A Supernova Turns 10

Birthday of an explosion

By RON COWEN

More than 160,000 years ago, a massive star in the Large Magellanic Cloud galaxy suffered a catastrophic explosion. Radiation and subatomic particles generated in the fireball sped outward, and on Feb. 23, 1987, some of the fireworks reached Earth.

The proximity of the explosion, known as a supernova, made it the brightest such event since 1604. At its peak, it glowed with the luminosity of 100 million suns. "We had seen nothing like this since the time of [astronomers] Tycho and Kepler," says Stanford E. Woosley of the University of California, Santa Cruz.

In addition to observing X rays, radio waves, and a bright dot of light briefly visible to the naked eye, astronomers in 1987 detected gamma rays from a supernova for the first time. As debris from the explosion ballooned into surrounding space, they also tracked the early stages of the supernova's evolution.

Now, a decade later, 1987A has dimmed considerably in visible light; however, it brightened recently at X-ray and radio wavelengths. As astronomers look forward to 2007, when they predict the shock wave from the exploded star will generate new celestial pyrotechnics, they continue to grapple with two puzzles.

On the same day that photographic plates captured the first visible-light image of 1987A, a set of underground detectors recorded a handful of neutrinos from the explosion. The neutrinos arrived within 10 seconds of each other. Detection of these subatomic particles thrilled astrophysicists because it confirmed their basic theory about supernovas.

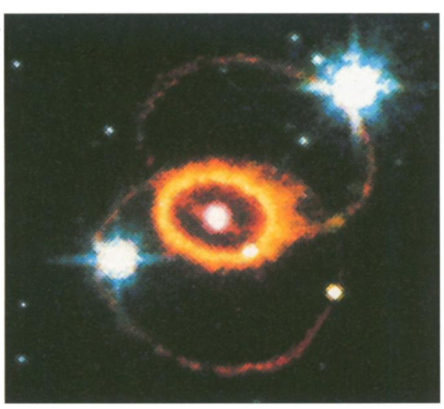
According to the standard model, when an aging star more massive than eight suns finally succumbs to gravity, its core implodes and a shock wave racing out from the collapsed interior ejects the star's outer layers. The remaining core, which is so dense that protons and electrons are pushed together, is known as a neutron star. As it forms, a neutron star emits a brief, but intense, burst of neutrinos.

Since the triumphal detection of the neutrinos, however, astronomers have seen neither hide nor hair of the neutron star. They had expected that its rapid rotation would produce radio waves or that material falling onto it would produce X rays.

Such emissions from the core of the supernova remnant couldn't have been seen directly, but they should have added to the total energy spewed out by the supernova. All of the radiation emitted by supernova 1987A, however, can be accounted for by the radioactive decay of heavy elements forged during the supernova explosion. If the neutron star exists, it's unusually silent.

Some astrophysicists argue that the neutron star's emissions are hidden by dense material surrounding the body. Other researchers conjecture that gas hurled into space during the explosion fell back onto the newly forged neutron star. If the star already had the maximum amount of mass it could hold, the additional material might have transformed it into a black hole, notes Roger Chevalier of the University of Virginia in Charlottesville. Subsequent material falling onto a black hole might not emit significant amounts of radiation.

NASA



The inner and outer rings in this Hubble image are composed of material ejected by a star some 20,000 years before it exploded as supernova 1987A. The rings form an hourglass shape. The central spot is debris from the supernova.

The other puzzling aspect of 1987A concerns a group of three rings that surround the supernova. The innermost ring, which has a radius of about 1 light-year, encircles the center of the explosion. The two outer rings, which lie on opposite sides of the inner ring, complete an hourglass shape, with the inner ring as its waist. Astronomers believe the rings were sculpted by the star thousands of years before it exploded and were lit up by the explosion.

Evidence suggests that as recently as 20,000 years before its demise, the aging star had swollen to some 100 times its normal diameter and had become what astronomers call a red supergiant. A gentle, low-speed wind then lifted off some of the puffy star's outermost layers of gas.

Next, the massive star did something unexpected. The red supergiant shrank and became a blue supergiant, a star considerably less swollen but, at 10 times its original diameter, still far from svelte.

The blue supergiant ejected a high-speed wind that eventually caught up with the sluggish material expelled by the star in its previous, red supergiant incarnation. When the blue wind ran into the red wind, it swept the material up into dense clumps that became the three gaseous rings.

Soon after the explosion, ultraviolet radiation from the supernova ionized gas in the rings. As the gas cooled and recombined with the electrons, it emitted the light seen as rings by the Hubble Space Telescope.

That simple scenario works well, says Chevalier, up to a point. It explains why the shock wave from 1987A—unlike that from other supernovas—didn't light up its immediate surroundings. There simply wasn't much material there. The blue supergiant's fast wind had already cleared out a cavity.

The model also explains why the supernova remnant, after fading, would start radiating more radio waves and X rays. As the expanding shock wave from the explosion ventured farther out and slammed into denser material beyond the blue supergiant's wind, it accelerated electrons to high speeds, causing them to emit radiation. The denser material, in fact, slowed the shock wave from one-tenth the speed of light to less than one-sixtieth.

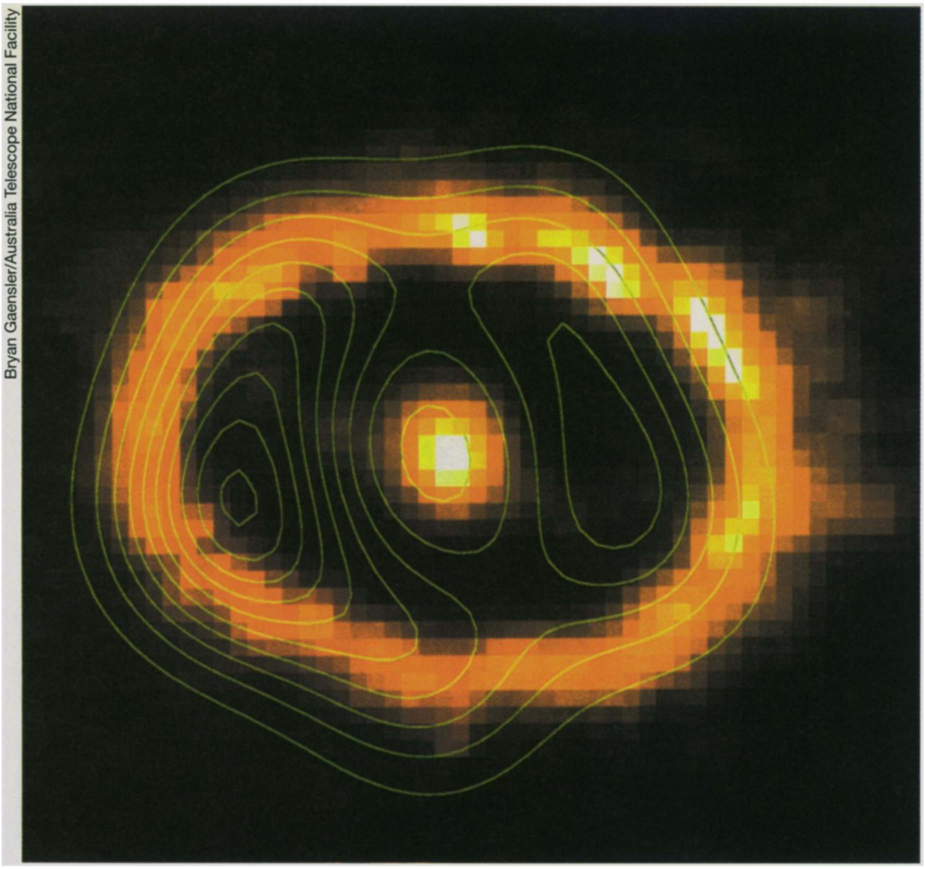
This model can't explain, however, why the material swept up by the fast wind should form rings instead of a spherical shell. Researchers, including Richard McCray of the University of Colorado at Boulder, suggest that the wind expelled by the red supergiant blew stronger in some directions than others.

One explanation for an uneven wind is

that the gravitational influence of an unseen companion star may have directed it. No one has seen evidence of such a companion, but astronomers will continue to look as the supernova grows dimmer in visible light. Alternatively, if the red supergiant rotated rapidly, it would have forced material to be blown asymmetrically.

Recent Hubble images of the supernova debris, displayed last month at a meeting of the American Astronomical Society in Toronto, show a dumbbell shape consisting of two connected blobs of debris flying apart at nearly 10 million kilometers per hour. The blobs are moving perpendicularly to the plane of the rings, suggesting that whatever property of the red supergiant created the rings may also have influenced the explosion, says Jason Pun of NASA's Goddard Space Flight Center in Greenbelt, Md. Two new instruments installed Feb. 15 on Hubble should provide further details on the velocities and shapes of the blobs.

Astronomers expect the supernova's fading image to experience a renaissance 10 years from now. At that time, they predict, debris from the supernova will strike the inner ring. Unlike the explosion a decade ago, this one will require a telescope in order to be seen. In colliding with the ring, says McCray, the supernova will shed light on material from its past and may help astronomers to predict its future. □



Bryan Gaensler/Australia Telescope National Facility

Contour lines overlying this Hubble image of supernova 1987A and its inner ring indicate regions of bright radio emissions. The emissions occur at places where the supernova's blast wave has slammed into gas.