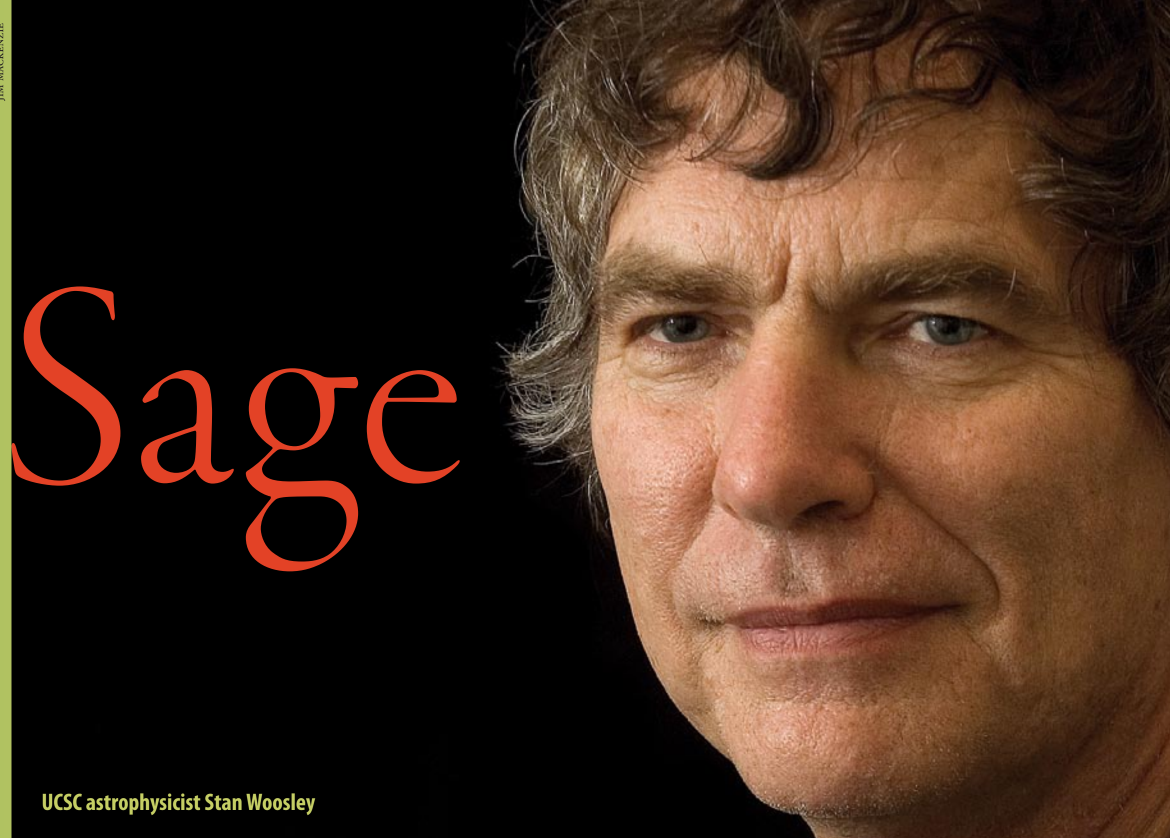
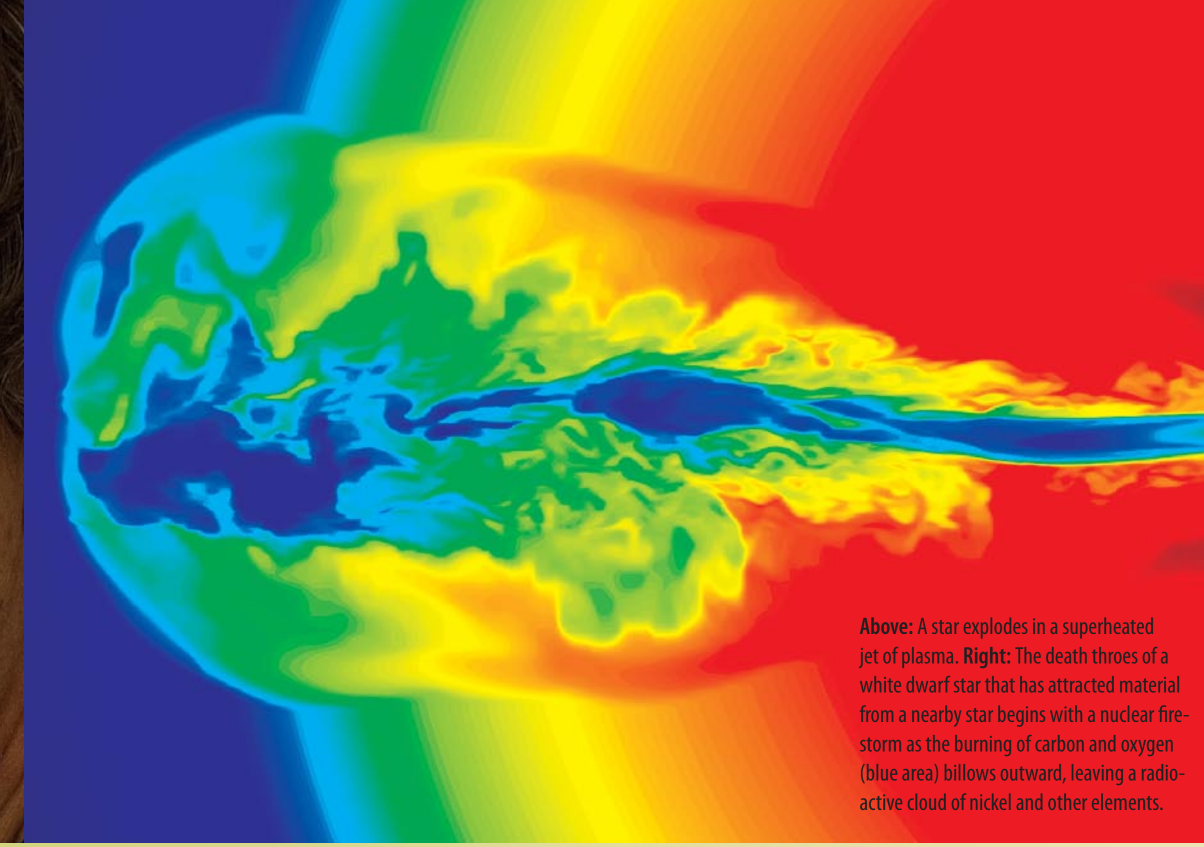
Supernova Sage

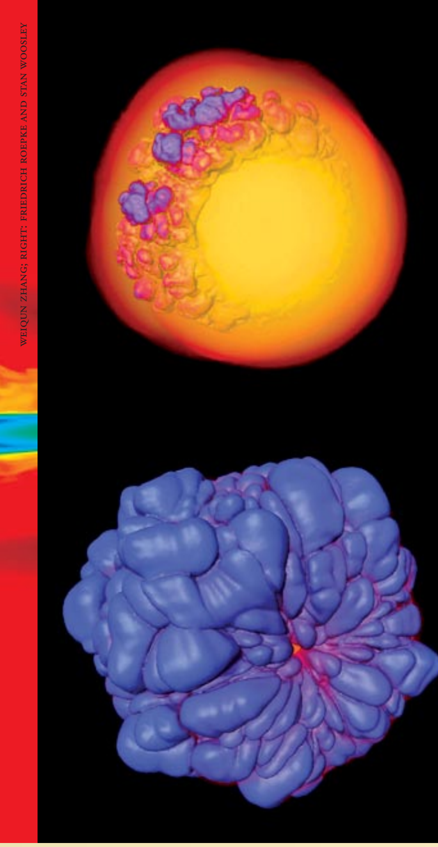
By Tim Stephens



JIM MACKENZIE

UCSC astrophysicist Stan Woosley





WEIQUN ZHANG; RIGHT: FRIEDRICH ROEPKE AND STAN WOOSLEY

Above: A star explodes in a superheated jet of plasma. **Right:** The death throes of a white dwarf star that has attracted material from a nearby star begins with a nuclear firestorm as the burning of carbon and oxygen (blue area) billows outward, leaving a radioactive cloud of nickel and other elements.

Given enough mass, a star can end its life in a glorious blaze of radiant energy. The death throes of massive stars are the most violent explosions in the universe—supernovae that shine with the brilliance of 10 billion Suns and gamma-ray bursts that release a concentrated blast of intense radiation more powerful than a supernova.

Stan Woosley knows supernovae and gamma-ray bursts as well as anyone. A professor of astronomy and astrophysics at UC Santa Cruz, he is one of the world's leading theoretical astrophysicists, with a long list of honors and achievements to his credit. But he remains focused on unresolved questions, saying no one really understands what happens when a star explodes.

Woosley leads a consortium of top scientists, including researchers at five universities and three national laboratories, using supercomputer simulations to study the evolution of massive stars and their explosion as supernovae and gamma-ray bursts. Funded by the U.S. Department of Energy with a five-year, $9.5 million grant, the Computational Astrophysics Consortium has access to some of the most powerful supercomputers in the world.

"Almost all of modern physics comes to bear in a supernova explosion, and we can put all that physics into a simulation. But you need powerful computers to do all the calculations involved," Woosley says.

The results of these investigations are crucial to scientists exploring fundamental questions about the nature of the universe. In recent years, for example, astronomers have used supernova observations to conclude that a mysterious "dark energy" permeates the universe and is pushing it to expand at an ever-faster pace.

These studies rely on a class of supernovae known as type Ia, which are used for cosmic distance measurements because their brightness evolves over time in a predictable manner. According to Woosley, however, it is not clear what accounts for the features that make them so useful. And that bothers him.

"Cosmologists have used these supernovae very productively, but it's all based on empirical observations. We would like to have a basic understanding of what causes this phenomenon so that we can make the distance determinations more accurate," he says.

On one level, type Ia supernovae are well understood as the thermonuclear explosions of white dwarf stars. The explosion is triggered when the white dwarf siphons off enough matter from a companion star to reach a critical mass (about 1.4 times the mass of the Sun). The mystery is what exactly takes place during the explosion.

A related category of cosmic explosions—the type II supernovae—presents theorists with another set of challenges. A type II supernova pops off somewhere in the universe about once a second. These explosions of massive stars (at least eight times the mass of the Sun) determine the compositions of galaxies, stars, and planets, stocking the universe with all the elements of the periodic table. This creation of the elements, called nucleosynthesis, is what got Woosley interested in supernovae in the first place.

Starting as a graduate student at Rice University in the 1960s, Woosley spent decades working with various collaborators to describe in exacting detail the origins of every naturally occurring element. Carbon, oxygen, iron, gold—these elements and more are forged either in the nuclear furnaces of stars as they evolve or in the blaze of energy when they explode.

Supernova explosions spew the newly forged elements into space, where they drift in great clouds of gas and dust that eventually collapse to form new stars and planets. Star formation may even be triggered by the mixing effects of supernova blasts, Woosley says.

"They stir things up, they are bright and interesting in themselves, and they make the elements. But we still don't understand them in detail," he says.

While Woosley's decades of work on supernovae and nucleosynthesis established his reputation as a theoretical astrophysicist, he has gained further recognition in recent years for groundbreaking work on gamma-ray bursts.

For decades after their initial discovery by military satellites in the 1960s, gamma-ray bursts were one of astronomy's most baffling mysteries. By the 1990s, there were hundreds of competing theories about what causes these brief but powerful flashes of gamma radiation. Observations now support the "collapsar" model developed in 1998 by Woosley and his graduate student Andrew MacFadyen, now at the Institute for Advanced Study in Princeton, N.J.

According to this model (which applies to "long-duration" bursts lasting more than two seconds) a gamma-ray burst accompanies the birth of a black hole from the collapse of a massive star. But many fundamental questions remain unanswered, Woosley says.

"With gamma-ray bursts, we're still just trying to figure out what's going on," he says.

In the new consortium, Woosley and his fellow theorists are teaming up with a large group of observational astronomers who are gathering new data on supernovae and gamma-ray bursts, and with computer scientists with expertise in writing code for the fastest supercomputers in the world. Comparing the results of theory-based simulations with real-world observations gives scientists a crucial "reality check" for their theories.

Simulations of exploding stars run on powerful supercomputers are beginning to capture the full complexity of the physical processes involved, Woosley says. "Those simulations make beautiful pictures that look more and more like nature because they are beginning to have the same complexity as nature."