Large Magellanic Explosion

Supernova 1987A is nature's most spectacular blast

By DIETRICK E. THOMSEN

A supernova is a giant explosion involving a star that is usually about a dozen or more times as massive as the sun. It is, as Stirling Colgate of Los Alamos (N.M.) National Laboratory puts it, "the largest explosion in nature except for the formation of the universe itself." For this reason and because they are the terminal phase of certain stars' existence, supernovas interest scientists. In the words of a scientist who calculates theoretical models of supernovas, Stanford E. Woosley of the University of California at Santa Cruz, the modeling process involves the "diagnostics of a 10^{31}-megaton test."

Those who make models of supernovas were overjoyed when supernova 1987A exploded Feb. 23 in the nearby Large Magellanic Cloud. For the first time in the history of modern astrophysics, they had a supernova they could follow in close detail and compare with their models. In the months since — in spite of some early confusion and some readjustments necessitated by the unexpected nature of the star that exploded — the modelers have been able to arrive at basic explanations for what has happened, and they generally agree on the range of models that can fit.

This agreement was evident recently during discussions in Fairfax, Va., at the Fourth George Mason University Workshop on Astrophysics. In Colgate's judgment: "It's incredible how well the models agree." But, he says, there are "still some points that aren't understood, some mysteries."

One point on which all observers seem to agree is that the star that exploded is the one catalogued as Sanduleak −69°202. Nick R. Sanduleak of Case Western Reserve University in Cleveland has been cataloguing certain kinds of peculiar stars for a long time. In his catalog this was the 202nd star listed in the 69th degree of declination south of the celestial equator.

Unlike the progenitors of previously observed supernovas, Sanduleak −69°202 had been observed before the explosion. "This is the first time we have information on a supernova progenitor," says Nolan R. Walborn of NASA Goddard Space Flight Center in Greenbelt, Md. However, he qualifies that with: "But little is really known." Walborn managed to find 32 plates in various colors and filters that show the star; to explain the paucity of information he says: "In 100 years it never did anything [such as display light variations] to draw attention."

At the time of the explosion, Sanduleak −69°202 appeared to be a blue supergiant. However, Type II supernova explosions like 1987A are expected to happen to *red* supergiants. That raises the question, according to Robert P. Kirshner of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., of "whether it was blue before it blew, or whether it was red before it was blue before it blew."

Kirshner presented evidence for a red phase from the ultraviolet observations he has supervised since the beginning of the explosion. The details of the ultraviolet spectrum suggest that the star had an episode of mass loss a long time ago. Such a mass loss would have turned a red supergiant blue.

Kirshner supposes that the star originally had a mass about 15 times that of the sun, which he divides into a core of six solar masses and a mantle of nine solar masses. "How much of the nine solar masses left the scene before it blew?" he asks. Whatever amount left — and Kirshner thinks it was less than the whole nine yards — went out as a slow, dense stellar wind to form a shell of interstellar matter that now lies about a light-year from the star. Kirshner sees in the ultraviolet observations evidence for fluorescence from this material.

Nino Panagia of the University of Catania in Sicily presented what he called "complementary observations" indicating the presence of a "circumstellar shell created by the progenitor's wind in the red supergiant phase." He concludes that — in spite of the differences from the usual behavior of a Type II supernova that have so excited and perplexed many astrophysicists — "SN1987A is a normal Type II exploding in a massive star in an unusual phase. The blue supergiant is responsible for the differences."

Woosley suggests that perhaps a lack of metals made the star blue. The first generation of stars in the universe made the first metals. When these stars exploded, their metal content went into the interstellar matter of the galaxies they happened to be in. As stars of later generations, including Sanduleak −69°202, condensed out of this interstellar matter, they were endowed with a certain abundance of metals. The Large Magellanic Cloud, a small satellite galaxy to our own Milky Way, is known to be poor in metals compared with the Milky Way and other galaxies, so any star that condensed in it would likely be deficient in metals, and that could make it blue. James W. Truran of the University of Illinois in Urbana-Champaign rates the progenitor's metallicity at about half that of the sun and says that may be "why we had not seen a Type II supernova in an irregular metal-deficient galaxy like the Large Magellanic Cloud."

As Woosley further remarks, some models make a red supergiant stage, while others do not. Another supernova modeler, J. Craig Wheeler of the University of Texas at Austin, agrees: "There are both red and blue solutions." Yet another expert, W. David Arnett of the University of Chicago, says, "Classes of models can satisfy the observational constraints."

Classes, but not all possible models. Observations of SN1987A and the general agreement on some of the basic things they signify have narrowed the field. Precisely how a supernova explosion proceeds depends on a number of factors, such as the precursor star's mass, its temperature and the proportions of different chemical species in it. Changes in one or more of these variables will change the details of how the explosion proceeds. The models are so many that they are coded with letters and numbers, and as was evident in the discussion, even those who deal with these models every day sometimes forget the values of the input quantities represented by a particular designation. What observation and agreement have done is to narrow the range of acceptable models for this particular supernova.

The assembled astrophysicists mostly seemed to agree that the progenitor had 15 to 20 times the sun's mass. As Ken'ichi Nomoto of the University of Tokyo draws the cross section, its innermost region is an iron-rich core of about 1.5 solar masses. This is surrounded by a layer of fairly heavy elements – carbon, oxygen, silicon, nickel. The total mass so far is about 3 solar masses, of which 0.07 solar mass is nickel, an element particularly significant to the modeling, as energy from its radioactive decay is expected to dominate the supernova's light in its later stages. The heavy elements are surrounded by a layer of helium, which brings the total mass so far to 6 solar masses. The rest of the mass is in a hydrogen-rich envelope, some of which may have departed before the supernova blew. In fact, Woosley suggests that all of this hydrogen envelope would have to have left the star to make a red giant blue before it blew, and he says this won't work. "Mass loss did not by itself make it blue, but it still lost mass," he says.

Woosley, Nomoto and others seem to agree that it was the innermost, iron-rich core of about 1.5 solar masses that collapsed to initiate the explosion. The abrupt collapse of the core started a shock wave that drove the rest of the star outward. According to theory, 1.5 solar masses should collapse to a neutron star, a potential pulsar.

As the rest of the star flies outward, Woosley says, the light and other radiation it emits should at first be dominated by the expansion of the explosion itself. Then, as the explosion begins to slow, energy from chemical recombinations – the formation of atoms and molecules – should dominate. Finally, energy from radioactivity will dominate the light.

In the first stages, SN1987A was much less luminous than previously observed Type II supernovas, and this caused some consternation. Lately, however, it seems to be conforming to precedent. Michael W. Feast of the South African Astronomical Observatory at the Cape of Good Hope, remarks, "As it comes into the tail [the long drawn-out decline in brightness], it is getting more like the models and other supernovas." Specifically, he reports an exponential decline in brightness with a half-life of about 113.6 days. This is just the half-life for the radioactive decay of cobalt-56, according to the latest nuclear data sheets, he points out.

Cobalt-56 comes from the radioactive decay of the nickel-56 mentioned above, and in its turn decays to iron-56. "Then, says Woosley, "it gets in your blood." Woosley is taking the coincidence between the decay time of the supernova's brightness and the decay time of cobalt-56 as possible evidence that the supernova has entered the stage where such decay dominates its energy balance.

Another possibility, however, is that radiation from the pulsar, into which the iron-rich inner core of the precursor should have collapsed, is now dominating. Yasuo Tanaka of the Institute for Space and Astronautical Science in Tokyo says that further observations of the supernova's X-ray output by the Ginga satellite, planned as a sequel to the ones he reported at the meeting (SN: 10/24/87, p.263), should be able to tell the difference.

So far there is no direct evidence of a pulsar. Jerome Kristian of the Mount Wilson and Las Campanas Observatories in Pasadena, Calif. (with equipment at Las Campanas, Chile) reported for a group that has been looking for the characteristic pulsed radiation of a pulsar. He says the result so far is "nil."

However, evidence is beginning to accumulate for something else. A supernova is supposed to leave behind a glowing nebula, a supernova remnant like the Crab nebula. Reporting on observations done at the European Southern Observatory at La Silla, Chile, I. John Danziger says the effects of a nebular spectrum are possibly being seen in the infrared. Like Danziger, Mark Phillips of Cerro Tololo Inter-American Observatory at La Serena, Chile, reports the presence of various metals and other elements characteristic of such a development. In addition, Harold P. Larson of the University of Arizona in Tucson reports that an April 11 observation by the Kuiper Airborne Observatory, flying over New Zealand, gave evidence for dust that could be ejecta from the supernova precursor or interstellar material.

"Solid material near the supernova is similar to stuff we find in our own solar system," Larson says, and he speculates about "a connection between formation of dust in supernovas and what's left over in our solar system." □