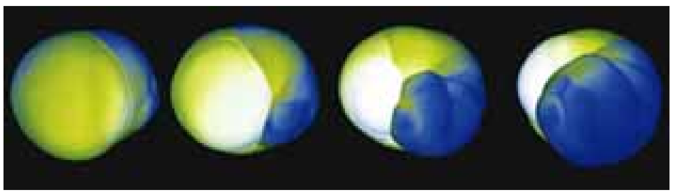
ORNL team discovers new way to spin up pulsars

January 5 2007



This visualization shows the progression of spiral formation in a supernova, which eventually results in a pulsar's spin. The darkest portion of the accretion shock denotes the front edge of the wave as it rotates around the supernova's center. Three-dimensional computer models are the only models that show this effect. This 3D model of pulsar formation was performed at DOE's Leadership Computing Facility at Oak Ridge National Laboratory.

A team of scientists using Oak Ridge National Laboratory supercomputers has discovered the first plausible explanation for a pulsar's spin that fits the observations made by astronomers. Anthony Mezzacappa of the Department of Energy lab's Physics Division and John Blondin of North Carolina State University explain their results in the Jan. 4 issue of the journal *Nature*.

According to three-dimensional simulations they performed at the Leadership Computing Facility, located at ORNL, the spin of a pulsar is determined not by the spin of the original star, but by the shock wave created when the star's massive iron core collapses.

That shock wave is inherently unstable, a discovery the team made in 2002, and eventually becomes cigar-shaped instead of spherical. The instability creates two rotating flows—one in one direction directly below the shock wave and another, inner flow, that travels in the opposite direction and spins up the core.

"The stuff that's falling in toward the center, if it hits this shock wave that is not a sphere any more but a cigar-shaped surface, will be deflected," Mezzacappa said. "When you do this in 3-D, you find that you wind up with not only one flow, but two counterrotating flows."

The asymmetrical flows establish a "sloshing" motion that, in the complex 3-D models, accounts for the pulsars observed spin velocities from once every 15 to 300 milliseconds, which is much slower than previous models predicted.

Previously, astronomers did not have a workable explanation for how the pulsar gets its spin. The assumption to this point has been that the spin of the leftover collapsed core comes from the spin of the original star. Being much smaller, the pulsar would then spin much faster than the original star, just as a figure skater spins faster by pulling his or her arms in.

The problem with that approach is that it would explain only the fastest observed pulsars. The ORNL-NCSU team, on the other hand, predicts spin periods that are in the observed range between 15 and 300 milliseconds.

The work was funded under the DOE Office of Science's Scientific Discovery through Advanced Computing, or SciDAC, program.

"Our discovery came at a critical time," Mezzacappa noted. "It came at a time when there was no description in the literature of how neutron stars are spun up and, therefore, how pulsars are born, that are consistent with observation. It was a crisis, if you will. Now our simulations come along and provide a way around that conundrum."

The discovery is an outgrowth of the team's use of three-dimensional simulations and the advances in high-performance computing that made the simulations possible. The simulations performed for the Nature paper used the Cray X1E system at ORNL, known as Phoenix. That system boasts a peak performance of more than 18 teraflops and is currently the fastest vector computer in the United States. Later simulations done by the team made use of the center's Jaguar system, a Cray XT3 with a peak performance of more than 50 teraflops.

The team used the VH1 code, developed by Blondin when he was a postdoctoral research associate at the University of Virginia, and moving the simulation data was problematic. Mezzacappa noted that researchers are able now to perform visualizations remotely, without having to move the data off site, but at the time of their early three-dimensional simulations this capability was not in place.

He stressed also that the team is looking forward to further advances in high-performance computing that will be coming to ORNL. For example, the team's simulations have not incorporated the influence of nearly massless, radiation-like particles known as neutrinos and the star's magnetic field.

The real prize, though, for his and other teams is a complete explanation of how the collapse of a star's core leads to the explosion that ejects most of its layers. So far, that explanation has proved elusive.

"In a nutshell, this rapid advance in supercomputing technology will give us the tools to solve this problem and to make these important predictions and to understand these events and their role in our universe.

This is a very, very exciting and very satisfying thing," Mezzacappa said.

Source: Oak Ridge National Laboratory