Hotter than expected neutron star surfaces help explain superburst frequency

April 13 2007

Neutron star accreting matter from a red giant star. The red giant (on the upper right) is expanding and dumping material onto the neutron star. This material forms a disk and then finally falls to the neutron star surface. Credit: Tony Piro, U.C. Berkeley

A new theoretical thermometer built from heavy-duty mathematics and computer code suggests that the surfaces of certain neutron stars run significantly hotter than previously expected. Hot enough, in fact, to at least partially answer an open question in astrophysics -- how to explain the observed frequency of ultra-violent explosions known as superbursts that sometimes ignite on such stars' surfaces?

"This is the first model that goes into some reasonable detail about the nuclear physics that occur in the crusts of accreting neutron stars," said Hendrik Schatz, NSCL professor and co-author of a paper that will be published in *The Astrophysical Journal* in June. One of Schatz's co-authors, NSCL assistant professor Ed Brown, will present the results April 17 at a meeting of the American Physical Society in Jacksonville, Fla.

Superbursts emanate from binary systems in which a neutron star orbits a companion star. When the two stars get close enough together, a steady rain of material is sucked away from the companion star onto the surface of the neutron star.

Because a neutron star is so dense -- on Earth, one teaspoonful would weigh a billion tons -- the companion star material that reaches the neutron star surface is strongly compressed and heated. Eventually nuclear reactions trigger an explosion that burns through the surface layer of accumulated material, resulting in a burst of X-rays clearly detectable by ground- and space-based instruments.

X-ray bursts repeat every few hours to days, along the way fusing hydrogen and helium into a mixture of elements that is itself potentially reactive. In contrast, superbursts occur when, after many months, the accumulated "ashes" produced in the X-ray bursts ignite in a different, even more dramatic nuclear explosion.

The result is an outpouring of X-rays some 1,000 times as energetic as a standard X-ray burst. One superburst, which lasts only on the order of a few hours, releases as much energy as the sun will radiate in a decade.

Though hardly subtle astrophysical phenomena, superbursts remain shrouded in some mystery, largely because only twelve of the extreme events have ever been observed. This mystery is what attracted the attention of researchers participating in the Joint Institute for Nuclear Astrophysics, or JINA, project.

Working with colleagues at Los Alamos National Laboratory and the University of Mainz in Germany, JINA-affiliated NSCL scientists set out to build the most accurate model to-date of the crusts of accreting neutron stars. The team calculated that reactions in the stars' crusts release 10 times more heat than indicated by earlier models.

At least in part, this newly discovered heat helps to reconcile the work of theorists and experimentalists who study neutron stars. Prior to Schatz and Brown's research, theoretical astrophysicists predicted that superbursts should occur every ten years or so. Now, according the new calculation, theorists can explain why the gigantic explosions should occur every three or four years.

But more work remains to be done. According to observational data, superbursts occur roughly annually -- and scientists still aren't altogether sure why.

"So this doesn't quite solve the problem," Brown said. "It's still an open question as to how nature ignites superbursts."

Preprint of forthcoming *Astrophysical Journal* paper, "Heating in the Accreted Neutron Star Ocean: Implications for Superburst Ignition": arxiv.org/abs/astro-ph/0609828

Source: Michigan State University