with a combined mass of around 3.5 Solar masses. More importantly, the ratio of the masses of the two participants was more unequal, possibly as high as two to one.

While that may not seem like such a huge difference, neutron stars can exist only in a narrow range of masses between about 1.2 and three times the mass of our Sun, according to Radice. Lighter stellar remnants don’t collapse to form neutron stars, forming white dwarfs instead. 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.

How Supercomputers Helped

To run his simulations, Radice needed ample levels of computing speed, large memory, and flexibility in moving data between memory and computation as found in today’s larger supercomputers. That’s partly because scientists know so little about these mergers for certain.

Testing their theories required running about 20 simulations, each of which needed 500 compute cores for several weeks.

While *Comet* at UC San Diego was a key component of the research, Radice employed a number of supercomputers for this work, including the XSEDE-allocated *Stampede2* at the Texas Advanced Computing Center and *Blue Waters* at the National Center for Supercomputing Applications, which is an XSEDE Level-2 resource. Their hope is that the simulated signature they found can be used by astronomers using a combination of gravity-wave and conventional telescopes to detect the paired signals that would herald the breakup of a smaller neutron star merging with a larger one.

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