Supernova 1987A: A Mysterious Stranger

A computerized technique for high-resolution imaging suggests that the supernova has a companion; but astronomers are having an easier time saying what it is not *than saying what it could be*

An extraordinarily bright energy source, located only a fraction of a light-year from the even more extraordinary cataclysm of Supernova 1987A, has left supernova watchers both surprised and perplexed.

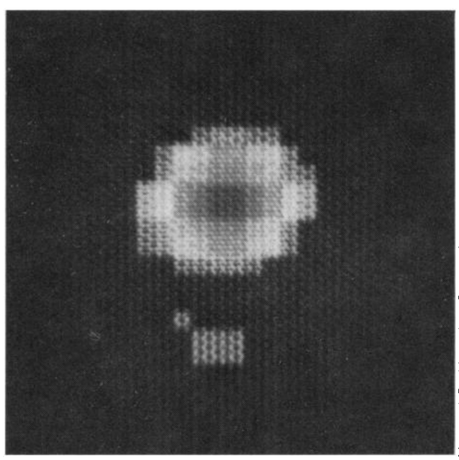
The source is presumably real—at least two groups have now seen it—and it is presumably no coincidence. Nothing of this magnitude was present before the eruption, and yet now, as one astronomer puts it, "The brightest and the second brightest sources in the Large Magellanic Cloud are separated by only two light-weeks." At the moment, however, astronomers have only the vaguest guesses about what the object might be.

The first observations of the source were made this past spring by Peter Nisenson, Kostos Papaliolios, and Margarita Karovska of the Harvard-Smithsonian Center for Astrophysics. Working at the Cerro Tololo Interamerican Observatory in Chile, the group used a technique known as speckle imaging to clear away much of the distortion introduced into the supernova images by the atmosphere. Given a bright source, sensitive electronic detectors, and lots of computer time for image processing, this technique can achieve resolutions as good as 0.02 arcsecond. Ordinary images, by contrast, are limited by the atmosphere to little better than 1 arcsecond.

The team's results show here a reddish companion about 10% as bright as the main supernova, located 0.057 arcsecond to one side. At the distance of the Large Magellanic Cloud, that separation amounts to roughly 2800 astronomical units, or about 17 light-days. Both of the objects are consistent with being point sources in this image; the apparent structure is caused by residual blurring. The main supernova is about 1000 times brighter than its progenitor star, a blue supergiant known as Sanduleak −69° 202. The companion is about 100 times brighter than the progenitor.

The three astronomers announced their finding on 4 May. Shortly thereafter they received a telephone call from the Imperial College, London: Peter Miekle and his colleagues had seen the same thing using data from the Anglo-Australian Telescope in Australia. Thus, says Papaliolios, "there is no doubt in our minds that the companion is real."

That leaves the question of what the companion is. Papaliolios, for one, refuses to speculate. And most other astronomers are taking a wait-and-see attitude, largely because the speckle imaging technique is still so new and so arcane that few observers know how to evaluate it. Moreover, it seems easier to imagine what the companion cannot be than to imagine what it is.



Harvard-Smithsonian Center for Astrophysics

The supernova's companion. *In this computer-generated image created by Nisenson, Papaliolios, and Karovska, the companion lies 0.057 arcsecond—roughly 2 light-weeks—to the south of the supernova. The apparent structure seen in the two sources is an artifact; both are consistent with being point sources.*

For example, the simplest explanation is that the supernova is just lighting up a nearby cloud of interstellar gas and dust. However, even if the cloud were a perfect mirror—which no interstellar cloud is—it would still have to cover at least 10% of the sky as seen from the supernova in order to look 10% as bright to us. But to do that it would have to subtend an angle of roughly 80° as seen from the supernova, which means that it would look much, much bigger in the image than it does.

Alternatively, one might imagine that a cloud or some other nearby object is being buffeted by the supernova's shock wave, which carries a great deal more energy than the light itself. However, the fact that the companion was detected in data taken 6 weeks after the explosion, combined with its minimum distance from the supernova of about two light-weeks, means that the shock wave would have to have traveled at one-third the speed of light or faster. Yet spectroscopic measurements of the supernova show that the bulk of the shock wave material is moving at only about 6% of the speed of light. In fact, the shock wave is still inside the region of the image covered by the central blob. (On the other hand, the shock wave will reach the position of the companion sometime after the end of the year, with possibly spectacular results if the companion presents a substantial obstacle.)

Finally, one might consider a "coiled spring" model, in which the supernova nudges a nearby system that is somehow full of repressed energy like a jack-in-the-box, and thereby trips the latch. The problem is that to achieve 10% of the brightness of the supernova, this mysteriously erupting jack-in-the-box would essentially have to *be* another supernova; no other energy source even comes close. And yet, quite aside from the fact that no one can see any plausible mechanism for one supernova to trigger another like this, it seems highly unlikely that two unstable stars would just happen to be so close to one another at precisely the same time.

One of the few suggestions that does have a certain measure of plausibility is that the companion represents emission from shocked gas at the leading edge of a relativistic jet—that is, a stream of material that squirts out of the supernova and plows through the surrounding interstellar matter like the jet from a fire hose. Indeed, Cambridge University theorist Martin Rees has pointed out at least one mechanism for forming such a jet.

It is widely believed that the collapsing core of the supernova has coalesced into a very rapidly spinning pulsar, says Rees, who was one of the pioneers in developing the theory of such systems. If so, then the magnetic field of the pulsar will be sweeping through the surrounding particles and whipping them up into a relativistic wind. This wind will in turn push outward against the debris of the explosion—the so-called supernova remnant—and blow a bubble of relativistic particles at the center.

"Now, let's suppose there is a hole in the remnant, a leak," says Rees. "The plasma will all squirt out the hole at almost the speed of light." Thus the jet. In fact, he says, "essentially all the power of the central pulsar comes out in the jet." That power is estimated to be about 10^{41} ergs per second, which also happens to be roughly the optical luminosity of the supernova as a whole. Thus, the numbers are reasonable: a jet would have the right velocity and the right amount of energy to produce the companion source that we see.

"Now," says Rees, "Why is there a hole?" One possibility is that Sanduleak −69° 202 may have had a binary companion star, he says. (Most stars do.) "The ejecta from the explosion would have been blocked in that direction, and you would have had a shadow—a conical region where there is no ejecta. Then, as the companion moved away in its orbit, you would have been left with a hole."

Rees is the first to agree that the jet model needs to be tested against new data. In particular, if the companion is the leading edge of a jet then it will move further and further away from the supernova as time passes. Moreover, the jet will slow down as it goes. (The velocity of known astrophysical jets decreases inversely with the distance they have traveled.)

One such test may well come from the new observations of the supernova made by Nisenson, Papaliolios, and Karovska at the end of May. Reducing the data and creating the image will take a month or more, they say. But assuming that the companion is really there—and a new confirmation of its existence is critically important—then the new images should clearly show whether it has moved. ■ M. MITCHELL WALDROP

Four Groups Build More Efficient Atom Traps

Hydrogen, sodium, and cesium atoms can now be cooled and stored for up to 20 minutes with some combination of a laser, a magnetic field, and a helium dilution refrigerator

ULTRAHIGH-resolution spectroscopy, atomic clocks of unprecedented accuracy, detailed studies of the kinetics of atomic collisions, and observation of unusual quantum phenomena are some of the things that physicists expect from the ability to confine atoms for long times in a nearly motionless state at temperatures much less than 1 millikelvin (mK). During the past 2 years, researchers have shown they can hold up to 100,000 sodium atoms for a second or two, thereby demonstrating the feasibility of atom trapping.

Now four groups have built more efficient traps that can hold substantially larger numbers of atoms for durations of 2 minutes or longer, times that are much closer to those needed for some of the experiments envisioned. Moreover, investigators have extended the variety of atoms confined from sodium, heretofore the fruit fly of atom trapping, to hydrogen and cesium, which should broaden interest in the techniques. At the moment, the confinement record is held by a Massachusetts Institute of Technology (MIT) group, which held 5×10^{12} hydrogen atoms for 20 minutes in a magnetic trap.

At MIT, Thomas Greytak and Daniel Kleppner have been interested for many years in an unusual form of hydrogen gas called spin-polarized hydrogen. Normally, hydrogen atoms combine quickly to form hydrogen molecules. But, if the electronic spin angular momenta of the atoms are aligned in a magnetic field, the Pauli exclusion principle prevents the formation of molecules. Physicists are interested in spin-polarized hydrogen because of its statistical properties. When the spins of the electron and the proton are taken into account, the net atomic spin is either 0 or 1, making the atom a boson.

According to quantum statistical mechanics, at high densities and low temperatures, a system of noninteracting bosons undergoes a phase transition with the jargon name Bose-Einstein condensation. Here, condensation does not mean formation of a liquid but refers to a special quantum condition in which nearly all the bosons occupy the same quantum state—the one with the lowest energy. Physicists believe that the condensed state of spin-polarized hydrogen will be a viscosity-free superfluid similar to liquid helium-4 below 2.18 K, which is also thought to be a Bose-Einstein condensed state. But hydrogen remains a gas, even at 0 K and as the simplest atom it may also be easier to study in detail than helium. On the practical side, it has been proposed that spin-polarized hydrogen could be the basis for an improved hydrogen maser, and it could be a source of polarized protons in high-energy physics experiments.

Achieving an appropriate combination of high hydrogen atom density and low temperature has not, however, been possible up to now because of so-called three-body collisions involving two spin-polarized hydrogen atoms and a third atom in the gas at high densities or on the walls of the refrigerator at low temperatures. The three-body collisions permit the formation of hydrogen molecules. Harald Hess, who is now at AT&T Bell Laboratories, devised a magnetic trap for spin-polarized hydrogen. The idea is to keep the density low enough to avoid three-body collisions in the gas and to insulate the atoms from the wall magnetically while the temperature is decreased.

At MIT, Hess collaborated with Greg Kochanski, John Doyle, Naoto Masuhara, Kleppner, and Greytak of MIT in implementing the scheme. With an appropriate combination of magnet coils, it is possible to generate a static magnetic field with a minimum value in a specified region of space. In a large magnetic field, atomic hydrogen has four relevant quantum (hyperfine) states, according to the four combinations of parallel and antiparallel orientation of the electron and proton spin angular momenta relative to the field. Once in the trap, the atoms with electron spins parallel to the field are attracted to the minimum, whereas those with antiparallel spins are ejected, giving a sample of spin-polarized atoms. The investigators actually went a step farther and retained only those atoms with both electron and proton spins parallel to the field, further reducing the already small but still significant probability of two-body collisions resulting in molecule formation.

The maximum depth (expressed as a temperature) of the trap with magnetic fields of 0.87 tesla was 580 mK, so that the atoms had to be cooled with a helium dilution refrigerator before they could be trapped. In the present experiment, the trapped atoms were at an estimated 40 mK.

In their experiment, the investigators ini-