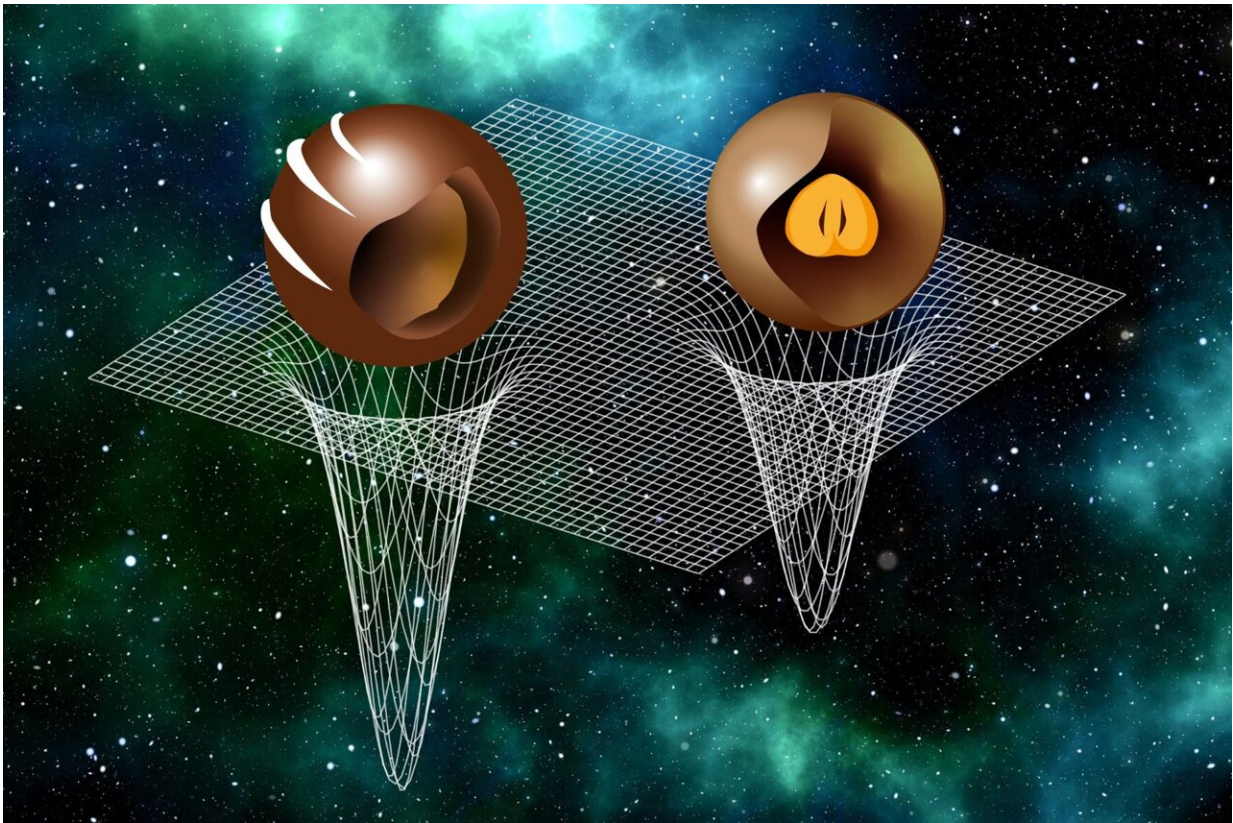


# Cosmic chocolate pralines? General neutron star structure revealed

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The study of the sound speed has revealed that heavy neutron stars have a stiff mantle and a soft core, while light neutron stars have a soft mantle and a stiff core—much like different chocolate pralines. Credit: Peter Kiefer & Luciano Rezzolla

So far, little is known about the interior of neutron stars, those extremely

compact objects that can form after the death of a star. The mass of our sun or even more is compressed into a sphere with the diameter of a large city. Since their discovery more than 60 years ago, scientists have been trying to decipher their structure.

The greatest challenge is to simulate the [extreme conditions](#) inside neutron stars, as they can hardly be recreated on Earth in the laboratory. There are therefore many models in which various properties—from density and temperature—are described with the help of so-called equations of state. These equations attempt to describe the structure of neutron stars from the stellar surface to the [inner core](#).

Now, physicists at Goethe University Frankfurt have succeeded in adding further crucial pieces to the puzzle. The working group, led by Prof. Luciano Rezzolla at the Institute of Theoretical Physics, has developed more than a million different equations of state that satisfy the constraints set by data obtained from theoretical nuclear physics on the one hand, and by [astronomical observations](#) on the other. Their work is published in *The Astrophysical Journal Letters*.

When evaluating the equations of state, the working group made a surprising discovery: "Light" neutron stars (with masses smaller than about 1.7 [solar masses](#)) seem to have a soft mantle and a stiff core, whereas "heavy" neutron stars (with masses larger than 1.7 solar masses) instead have a stiff mantle and a soft core.

"This result is very interesting because it gives us a direct measure of how compressible the center of neutron stars can be," says Prof. Luciano Rezzolla, "Neutron stars apparently behave a bit like chocolate pralines: Light stars resemble those chocolates that have a hazelnut in their center surrounded by soft chocolate, whereas heavy stars can be considered more like those chocolates where a hard layer contains a soft filling."

Crucial to this insight was the [speed of sound](#), a study focus of Bachelor's student Sinan Altiparmak. This quantity measure describes how fast sound waves propagate within an object and depends on how stiff or soft matter is. Here on Earth, the speed of sound is used to explore the interior of the planet and discover oil deposits.

By modeling the equations of state, the physicists were also able to uncover other previously unexplained properties of [neutron](#) stars. For example, regardless of their mass, they very probably have a radius of only 12 km. Thus, they are just as large in diameter as Goethe University's hometown of Frankfurt.

Study author Dr. Christian Ecker explains, "Our extensive numerical study not only allows us to make predictions for the radii and maximum masses of [neutron stars](#), but also to set new limits on their deformability in binary systems, that is, how strongly they distort each other through their gravitational fields. These insights will become particularly important to pinpoint the unknown [equation](#) of state with future astronomical observations and detections of gravitational waves from merging stars."

**More information:** On the Sound Speed in Neutron Stars, *The Astrophysical Journal Letters* (2022). [DOI: 10.3847/2041-8213/ac9b2a](https://doi.org/10.3847/2041-8213/ac9b2a)

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