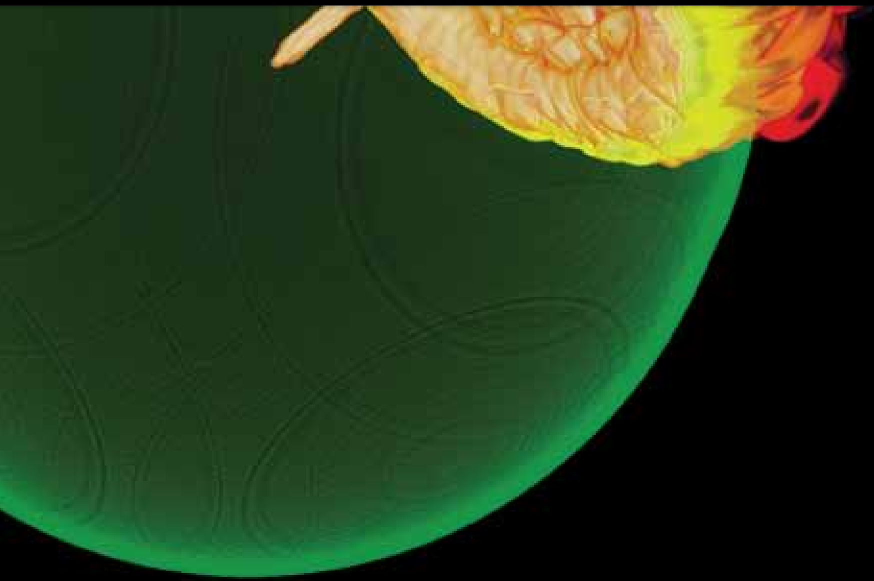
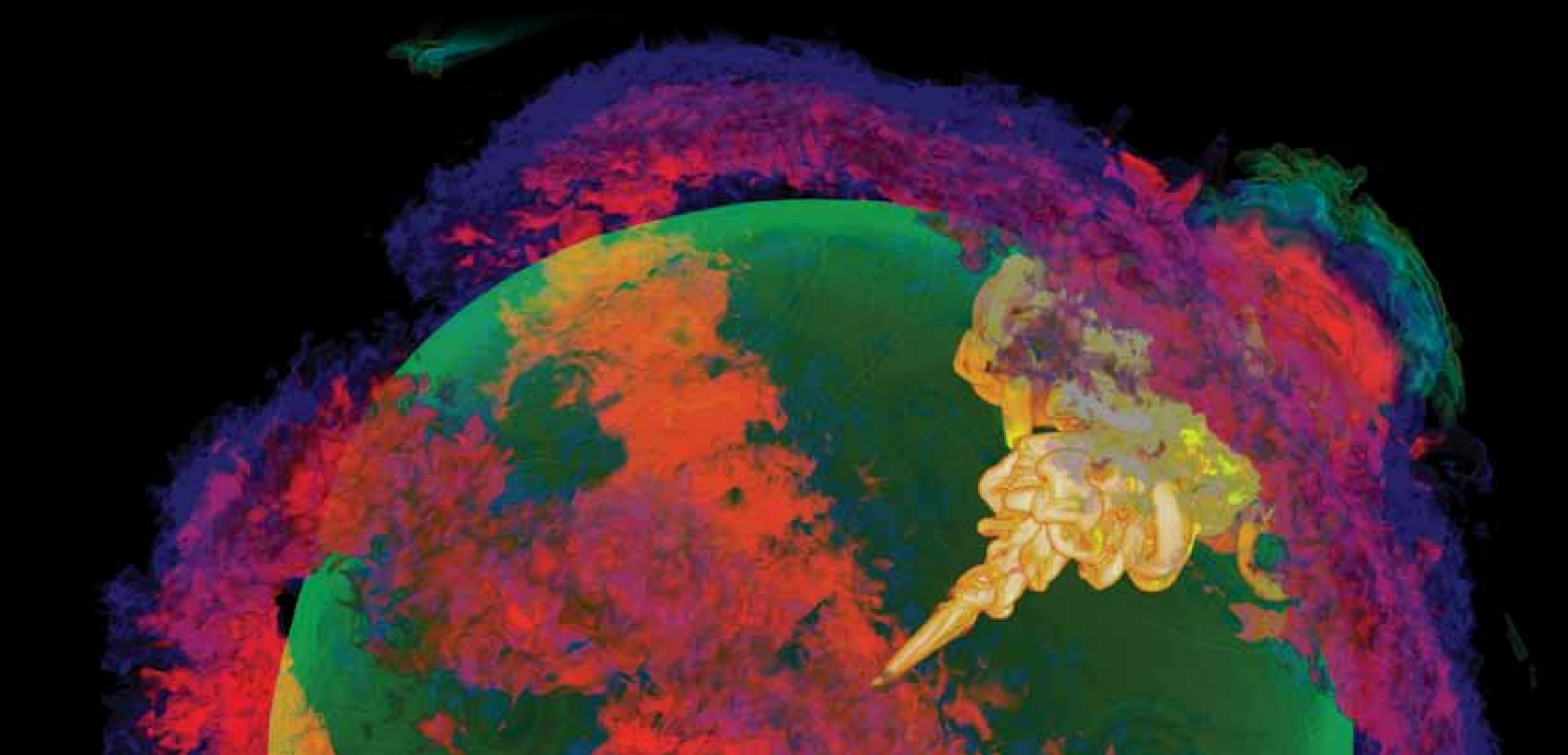


CATCH THE WAVE



by Barbara Jewett

Modeling and simulation using NCSA resources helps scientists advance work with supernovas.

OVERHEAR Robert Fisher and Gaurav Khanna discussing hotel stars and catching the wave, and you'd think they're discussing a recent vacation. Wait. Now the conversation has shifted to Type Ia. Isn't that the person who thrives on work?

While the University of Massachusetts Dartmouth professors are really talking about their collaboration on groundbreaking computational astrophysics research—their team is the first to successfully predict the gravitational wave signature for Type Ia supernovae—the eavesdropper's confusion can be excused. These researchers believe that scientists should explain their work in a manner such that others can learn from them and understand the importance of what they do. Often this requires using analogies easy for non-scientists to grasp.

Exploding stars, or supernovae, "are just intrinsically wonderful and interesting systems to study," says Fisher. Type Ia supernovae are the result of explosions of white dwarf stars.

"A white dwarf is like a retirement for stars," says Fisher. "They've had their careers burning nuclear fuels and they go off to the retirement home or retirement hotel, continuing to sort of shine although they are no longer working, no longer burning nuclear fuels. They just are living off their retirement account if you will, giving off whatever remnant heat they have in the form of visible light."

After billions of years of active nuclear burning, the white dwarf heads off to the retirement hotel with its companion, a binary star. And that binary star can donate mass to the white dwarf through a process called accretion, Fisher explains. But the donation can drive the white dwarf to the point of instability and it explodes, becoming a supernova.

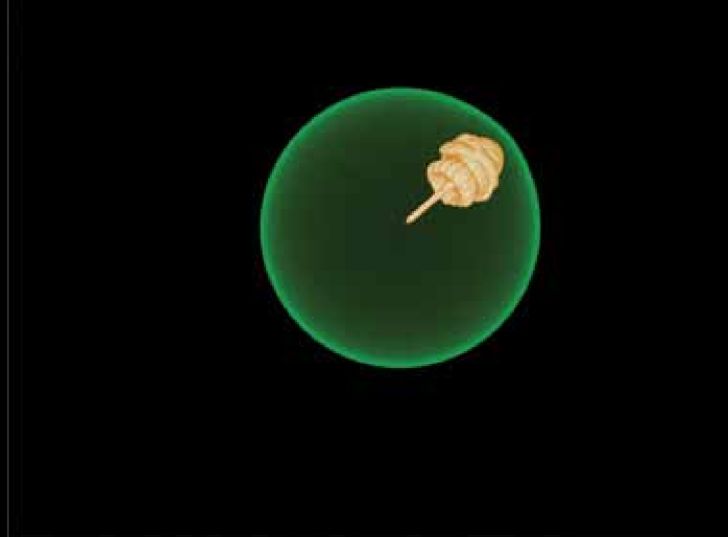
The team's groundbreaking research also demonstrated what researchers can do with modern supercomputers. Fisher has used high-performance computers at NCSA since 1992, when he was a sophomore in college and worked with Ronald Taam at Northwestern doing computational astrophysics.

"I go way back, almost to the very beginning of NCSA," he says with a laugh. "And note, I'm not that old! I can see from my research, and from the students I've trained to use supercomputers, they've just had such a huge impact. It is impossible to estimate what the true value is. It is truly an amazing resource, to have a national center for supercomputing. "

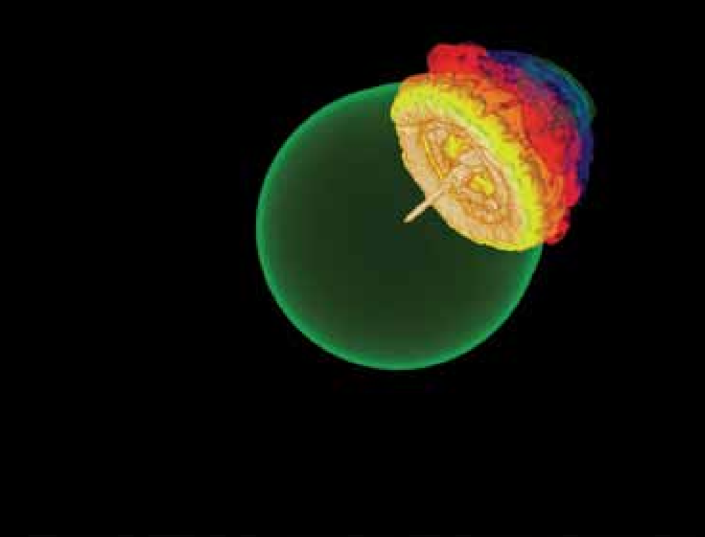
Only in the last few years, however, have the sizeable advances in computing power made it possible to study the evolution of a supernova from first principles simulations in three dimensions. "These models are so extremely realistic, it's incredible," he says.

Master's student David Falta assisted the project, running 3D simulations on NCSA's now-retired Abe cluster in addition to the Louisiana Optical Network Initiative's QueenBee. The team's results were published earlier this year in Physical Review Letters.

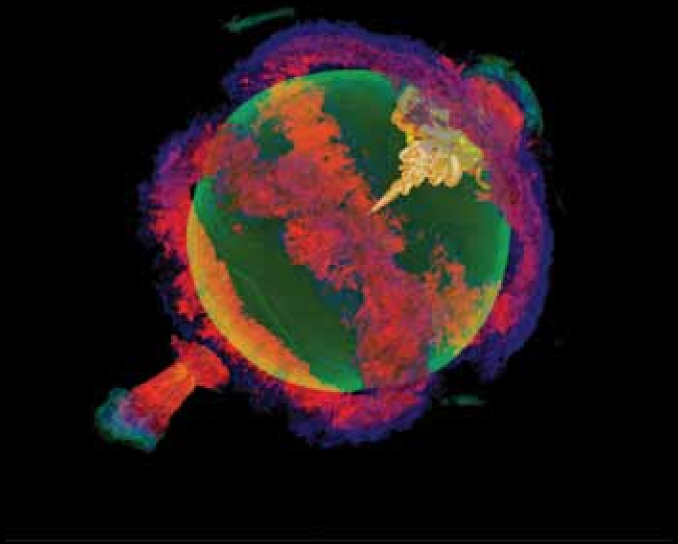
Images : Flash Center, University of Chicago



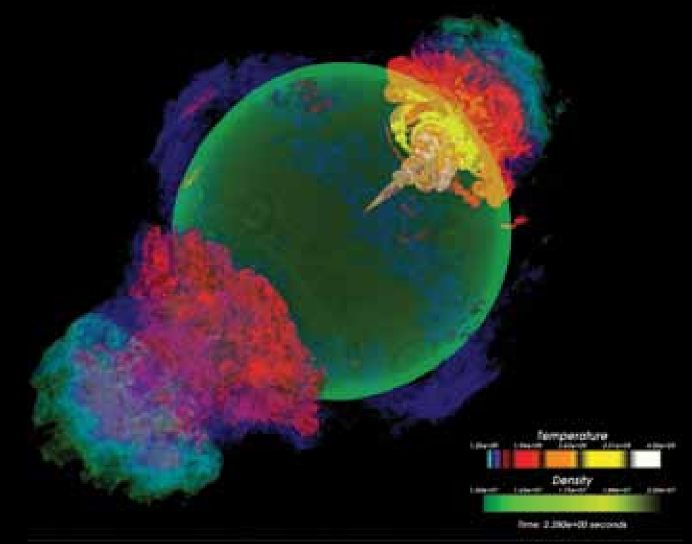
(a) The simulation is initiated near the endpoint of the white dwarf's lifespan, when a single nuclear flame bubble has been ignited near its center. The buoyancy of the bubble rapidly pushes it up to the surface of the white dwarf.



(b) Within one second of physical time, the bubble emerges from the surface of the white dwarf.



c) The ash rushes over the surface of the white dwarf, which remains intact and gravitationally-bound, culminating in a intense jet which sets off a detonation on the opposite end of the star about one second later.



(d) The resulting detonation releases an amount of energy comparable to the entire luminous output of our sun in a fraction of a second.

Gravitational waves

Currently, researchers are only able study the Type Ia supernovae in visible light, which comes out over weeks and months. This is due to the fact that even though the real time white dwarf explosion into a Type Ia supernova only lasts about two seconds, the star shrouds the information that initially comes out in the visible light, making it nearly opaque.

Gravitational waves, on the other hand, go through anything very freely. That's what makes them so hard to detect but also what makes them amazing sources of information, says Fisher. The actual process of the two-second explosion would be "right there in the gravitational wave."

The team looked at the simulated explosions with a fresh viewpoint. Instead of just trying to simulate the supernova explosion, they explored the consequences of it.

By focusing on the consequences, they noticed the explosion doesn't originate from the star's center; it goes off asymmetrically. Recent optical measurements by Keiichi Maeda of the University of Tokyo and colleagues, published in Nature, have independently confirmed that Type Ia supernovae are asymmetric.

Albert Einstein's Theory of Relativity predicts that if you take a large amount of mass that is asymmetric, it will give off another form of radiation that is not seen by visible light but is actually a distortion in space and time, explains Khanna.

"If you have violent events that are very asymmetric, like a Type Ia supernova, that can cause a ripple in spacetime that travels at the speed of light," he says. "So, very much like you were to throw a pebble on the surface of a pond that causes ripples, you would have a ripple propagating outward. But this would be a ripple in spacetime itself. And this ripple would be what we call gravitational waves, and would eventually come to us on Earth and we would be able to pick it up."

The ability of gravitational waves to pass through matter without corruption of information, or any kind of issue, "and get to us, carrying that information," is one of the reasons behind the emerging field of gravitational wave astronomy, notes Khanna. Using gravitational waves supplements what astronomers learn from light.

"And if we can read that information, using gravitational wave detectors, we would have high-quality information about any source we're studying," he says.

Direct detection of cosmic gravitational waves has long been sought. The Laser Interferometer Gravitational-Wave Observatory, or LIGO, is a large-scale physics experiment to detect gravitational waves, and develop gravitational-wave observations as an astronomical tool. Funded by the National Science Foundation, the project is operated by Caltech and the Massachusetts Institute of Technology. Research is carried out by the LIGO Scientific Collaboration, a group of more than 800 scientists at universities around the United States and in 11 foreign countries. The project has observatories in Hanford, Washington, and Livingston, Louisiana.

But all gravitational waves are not equal. Drawing again on a non-science comparison, Fisher explains that if you could tap a white dwarf star it would ring like a bell, tinkling about every second because of its relatively high density—over a billion times that of water at its center. Compare that to our sun, he says, which would oscillate slowly and ring about once every 30 minutes if tapped. That characteristic ringing frequency is usually about the characteristic frequency of the gravitational wave emission. Extremely dense astrophysical sources, such as neutron stars and black holes, ring at very high frequencies, up to a thousand times a second—right in the range of LIGO. Because Type Ia supernovae are less dense than neutron stars and black holes, their gravitational waves are at a lower frequency than these events, about 1 Hertz, he says.

Catching the wave

Khanna emphasizes that Type Ia gravitational waves are not detectable with current instruments. While LIGO may have advanced instruments detecting neutron stars and white dwarfs in 2014 or 2015, he says, LISA, the Laser Interferometer Space Antenna, would be more likely to capture the Type Ia's lower frequency gravitational waves. This is because instead of being ground-based, it will actually be an antenna orbiting in space.

LISA was to be a joint project of NASA and the European Space Agency (ESA). Due to budget cuts, NASA pulled out of the project early in 2011. ESA is planning to continue the project, but it most likely will be at a smaller scale, which may then limit the antenna's ability to capture the Type Ia waves. Future planned spaceborne instruments, including the Big-Bang Observer, currently under consideration by NASA, are more ideally suited to the detection of Type Ia supernovae.

But until then, the team's work is a starting point.

"We were able to show Type Ia's have a gravitational wave signature, and make a prediction of what the gravitational wave signature would be. That was a first that came out of this work," says Fisher.

"When we first did this study, we thought the chance of a supernova exploding close enough to be easily detectible by future instruments would be quite serendipitous. Then just as the ink on our paper was drying, astronomers caught the closest Type Ia in half a century, SN 2011fe. This supernova would have been detected in gravitational waves by the proposed Big Bang Observer mission," he added.

In the meantime, modeling and simulation will have to suffice. Hopefully, one day in the next decade, another supernova like SN 2011fe will once again light the skies, finally allowing Robert Fisher and Gaurav Khanna to catch the wave.

PROJECT AT A GLANCE

TEAM MEMBERS

David Falta
Robert Fisher
Gaurav Khanna

FUNDING

National Science Foundation

FOR MORE INFORMATION:

www.novastella.org/Fisher_Computational_Astrophysics_Group/home.html
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