Distant, spiralling stars give clues to the forces that bind sub-atomic particles

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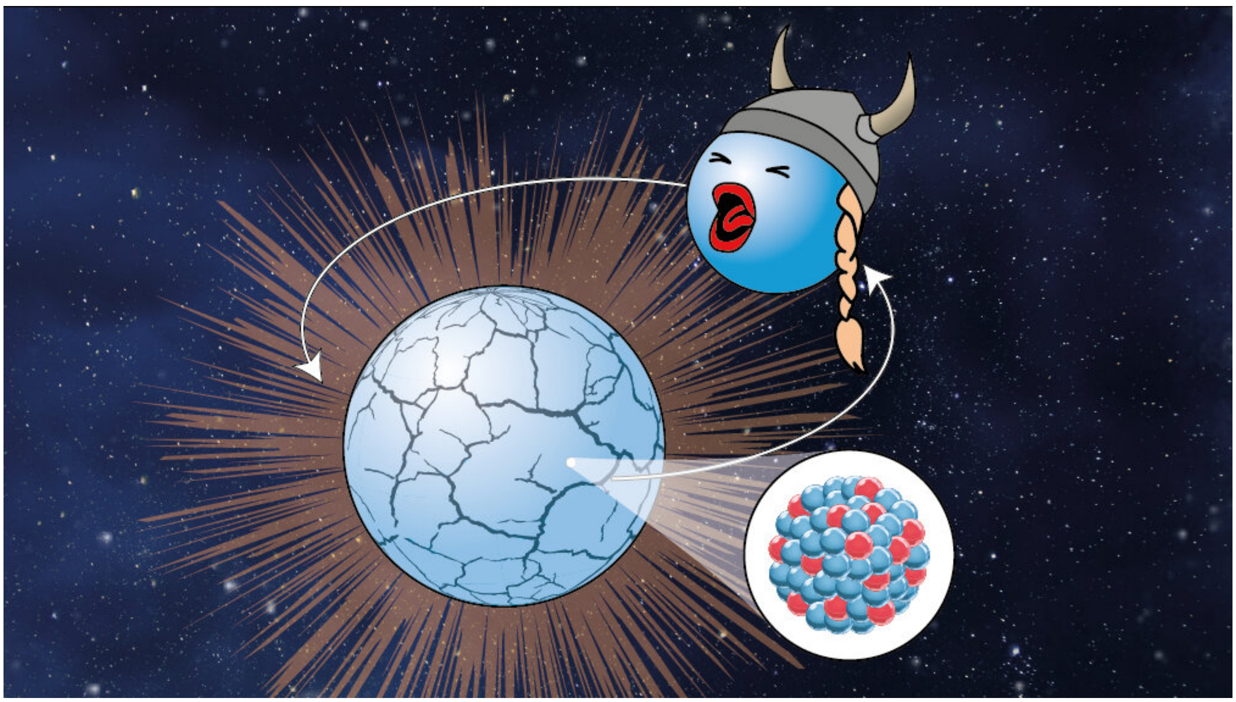

The physics of massive nuclei can be studied by measuring the 'note' at which tidal resonance between merging neutron stars causes the solid crust of the neutron stars to shatter. Credit: University of Bath

Space scientists at the University of Bath in the UK have found a new way to probe the internal structure of neutron stars, giving nuclear physicists a novel tool for studying the structures that make up matter at an atomic level.

Neutron stars are dead stars that have been compressed by gravity to the size of small cities. They contain the most extreme matter in the universe, meaning they are the densest objects in existence (for comparison, if Earth were compressed to the density of a neutron star, it would measure just a few hundred meters in diameter, and all humans would fit in a teaspoon). This makes neutron stars unique natural laboratories for nuclear physicists, whose understanding of the force that binds sub-atomic particles is limited to their work on Earth-bound atomic nuclei. Studying how this force behaves under more extreme conditions offers a way to deepen their knowledge.

Step in astrophysicists, who look to distant galaxies to unravel the mysteries of physics.

In a study described in the *Monthly Notices of the Royal Astronomical Society*, Bath astrophysicists have found that the action of two neutron stars moving ever faster as they spiral towards a violent collision gives a clue to the composition of neutron-star material. From this information, nuclear physicists will be in a stronger position to calculate the forces that determine the structure of all matter.

Resonance

It is through the phenomenon of resonance that the Bath team has made its discovery. Resonance occurs when force is applied to an object at its natural frequency, generating a large, often catastrophic, vibrational motion. A well-known example of resonance is found when an opera singer shatters a glass by singing loudly enough at a frequency that matches the oscillation modes of the glass.

When a pair of in-spiraling neutron stars reach a state of resonance, their solid crust—which is thought to be 10-billion times stronger than steel—shatters. This results in the release of a bright burst of gamma-rays (called a Resonant Shattering Flare) that can be seen by satellites. The in-spiraling stars also release gravitational waves that can be detected by instruments on Earth. The Bath researchers found that by measuring both the flare and the gravitational-wave signal, they can calculate the 'symmetry energy' of the neutron star.

Symmetry energy is one of the properties of nuclear matter. It controls the ratio of the sub-atomic particles (protons and neutrons) that make up a nucleus, and how this ratio changes when subjected to the extreme densities found in neutron stars. A reading for symmetry energy would therefore give a strong indication of the makeup of neutron stars, and by extension, the processes by which all protons and neutrons couple, and the forces that determine the structure of all matter.

The researchers stress that measurements obtained by studying the resonance of neutron stars using a combination of gamma-rays and gravitational-waves would be complementary to, rather than a replacement for, the lab experiments of nuclear physicists.

"By studying neutron stars, and the cataclysmic final motions of these massive objects, we're able to understand something about the tiny, tiny nuclei that make up extremely dense matter," said Bath astrophysicist Dr. David Tsang. "The enormous difference in scale makes this fascinating."

Astrophysics Ph.D. student Duncan Neill, who led the research, added: "I like that this work looks at the same thing being studied by nuclear physicists. They look at tiny particles and we astrophysicists look at objects and events from many millions of light years away. We are looking at the same thing in a completely different way."

Dr. Will Newton, astrophysicist at the Texas A&M University-Commerce and project collaborator, said: "Though the force that binds quarks into neutrons and protons is known, how it actually works when large numbers of neutrons and protons come together is not well understood. The quest to improve this understanding is helped by experimental nuclear physics data, but all the nuclei we probe on Earth have similar numbers of neutrons and protons bound together at roughly the same density.

"In neutron stars, nature provides us with a vastly different environment to explore nuclear physics: matter made mostly of neutrons and spanning a wide range of densities, up to about ten times the density of atomic nuclei. In this paper, we show how we can measure a certain property of this matter—the symmetry energy—from distances of hundreds of millions of light years away. This can shed light on the fundamental workings of nuclei."

More information: Duncan Neill et al, Resonant Shattering Flares as Multimessenger Probes of the Nuclear Symmetry Energy, *Monthly Notices of the Royal Astronomical Society* (2021). DOI: 10.1093/mnras/stab764

Provided by University of Bath