Department of Physics & Astronomy
COLLEGE OF ARTS & SCIENCES

Rethinking the Speed of Sound

February 12, 2015

The speed of sound might just be faster than originally thought, and Assistant Professor Andrew Steiner has revisited this boundary in “Sound velocity bound and neutron stars,” published in *Physical Review Letters*. Paulo Bedaque from the University of Maryland is co-author on the paper, which was selected by PRL as an Editor’s Suggestion: one of a few publications recommended each week both for the interesting scientific results presented and successful communication across fields.

The paper describes how Steiner and Bedaque used the speed of sound to investigate the mysteries of matter at high density: one of the outstanding problems in nuclear and astrophysics. As Steiner explained, “the basic motivation [for looking at high-density matter] is that examining extreme forms of matter often gives us insight into what's going on inside matter on earth. This is generally true: physicists are always looking at the hottest, coldest, densest, spinningest, lightest, heaviest, slowest, fastest, stickiest, or slipperiest things in order to try to figure out how stuff works.”

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Neutron stars serve as a good test case for these kinds of studies because they comprise the most dense observable matter in the universe. They’re sort of the winter of a star’s life—the final stage of its evolution. While accurate measurements have shown some to have 1.4 times the sun’s mass, in recent years two neutron stars have been discovered to have a mass twice that of the sun. The speed of sound is a useful measure, Steiner said, because it’s a more basic quantity of matter.

“We're relatively ignorant about how high-density matter works, so sound speed is one of the first places to start,” he explained.

Physicists have known about the speed of sound for centuries. In the 1660s English scientist Robert Boyle proved that sound waves need to travel through a medium in order to transmit sound. Sir Isaac Newton showed that the *characteristics* of the medium (density, temperature, whether it’s a liquid or solid) determine how fast sound travels. The speed of sound tends to increase with the density or the temperature of the medium it’s travelling through. In water at 20°C, for example, the speed of sound is 1,482 meters per second; it moves through steel at 5,960 meters per second.

As Steiner and Bedaque explain in *PRL*, the speed of sound is typically limited to the speed of light divided by the square root of three. At high enough densities or temperatures, it always approaches this limit due to quantum chromodynamics (QCD)—the theory that describes how neutrons and protons interact. Their work, however, found this limit very likely does not hold.

They used Monte Carlo simulation (random, computer-generated numbers) of solutions of a particular form of Einstein's field equations. “These equations are the most basic expression of the theory of general relativity,” Steiner said. “We collected solutions of them for tens of thousands of models.”

What they found is that the speed of sound in neutron stars at some point must exceed the typical limit because existing models can’t produce neutron stars with masses twice the mass of the sun. The findings are significant because they tell scientists more about how neutrons and protons interact, both in neutron stars and on earth. They also provide insight on quantum chromodynamics at high densities and help explain some of the more extreme astrophysics processes like the explosion of supernovae and neutron star merges.

Steiner joined the faculty January 1 as an assistant professor. His specialty is theoretical nuclear astrophysics, and he holds a joint faculty appointment with the physics division at Oak Ridge National Laboratory. He was previously a research assistant professor at the University of Washington Institute for Nuclear Theory.

More Information

- **Andrew Steiner (http://web.utk.edu/~asteine1/)**
- **"Sound velocity bound and neutron stars," in *Physical Review Letters* (http://dx.doi.org/10.1103/PhysRevLett.114.031103)**