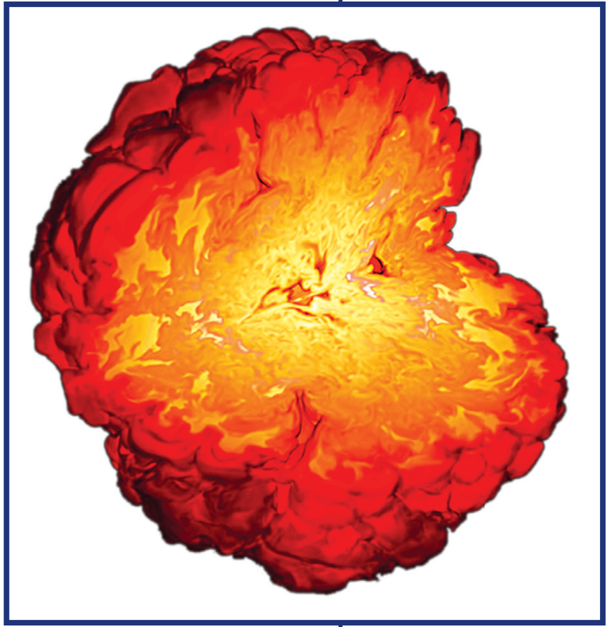
Explaining Our Expanding Universe

In 1998 two teams of astronomers—one based at Lawrence Berkeley National Laboratory and the other at Mount Stromlo Observatory in Australia—decided to see if the universe is still expanding, and how fast.



A white dwarf star is destroyed, leaving a radioactive cloud of nickel and other elements that glows as bright as a galaxy for weeks.

If what we saw of the universe were all there is, the primary force acting on it would be the gravitational pull of stars, galaxies, and other matter, which should be slowing it down. Instead, the two teams discovered not only that the universe is expanding, but that the expansion is accelerating.

Their conclusion, dubbed the "Breakthrough of the Year for 1998" by Science magazine, has profound implications. If the expansion of the universe is accelerating, something else must be at work. Therefore, the teams' observations provide compelling evidence for a newly discovered force—dubbed "dark energy" by physicists—that pervades empty space.

The American and Australian teams made their startling discovery by observing the universe's biggest thermonuclear explosions, stars that become as bright as galaxies for a few weeks as they blow apart. Known as Type Ia supernovas, these explosions serve a key role in cosmology by revealing both how far away the stars are and how fast they are receding.

Astronomers can calculate the distance to a Type Ia supernova because it produces a characteristic light curve, with the absolute brightness of the explosion closely link to the time it take to brighten and fade. Given information from expansion of the nearby universe, they also have an idea of how big the universe should be. In short, the most distant Type Ia supernovas are farther away than expected, making the universe bigger than predicted and leading to the conclusion that its expansion is accelerating rather than slowing.

So supernovas are being used to answer some profound questions. But to fully understand what they are telling us, scientists need to resolve a few critical questions about the supernovas themselves. The most important could be those that focus on the relationship between the supernova's light curve and its brightness. Simply put, does this relationship hold for all Type Ia supernovas? Astrophysicists discovered the relationship by observing nearby supernovas whose distances can be verified in other ways. They assume that the relationship holds for more distant explosions as well, an assumption that allows them to gauge the distance to events billions of light-years away. They would love to see proof that their assumption is valid.

To get that proof, they will need a better understanding of how Type Ia supernovas blow up. "We would like to understand the physics underneath," explained Stan Woosley, astrophysicist at the University of California–Santa Cruz. "Type Ia supernovas are still one of the most important pieces of evidence for an accelerating expansion of the universe."

A team led by Woosley is using the enormous computing power of the NCCS and its Cray XT4 Jaguar supercomputer to provide explanations by simulating the evolution of Type Ia supernovas.

Scientists believe a Type Ia supernova begins with a dead star known as a white dwarf. Having burned through its lighter elements and not being massive enough to burn through its heavier ones, a white dwarf is essentially a massive chunk of carbon and oxygen floating through space. To become a supernova, it must be closely teamed with another, less evolved star—a red giant—which rains hydrogen onto the white dwarf.

In this scenario the white dwarf becomes increasingly more massive as it takes on this new material, and its core becomes hotter as the dwarf's increasing gravity adds pressure. It goes through a centuries-long period of convection, in which hot material at the core rises and sinks like water boiling in a pot. As the white dwarf approaches a critical mass—nearly half again the mass of the sun—it goes through a runaway fusion reaction that eventually blows the star apart.

This runaway reaction also produces nearly a sun's mass of iron and radioactive nickel. It is the decay of this nickel, with a half-life of about 6 days, that makes the supernova billions of times as bright as the sun.

Woosley's team is simulating each aspect of the supernova: the long period of churning convection that leads to the supernova's first flames, the expansion of these flames to create an explosion, and the radiation at the end of the event that gives the supernova its brightness.

The job is exceptionally demanding, with scales ranging from the microscopic to the stellar. The simulations must include the initial flames, which have a thickness in the neighborhood of four one-hundred-thousandths of an inch, and the entire white dwarf, which is roughly the size of the earth. Without the leadership computing resources of the NCCS, calculations of such size and scale would be impossible.

As it moves forward, the team will be addressing many areas about Type Ia supernovas that are not well understood. Does the flame start at the center or off center? Is there just one flame or many? Does the explosion exceed the speed of sound and thereby become a detonation? And why are these events so consistent?

As it moves to answer these questions, Woosley's team will provide a key piece in the puzzle of where our universe is headed.

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