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Potential new NASA mission would reveal the hearts of undead stars

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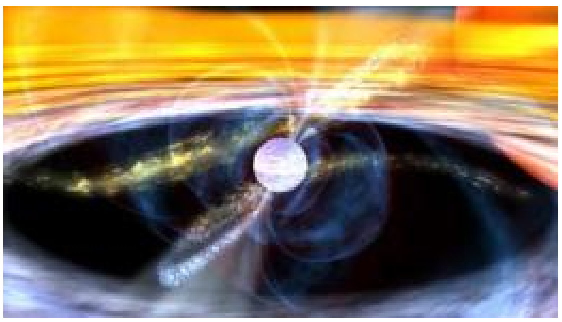


This is an artist's concept of a pulsar (blue-white disk in center) pulling in matter from a nearby star (red disk at upper right). The stellar material forms a disk around the pulsar (multicolored ring) before falling on to the surface at the magnetic poles. The pulsar's intense magnetic field is represented by faint blue outlines surrounding the pulsar. Credit: nasa

Neutron stars have been called the zombies of the cosmos, shining on even though they're technically dead, and occasionally feeding on a neighboring star if it gets too close.

They are born when a massive star runs out of fuel and collapses under its own gravity, crushing the matter in its core and blasting away its outer layers in a supernova explosion that can outshine a billion suns.

The core, compressed by gravity to inconceivable density – one teaspoon would weigh about a billion tons on Earth – lives on as a neutron star.

Although the nuclear fusion fires that sustained its parent star are extinguished, it still shines with heat left over from its explosive formation, and from radiation generated by its magnetic field, which became intensely concentrated as the core collapsed, and can be over a trillion times stronger than Earth's.

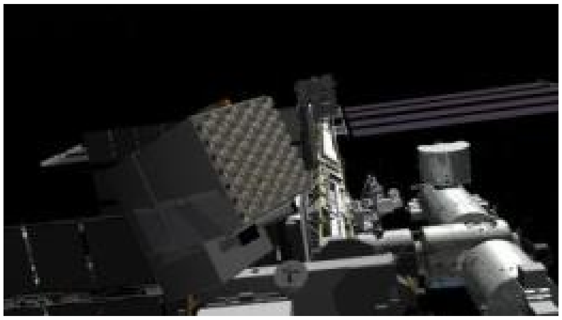
Although its parent star could easily have been more than a million miles across, a neutron star is only about the size of a city. However, its intense gravity makes it the ultimate trash compactor, capable of packing in an astonishing amount of matter, more than 1.4 times the content of the Sun, or at least 460,000 Earths.

"A neutron star is right at the threshold of matter as it can exist – if it gets any denser, it becomes a black hole," says Dr. Zaven Arzoumanian of NASA's Goddard Space Flight Center in Greenbelt, Md.

Arzoumanian is Deputy Principal Investigator on a proposed mission called the Neutron Star Interior Composition Explorer (NICER) that would unveil the dark heart of a neutron star. "We have no way of creating neutron star interiors on Earth, so what happens to matter under such incredible pressure is a mystery – there are many theories about how it behaves. The closest we come to simulating these conditions is in particle accelerators that smash atoms together at almost the speed of light. However, these collisions are not an exact substitute – they only last a split second, and they generate temperatures that are much higher than what's inside neutron stars."

If NASA approves it for construction, the mission will be launched by the summer of 2016 and attached robotically to the International Space Station. In September 2011, NASA selected NICER for study as a potential Explorer Mission of Opportunity. The mission will receive $250,000 to conduct an 11-month implementation concept study. Five Mission of Opportunity proposals were selected from 20 submissions.

Following the detailed studies, NASA plans to select for development one or more of the five Mission of Opportunity proposals in February 2013.



This is an artist's concept of the NICER instrument on board the International Space Station. NICER is the cube in the foreground on the left. The circular objects protruding from the cube are telescopes that focus X-rays from the pulsar on to the detector. Credit: NASA

NICER's array of 56 telescopes will collect X-rays generated both from hotspots on a neutron star's surface and from its powerful magnetic field. There are two hotspots on a neutron star at opposite sides, one at each magnetic pole, the place where the star's intense magnetic field emerges from the surface. Here, particles trapped in the magnetic field rain down and generate X-rays when they strike the surface. X-rays are an energetic form of light invisible to human eyes but detectable by special instruments. As the hotspots rotate into our line of sight, they produce a pulse of light, like a lighthouse beam, giving rise to the stars' alternate name, pulsars.

Many pulsars flash several times per second, because of the rapid rotation they inherit as they are born. All stars rotate, and as the parent star's core shrinks, it spins faster, like a twirling ice skater pulling in her arms. A neutron star's powerful gravity can also pull in gas from a neighboring star if it orbits too closely. This infalling gas can spin up a neutron star to even higher speeds; some rotate hundreds of times per second.

The key to understanding how matter behaves inside a neutron star is pinning down the correct Equation Of State (EOS) that most accurately describes how matter responds to increasing pressure. Currently, there are many suggested EOSs, each proposing that matter can be compressed by different amounts inside neutron stars. Suppose you held two balls of the same size, but one was made of foam and the other was made of wood. You could squeeze the foam ball down to a smaller size than the wooden one. In the same way, an EOS that says matter is highly compressible will predict a smaller neutron star for a given mass than an EOS that says matter is less compressible.

So if researchers know a neutron star's mass, all they need to do is find out how big it is to get the correct EOS and unlock the secret of what matter does under extreme gravity. "The problem is that neutron stars are small, and much too far away to allow their sizes to be measured directly," says NICER Principal Investigator Dr. Keith Gendreau of NASA Goddard. "However, NICER will be the first mission that has enough sensitivity and time-resolution to figure out a neutron star's size indirectly. The key is to precisely measure how much the brightness of the X-rays changes as the neutron star rotates."

This change in brightness with time is called a star's light curve, and it appears as a wavy line on a graph.

Because neutron stars pack so much mass into such a tiny volume, they generate strong gravity that actually bends space (and distorts time) in accordance with Einstein's theory of General Relativity. This warping of space enables researchers to determine a neutron star's mass if it has a nearby companion, either another neutron star or a white dwarf, a lower-density object that is the core remnant of a less-massive star. Neutron stars with these companions are actually fairly common.

The warping of space produces effects like an orbital shift called precession, which makes the orbit move like a hula-hoop around a dancer. Also, as the neutron star and its companion move around each other, they create ripples in space called gravitational waves. These waves carry away orbital energy, so the neutron star and its companion gradually move closer together and their orbit shrinks. NICER will measure these effects over time, and the greater these effects, the more mass the neutron star has.

Warped space also will let the NICER team figure out a neutron star's size. Suppose we have a neutron star lined up so that you can only see one hotspot, the one on the near side that faces us. As it rotates into view, the brightness increases until the hotspot is pointed directly at us, then the brightness decreases as it rotates away.

This alignment makes the star's brightness highly variable – it's quite bright when the hotspot is pointed at us, and very dim when the hotspot is on the far side out of our view. The drastic change in brightness produces a light curve with large waves, with deep troughs when the star is dim.

However, since light must follow the contours of space, warped space bends light. The distorted space around the neutron star bends its light so much that you can see parts of the far side, including the other hotspot. With the second hotspot visible, at least part of the time, you have bright light more often, so the brightness doesn't change as much. This makes a light curve that appears smoother, with smaller waves.

If a woman wearing stiletto heels walks on a trampoline, she will warp the surface more than if she wears snowshoes. In the same way, the more compact a neutron star is, the more it will bend space and light. This will allow us to see the far-side hotspot more often, which will make its X-ray brightness less variable, and the star will produce a smoother light curve.

The team has models that produce unique light curves for the various sizes predicted by different EOSs. By choosing the light curve that best matches the observed one, they will get the correct EOS and solve the riddle of matter on the edge of oblivion.

Provided by NASA's Goddard Space Flight Center

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