Study predicts distribution of gravitational wave sources

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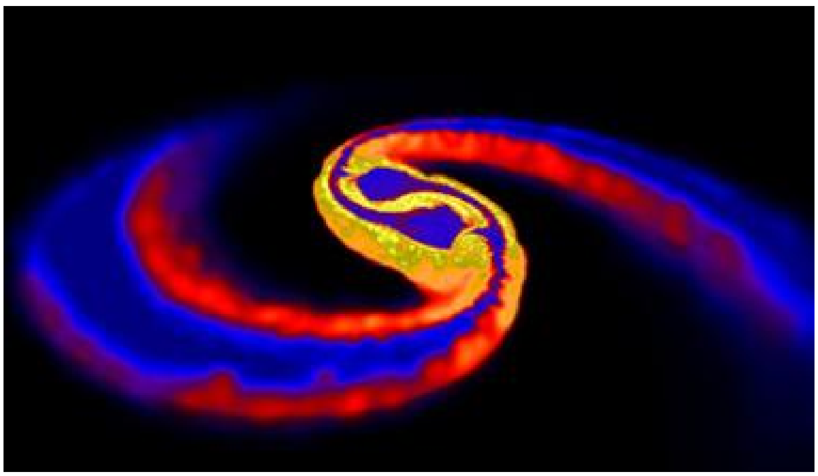

The merger of two neutron stars, shown in this snapshot from a computer simulation, creates gravitational waves that could be detected by sensitive instruments. Credit: Stephan Rosswog and Enrico Ramirez-Ruiz.

(PhysOrg.com) -- A pair of neutron stars spiraling toward each other until they merge in a violent explosion should produce detectable gravitational waves. A new study led by an undergraduate at the University of California, Santa Cruz, predicts for the first time where such mergers are likely to occur in the local galactic neighborhood.

According to Enrico Ramirez-Ruiz, associate professor of astronomy and astrophysics at UC Santa Cruz, the results provide valuable information for researchers at gravitational-wave detectors, such as the

Laser Interferometry Gravitational-Wave Observatory (LIGO) in Louisiana and Washington. "This is a very important result, as it is likely to significantly alter how gravitational-wave observatories currently operate," Ramirez-Ruiz said.

Luke Zoltan Kelley, a UCSC undergraduate working with Ramirez-Ruiz, is first author of a paper describing the new findings, to be published in the December 10 issue of Astrophysical Journal Letters and currently available online.

A key prediction of Einstein's general theory of relativity, gravitational waves are ripples in the fabric of space-time caused by the motions of massive objects. Scientists have yet to detect gravitational waves directly because they are so weak and decay rapidly, but a planned upgrade for LIGO (called Advanced LIGO) is expected to greatly increase its sensitivity. Compact binaries--which can consist of two neutron stars, two black holes, or one of each--are among the best candidates for emitting gravitational waves that could be detected by LIGO or other current experiments.

Kelley investigated the implications of a key observation about compact binaries: The two objects are not only moving in orbit around each other, they are also typically speeding through space together, their center of mass moving with a velocity that can be well above 200 kilometers per second.

"By the time the two objects merge, they are likely to be located far away from the galaxy where they were born," Kelley said.

This has implications for efforts to observe mergers that emit gravitational waves. Scientists hope to match a detection at a gravitational-wave observatory with telescope observations of the corresponding merger event. The new study suggests that astronomers might not want to look in the nearest galaxies for these "optical counterparts" of gravitational waves.

"Our predictions show that the proposed use of galaxy catalogs for follow-up from possible gravity-wave detections will need to account for the possibility of mergers away from the observed galaxies," Ramirez-Ruiz said.

The "kick" that sends compact binaries sailing out of their home galaxies comes from a slight asymmetry in the supernova explosions that give birth to neutron stars and black holes. When a massive star explodes, its core collapses to form either a neutron star (a rapidly rotating ball of densely packed neutrons) or a black hole. According to Kelley, a one-percent asymmetry in the supernova explosion would result in a recoil velocity of about 1,000 kilometers per second (about 2 million miles per hour).

"That is around the maximum velocity observed for lone neutron stars and pulsars," he said. "In binary systems, the net kick velocity to the center of mass is noticeably less, and still fairly uncertain, but is around 200 kilometers per second."

The researchers used a standard cosmological simulation of dark matter and the formation of structure in the universe to study how different kick velocities would affect the distribution of merging compact binaries. The simulation, run on a supercomputer at UCSC, showed the formation of halos of dark matter whose gravitational pull is thought to drive the formation of galaxies. The researchers populated the more massive halos with tracer particles representing compact binary systems. On separate runs, they gave the binaries different velocities.

After running the model for a simulated 13.8 billion years (the current age of the universe), Kelley found a region that looked like our local universe, with a galaxy the size of the Milky Way surrounded by a comparable set of neighboring galaxies. He then generated an image of the sky as it would appear to astronomers in the simulated universe, showing the locations of compact binaries and local galaxies.

The results showed that variations in kick velocity lead to marked differences in the distribution of compact binaries. If the merger of a compact binary occurs away from the bright background of a galaxy, it could be detected by a survey telescope such as the planned Large Synoptic Survey Telescope (LSST). The operators of gravitational-wave observatories would then know when and where to look in their data for a gravitational-wave signal, Ramirez-Ruiz said.

He and colleagues at UCSC, including theoretical astrophysicist Stan Woosley and graduate student Luke Roberts, are currently trying to work out what the optical signal of a compact-binary merger should look like. "Detecting the optical counterparts of gravitational-wave detections will be a lot easier if they are not within galaxies," Ramirez-Ruiz said.

Provided by University of California - Santa Cruz

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