Cosmic glitch: Super-dense star is first ever found suddenly slowing its spin

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The magnetar 1E 2259+586 shines a brilliant blue-white in this false-color X-ray image of the CTB 109 supernova remnant, which lies about 10,000 light-years away toward the constellation Cassiopeia. CTB 109 is only one of three supernova remnants in our galaxy known to harbor a magnetar. X-rays at low, medium and high energies are respectively shown in red, green, and blue in this image created from observations acquired by the European Space Agency's XMM-Newton satellite in 2002. Credit: ESA/XMM-Newton/M. Sasaki et al.

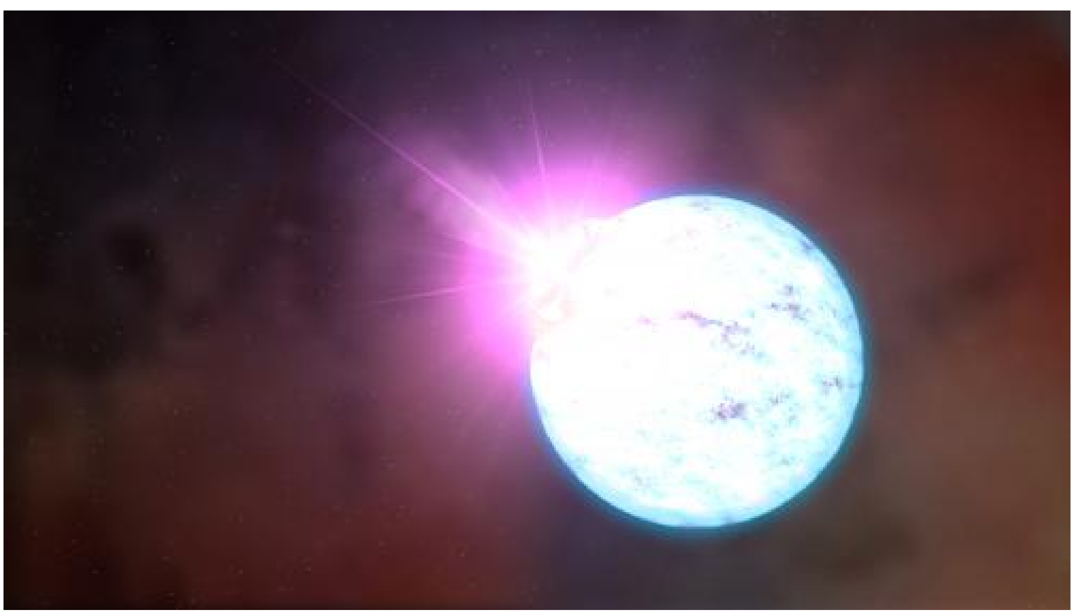
One of the densest objects in the universe, a neutron star about 10,000 light years from Earth, has been discovered suddenly putting the brakes on its spinning speed. The event is a mystery that holds important clues for understanding how matter reacts when it is squeezed more tightly than the density of an atomic nucleus—a state that no laboratory on Earth has achieved. The discovery by an international team of scientists will be published in the journal *Nature* on May 30, 2013.

The scientists detected the neutron star's abrupt slow-down with NASA's Swift observatory, a satellite with three telescopes whose science and flight operations are controlled by Penn State from the Mission Operations Center on the University Park campus. "Because Swift has the ability to regularly measure the spin of this unusual star, we have been able to observe its surprising evolution," said Penn State astronomer Jamie Kennea, a coauthor of the *Nature* paper. "This neutron star is doing something completely unexpected. Its speed of rotation has been dropping at an increasingly rapid rate ever since the initial sudden decrease in its spin."

Although astronomers have observed neutron stars suddenly speeding up their spins—an event called a "glitch"—they never before had observed a neutron star suddenly slowing down. "We've dubbed this event an 'anti-glitch' because it affected this star in exactly the opposite manner of every other clearly identified glitch seen in neutron stars," said co-author Neil Gehrels, the lead researcher on the Swift mission, at NASA's Goddard Space Flight Center. The star is in the Northern Hemisphere sky in the constellation Cassiopeia.

A neutron star is the closest thing to a black hole that astronomers can observe directly. It is the crushed core of a massive star that ran out of fuel, collapsed under its own weight, and then exploded as a supernova. The matter left behind after the explosion is compressed into a ball only about 12 miles across but with a mass roughly half a million times more than the mass of the Earth. One teaspoon of a neutron star weighs 1 billion tons, roughly twice the combined weight of all the cars in the United States.

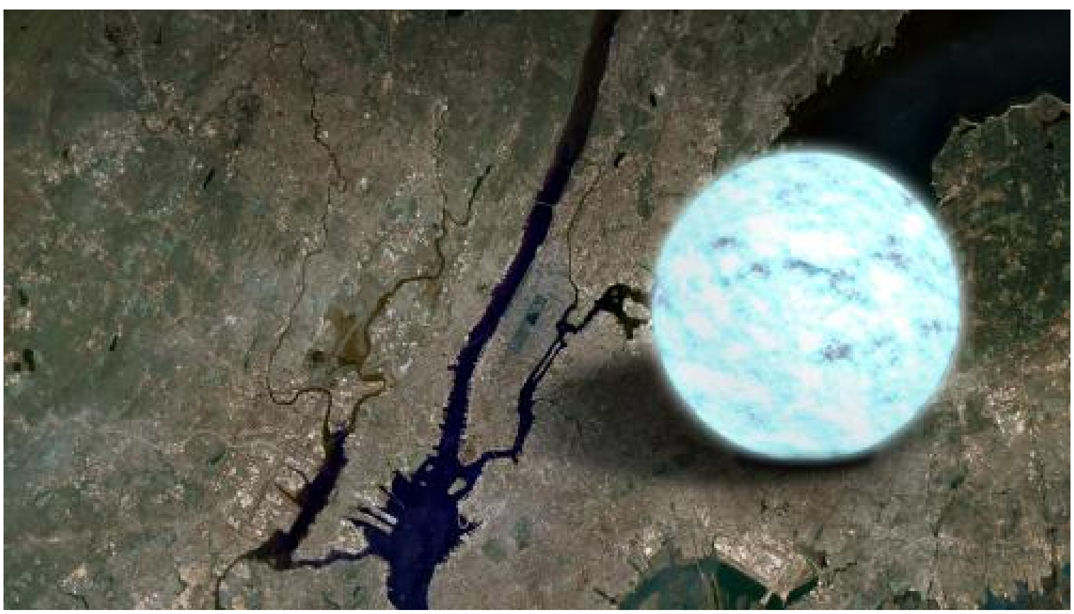
Neutron stars can reach speeds of rotation as fast as the blades of a kitchen blender—up to 43,000 revolutions per minute (rpm), and can have magnetic fields a trillion times stronger than the Earth's. But this abruptly slowing neutron star, named 1E2259+586, is an even more bizarre and rare kind of neutron star. It is one of fewer than two dozen neutron stars called "magnetars" because they have such ultra-strong magnetic fields—up to approximately 5,000 trillion times that of the Earth. Magnetars also can have dramatic outbursts of X-rays so strong that they can affect Earth's atmosphere, even if the magnetar is sending its blasts from the opposite side of our Milky Way galaxy. "Magnetars are the universe's strongest magnets and are some of the best laboratories we have for understanding pure physics," Kennea said. "The extreme conditions on these stars could never be replicated in any laboratory here on Earth."



This is an artist's rendering of an outburst on an ultra-magnetic neutron star, also called a magnetar. Credit: NASA's Goddard Space Flight Center

Using the Swift observatory's X-ray Telescope, the scientists observed regular X-ray pulses from magnetar 1E 2259+586 from July 2011 to mid-April 2012. During this time, the magnetar was spinning once every 7 seconds, or about 8 rpm, and it appeared to be slowing down at a gradual and stable rate. But at the next scheduled observation on 28 April 2012, the data captured by Swift showed the star's spin had abruptly slowed by 2.2 millionths of a second—the surprisingly sudden change that now is called an anti-glitch.

On 21 April, just a week before the Swift observation that discovered this anti-glitch, the magnetar produced a brief but intense X-ray burst detected by the Gamma-ray Burst Monitor aboard NASA's Fermi Gamma-ray Space Telescope. The scientists now think this 36-millisecond eruption of high-energy light likely marked the changes that drove the magnetar into the abrupt "anti-glitch" slowdown mode. In addition, continuing observations have revealed that the magnetar's spin is continuing to slow down at a much faster rate.



A neutron star is the densest object astronomers can observe directly, crushing half a million times Earth's mass into a sphere about 12 miles across, or similar in size to Manhattan Island, as shown in this illustration. Credit: NASA's Goddard Space Flight Center

These discoveries confront astronomers with a new theoretical challenge. What exactly could cause the magnetar's X-ray outburst, then the abrupt slowdown of its rotation, and now the even faster deceleration of the star's rotation that the Swift observatory is continuing to detect?

Theories of the internal structure of a neutron star, which were current before the anti-glitch discovery, envision a crust of electrons and charged particles above an interior containing, among other oddities, a bizarre, friction-free state of matter called a neutron superfluid. According to these theories, because the surface of a neutron star accelerates streams of high-energy particles through its intense magnetic field, the star's crust should always be losing energy and slowing down—but the fluid in the interior of the neutron star should resist being slowed. The crust could fracture under this strain, producing an X-ray outburst while also receiving a kick from the faster-spinning interior that would speed the star's rotation. So now, after the discovery of the anti-glitch, scientists need improved theories to explain the unexpected and continuing slowing-down of the rotation of magnetar 1E 2259+586.

In addition to the new anti-glitch mystery, this discovery is expected to catalyze renewed efforts to solve long-standing mysteries about the puzzling physics that rules super-dense states of matter in neutron stars and black holes—the most mysterious objects in the universe.

In addition to Kennea at Penn State and Gehrels at NASA Goddard, other coauthors of the Nature paper include astronomers at McGill

University in Montreal in Canada, the University of Hong Kong, and the University of Leicester in the United Kingdom. The Swift observatory, launched into Earth orbit in November 2004, is managed by Goddard Space Flight Center and operated in collaboration with Penn State University, the Los Alamos National Laboratory, and Orbital Sciences Corporation, with international collaborators in the United Kingdom and Italy and including contributions from Germany and Japan.

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