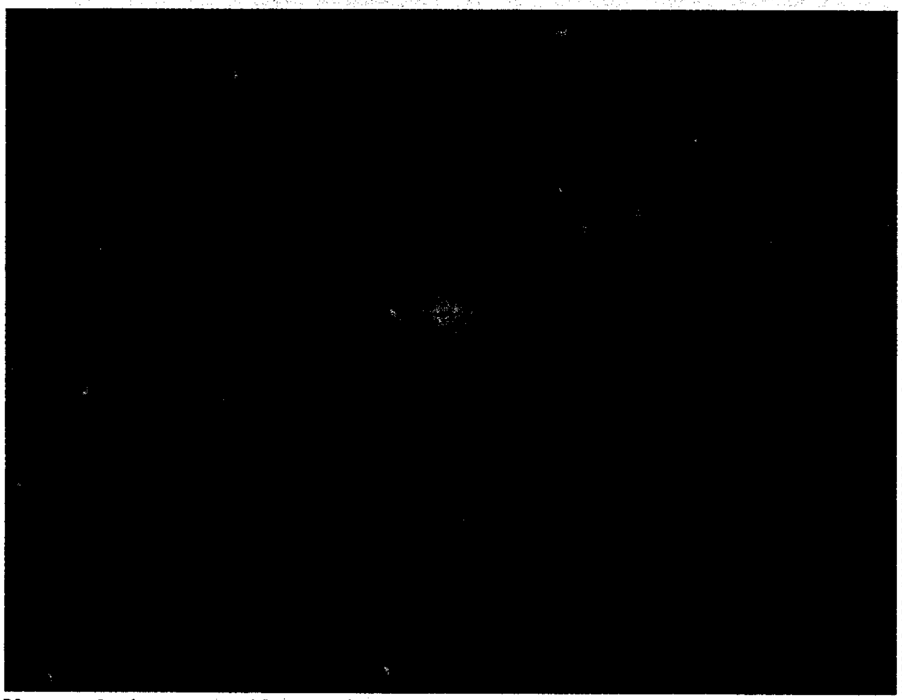
The Creation of Big Bang Bickering

SUMMARY: Widely accepted has been the notion that the universe began with a massive explosion. But the big bang theory may be exploding in the face of its creator and most ardent supporters. Five prominent physicists recently have questioned the theory's validity.

The image of a big bang — a single, massive explosion that led to the creation of the universe — has been firmly emblazoned upon popular consciousness and remains the leading scientific theory for the origin of the cosmos. The idea that the universe sprang from a hot, dense point more than 20 billion years ago was proposed by astronomer Georges Lemaitre in 1927 and has won overwhelming acceptance among cosmologists, those physicists who study the universe's origin.



HALTON C. ARP / IMAGE PROCESSED BY JEAN LORRE, JET PROPULSION LABORATORY

Young galaxies are considered evidence that the universe had no beginning or end.

Yet even within this secluded discipline, dissenters remain. In the new Hypothesis section of the prestigious scientific journal Nature, five prominent physicists questioned the validity of the big bang model, finding the evidence unsatisfactory and suggesting that "perhaps, there never was a Big Bang." The authors of the paper, titled "The Extragalactic Universe: An Alternative View," include Halton Arp of the Max-Planck Institute for Astrophysics in West Germany, Geoffrey Burbridge of the Center for Astrophysics and Space Sciences at the University of California at San Diego and Fred Hoyle of the University of Wales, all eminent scholars in cosmology.

In essence, they argue that recent observational evidence does not support the standard big bang model and, in fact, runs contrary to it in some instances. Instead, they argue for a steady state universe that has no beginning or end, is always expanding and in which matter is constantly being created rather than one in which all matter was created at the same time.

And they maintain that so-called cosmic microwave background radiation, first discovered in 1965 and usually used as evidence to support the big bang model, is too smooth to have been caused by a single massive explosion. Instead, they believe this radiation is caused by cosmic dust particles, what they call "iron whiskers."

"We're essentially arguing that the galaxies came first and gave rise to the microwave radiation through the generation of starlight and the production of dust particles," says Burbridge.

In addition, he and his coauthors argue that the common interpretation of quasars is incorrect. Although most astronomers believe these objects to be among the oldest and most distant structures in the universe, the dissenters contend that they are instead much younger and nearer to the universe's center than is commonly believed.

Scientists say the light these quasars give off appears to indicate that they are far away and fast-moving. Yet, the authors maintain, an unusually high number of quasars appear to be located next to galaxies that scientists believe are much younger and nearer than the quasars themselves.

That, they say, suggests that the quasars are intrinsically different from what scientists assume them to be. In fact, they write, the conclusion they draw is that "in these objects we are witnessing creation events involving the ejection of new matter from the nuclei of galaxies."

Some cosmologists are intrigued by their suggestions, but few are convinced. "They cite a number of examples, but their argument is lacking in hard statistics, which is why the astrophysics community isn't convinced," says Alan Guth, a professor of physics at the Massachusetts Institute of Technology. "They've made studies they regard as statistically valid, but others have found the statistics flawed and unconvincing."

The notion of a steady state universe arose during the 1920s but fell out of favor during in the 1950s as observational evidence seemed to point ever more conclusively toward a big bang instead. For the most part, the hypothesis still has but a few adherents. "The main objection to the steady state model is extremely simple. If you're in a steady state universe, then it should look the same at all times. Therefore, the universe should look the same at a large distance as it does near us," says Jeremiah Ostriker, a professor of astrophysical sciences at Princeton University. "Unfortunately, it doesn't."

"There's no question that most cosmologists are overwhelmingly convinced that the big bang is correct," says David N. Schramm, a physicist at the University of Chicago. "In fact, I would say that any new theory has to incorporate the big bang into it, just as Einstein's theory of gravity incorporated Newtonian mechanics."

Nevertheless, says Schramm, a small percentage of scientists remain unconvinced. "It's sort of like the Flat Earth Society," he says. "Just as you've got people out there who argue very seriously that the Earth isn't round, you've got these people saying that there never was a big bang. They've latched on to the steady state theory. No matter what evidence you come up with, they just won't believe you."

— *Richard Lipkin*

COVER STORY

Supernova!

Scientists are agog over the brightest exploding star in 383 years

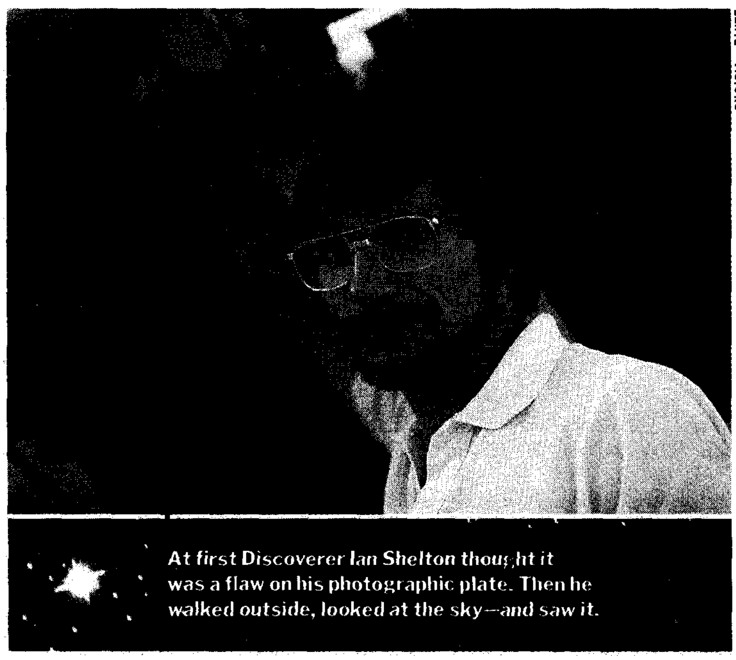
It was a glacial period, and in southern Africa the climate was cooler than it is today. Giraffes, hyenas and baboons abounded, along with now extinct giant horses and hartebeests and buffalo with 13-ft. horn spans. Neanderthal man had not yet emerged, but intelligent beings already roamed the savanna, upright creatures known today as archaic Homo sapiens, who could fashion crude axes, picks and cleavers out of stone. On a clear night 170,000 years ago, one of these ancestors of man may have looked up at a milky band of stars stretching across the sky, his eyes pausing briefly on a patch of light that seemed to have broken away from the band.

At that moment, in the distant patch—actually a small galaxy now known as the Large Magellanic Cloud—a supergiant star glowed fiercely, showing no outward signs of its impending doom. Suddenly, in a cataclysmic blast, it exploded, brightening until it outshone a hundred million stars the size of the sun. In every direction the intense light, traveling at 186,282 miles per second, radiated out into the universe, some of it heading toward a minor planet orbiting an average star in the neighboring and much larger Milky Way galaxy.

Some 170,000 years later, on that minor planet, man had evolved, developed technology, built great cities and, in an effort to better understand his place in the universe, developed great instruments that could peer deep into space. It was not until then, on the night of Feb. 23, 1987, that the first light emitted by the exploding star, having traveled a billion billion miles through space, finally reached the earth. Some of the light passed through the lens of a 10-in. telescope at Las Campanas Observatory on a windblown 8,000-ft. mountaintop in northern Chile and was reflected into a camera set up by Ian Shelton, a Canadian astronomer. Shelton, 29, assigned to the observatory by the University of Toronto, had been taking long exposures of the Large Magellanic Cloud (LMC), a task that occupied him until 2:40 a.m. on Feb. 24. Recalls Shelton: "I decided enough was enough. It was time to go to bed." But before turning in, he made up his mind to develop the last photographic plate. Lifting the plate from the developing tank, he scrutinized it, then stopped short. There, near a feature within the LMC known as 30 Doradus, or the Tarantula nebula, was an unfamiliar bright spot.

"I was sure that there was some plate flaw on it," Shelton says, "but it was no flaw." He walked outside, looked up at the Large Magellanic Cloud and, without a telescope or binoculars, clearly saw the exploding star, or supernova. While hundreds of supernovas occurring in incredibly distant galaxies have been spotted by powerful telescopes, this was the first one visible to the naked eye since 1885. More important, at a distance of only 170,000 light-years, it was the brightest one to appear in terrestrial skies since 1604.

News of Shelton's discovery, promptly named 1987A (for the first supernova of the year), was telegraphed to observatories around the world by the International Astronomical Union. Word spread through the scientific community at close to the speed of light, producing outright euphoria and the kind of giddy remarks seldom heard from scientists. "It's so exciting, it's hard to sleep," said John Bahcall, an astrophysicist at the Institute for Advanced Study in Princeton, N.J. "It's like Christmas," exclaimed Astronomer Stan Woosley of the University of California at Santa Cruz. "We've been waiting for this for 383 years."



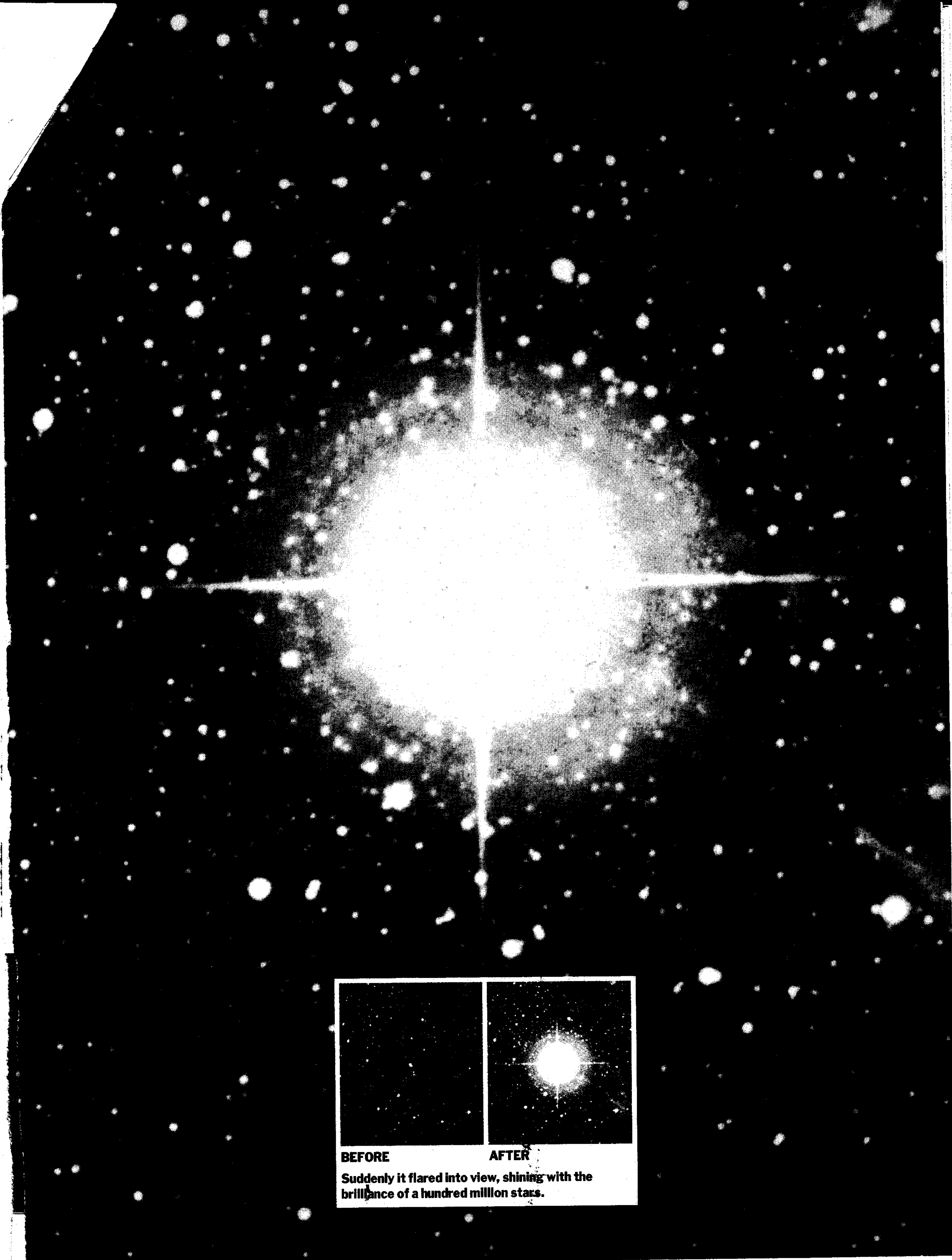
LENTZ—VISIONS

At first Discoverer Ian Shelton thought it was a flaw on his photographic plate. Then he walked outside, looked at the sky—and saw it.

STEVEN LEE—ANGLO-AUSTRALIAN OBSERVATORY

For the first time, modern scientists had the opportunity to observe close up, by astronomical standards, nature's most spectacular display. They could train sophisticated instruments on an exploding star and analyze in detail a phenomenon fundamental to the structure of the universe, to the formation of stars and indeed to life itself.

An overstatement? Hardly. The stupendous processes that lead to and occur during a supernova are responsible for the production of many of the elements in the universe. These elements are hurled into the cosmos by the force of the supernova blast to form great clouds of gas and dust. Subsequent supernovas send shock waves through the clouds, coalescing gas and dust and starting the formation of new stars and planets. Thus the planets and any life that evolves on them consist of elements forged in supernovas. Furthermore, these stellar explosions generate energetic particles, known as cosmic rays, that can cause mutations in terrestrial organisms and may have played a direct role in the evolution of life on earth. In a very literal sense, says University of Illinois Astrophysicist

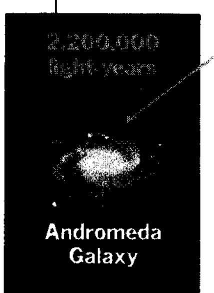


Suddenly it flared into view, shining with the brilliance of a hundred million stars.

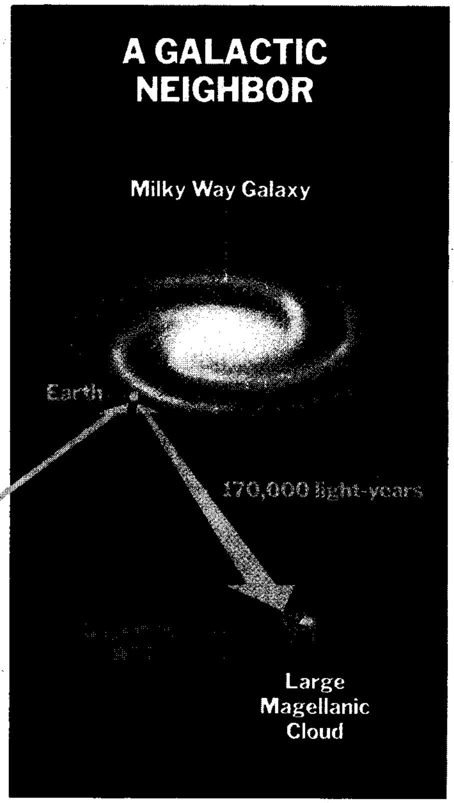
Larry Smarr, "we are the grandchildren of supernovas."

For scientists this opportunity to dissect a supernova, perhaps even to find on old photographic plates the very star that created the spectacle, will test theories of stellar evolution and death that until now were largely dependent on equations, computer runs and unbridled imagination. "What makes this supernova exciting," says Robert Garrison, an astronomer at the University of Toronto's telescope at Las Campanas, "is that it's writing the textbook. The theoreticians are letting themselves go wild thinking of all the possibilities." Says Physics Nobel Laureate Carlo Rubbia: "This is the beginning of scientific research on supernovas. It was science fiction before. Now it's science fact." What was perhaps most remarkable about the hubbub was that scientists were studying an event that occurred 170,000 years ago and was now being played out, like a rerun on television of an old newsreel, before their very eyes.

It is little wonder, then, that within hours of 1987A's discovery, an extraordinary array of scientific brainpower and hardware was brought to bear on the celestial phenomenon. Throughout the southern hemisphere (the supernova is not visible in northern skies), in South America, Australia and South Africa, telescopes of every size were focused on the bright newcomer in the Large Magellanic Cloud. NASA promptly ordered some of its satellites to do the same. On its way to a rendezvous with Neptune in 1989, the Voyager 2 spacecraft pointed its two ultraviolet-light detectors at the supernova. The Solar Max satellite turned its attention from its primary target, the sun, to measure the gamma rays emanating from 1987A. The International Ultraviolet Explorer began measuring the supernova's ultraviolet radiation. In Japan space officials hurried a newly launched satellite through its calibration tests so that it could begin detecting X rays emitted by 1987A's hot gases.



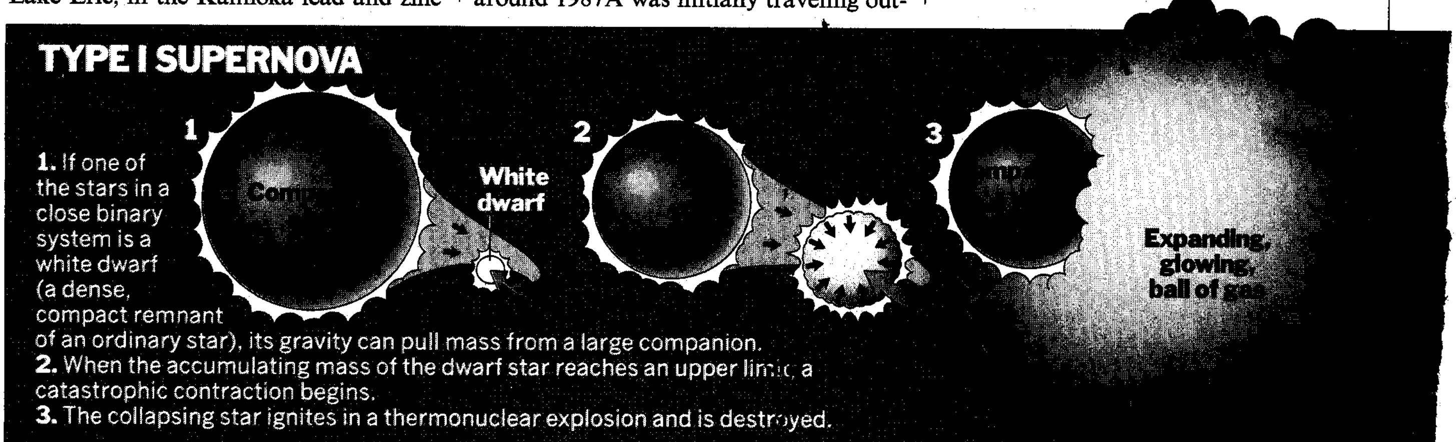
Far below ground, in a salt mine under Lake Erie, in the Kamioka lead and zinc mine in Japan, in the Mont Blanc Tunnel linking Italy and France, and in another tunnel under Mount Elbrus in the Soviet Union, scientists carefully examined data from computer printouts. They were hoping that some of the ethereal particles called neutrinos, predicted by theory to be produced during a supernova, had penetrated the earth, leaving their trail in huge liquid-filled neutrino detectors. Astrophysicist J. Craig Wheeler, of the University of Texas in Austin, summarized the activity while addressing a hastily convened meeting of astronomers at NASA's Goddard Space Flight Center the week after the discovery, "These are frantic times."



By the end of last week scientists had already amassed more data than they could immediately analyze, confirming some theoretical predictions and making several observations that for the time being puzzled everyone. Earliest readings showed that the shell of gases expanding around 1987A was initially traveling outward at nearly 10,000 miles per sec Since then the color of the supernova h been changing from blue to red mu faster than expected. "That change is five to ten times faster than other supernovas," says Robert Williams, director of the U.S.-financed Cerro Tololo Inter-American Observatory in Chile. This phenomenon indicates that the rapid expansion of the shell is causing it to cool, thus shifting the wavelength of the emitted light more deeply into the red end of the visible spectrum. Also surprising was 1987A's low luminosity. "If it had lived up to its initial expectations," says Williams, "it should have increased its brightness to a magnitude of around 1 to 0." (A lower number means a brighter star; Sirius, the brightest star in the sky, has a magnitude of −1.5.) That would have made it look nearly as bright as the brightest stars in the night sky. Instead, the supernova rose only to a magnitude of 4.5—equivalent to that of a medium-bright star—but then stopped and hovered around that figure.

Those early characteristics lead Williams to speculate that 1987A "may have had an antecedent star that was not that massive, as supernovas go." By comparing the supernova's position with older photographs of the Large Magellanic Cloud, many astronomers at first identified a hot blue supergiant star, called SK-69 202, as the probable progenitor of 1987A. But that conclusion troubled everyone; theory holds that a star with these characteristics is too young to expire in a final explosion. Two weeks ago, as the initial ultraviolet radiation from the blast began to die down, the astronomers breathed a collective sigh of relief: ultraviolet scans indicated that the blue star might still be intact. Says Catharine Garmany, an astronomer at the University of Colorado: "It is probably shaking in its boots, but we're beginning to think it's still there." The scientists shifted their attention to two nearby, somewhat fainter stars visible on older plates. But these choices also worried them, because the progenitor should have been much brighter.

At least one of the events predicted in theory apparently occurred. All four neutrino detectors recorded the arrival of bursts of the elusive little particles—before the light appeared.



TYPE I SUPERNOVA

1. If one of the stars in a close binary system is a white dwarf (a dense, compact remnant of an ordinary star), its gravity can pull mass from a large companion.
2. When the accumulating mass of the dwarf star reaches an upper limit, a catastrophic contraction begins.
3. The collapsing star ignites in a thermonuclear explosion and is destroyed.

Fascination with supernovas is hardly confined to modern science. Like today's astrologers, ancient civilizations believed the stars had a direct influence on earthly affairs, and the Chinese, who carefully recorded any changes in the sky, were especially impressed by "guest stars." They regarded such astronomical visitors as omens of important events on earth. What may be the earliest Chinese record of a supernova is an inscription on a bit of bone, dating from about 1300 B.C., that describes a bright star appearing near the star now known as Antares.

While there is some question whether this and several other of the earliest recorded sightings involved actual exploding stars, there is little doubt about the guest star of A.D. 185. "Second year of the Chung-p'ing reign period," reads an ancient Chinese text, "tenth month, day *kuei-hai,* a guest star appeared within *nan-men.* It was as large as half a mat; it was multicolored, and it scintillated. It gradually became smaller and disappeared in the sixth month of the year after next." The description, especially concerning the brightness and slow fade of the star, seems to confirm the appearance of a supernova.

Ancient records indicate that the Chinese spotted five more supernovas in the next millennium, all in the Milky Way galaxy, and some of these starbursts were also noted by other cultures. The brilliant supernova of A.D. 1006 was seen and described by an Egyptian scribe named Ali ibn Ridwan and by European monks. The exploding star of 1181 was noted by the Japanese. But it is the supernova of July 4, 1054, which suddenly blazed in the constellation Taurus, near Orion, that is perhaps most significant to present-day astronomers. It exploded only about 6,000 light-years away and left behind the slowly writhing, gradually expanding and delicately beautiful cloud of glowing gas known as the Crab nebula. Studies of the structure and dynamics of the Crab have provided modern astronomers with important insights into supernova explosions.

The Crab supernova was, at its brightest, as brilliant as the planet Venus and visible during the daytime; its appearance was noted not only by the Chinese and Japanese but possibly also by Indians in the American Southwest. The New World evidence comes in the form of images carved and painted on rock walls in northern Arizona showing a celestial object adjacent to a crescent moon. There is no proof that this primitive artwork represents the supernova, but archaeological dating techniques show the Indians were in the area when the star flared, and astronomers have calculated that the supernova indeed appeared in the sky very close to the crescent moon.

PALOMAR OBSERVATORY—CALIFORNIA INSTITUTE OF TECHNOLOGY

The Crab Nebula is the spectacular remnant of a supernova seen in A.D. 1054. At its center: a superdense, rapidly spinning neutron star.

Europeans left no known record of the Crab supernova, although some probably saw it, and no evidence has been found that they saw an 1181 stellar explosion. It was not until November 1572 that Europe joined the fraternity of distinguished supernova recorders. Although Danish Astronomer Tycho Brahe was not the first to spot the new star that appeared in the constellation Cassiopeia, he ensured that posterity would associate his name with it by writing a book titled *De Nova Stella* (Concerning the New Star).

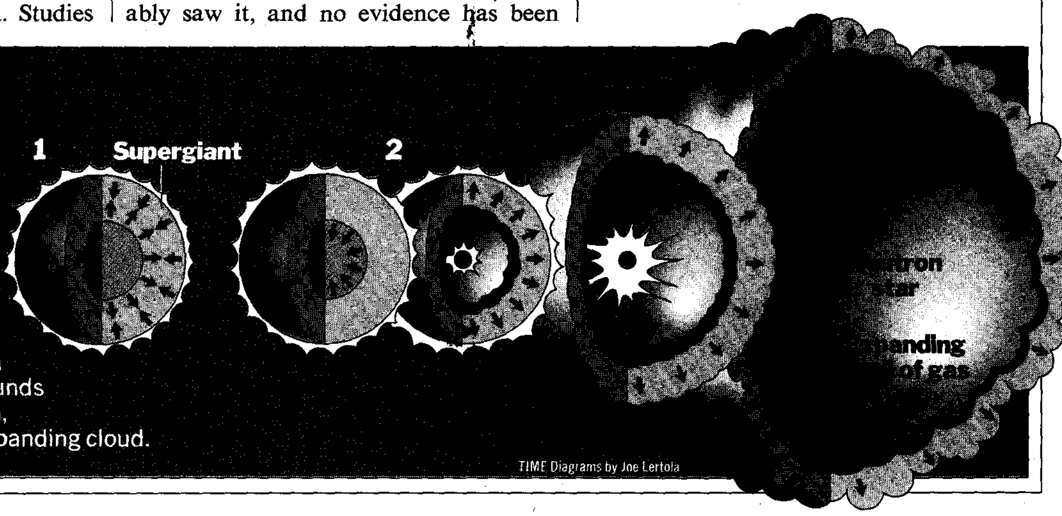
The next supernova to be seen by the naked eye happened only 32 years later, in 1604, in the constellation Ophiuchus, and its best-remembered witness was Brahe's former assistant Johannes Kepler. Unlike most supernovas, this one was seen before it reached maximum brightness, so Kepler's descriptions of the blazing star are of particular interest to astronomers. His observations would have been even more detailed and valuable had they been made with a telescope. Unfortunately, the star's timing was off. The supernova lighted the night skies just a scant five years before Galileo made the first documented telescopic scan of the heavens, discovering mountains on the moon and spots on the sun.

If the previous 1,800 years of astronomical history are any guide, astronomers say, a supernova visible to the naked eye should occur in or near the Milky Way galaxy four times every thousand years or so. But from 1604 to 1987, none were recorded. (The supernova of 1885, just on the threshold of visibility in the night sky, took place in the Andromeda galaxy, 2.2 million light-years away.) To be sure, many stars flared up during this interval. But astronomers now know they were not supernovas but nearby novas. These are shorter-lived events, caused by the sudden explosion of gases in a class of stars known as white dwarfs, that release only one ten-thousandth the energy of a supernova.

It was not until the 1930s that Caltech

TYPE II SUPERNOVA

1. Energy from the nuclear reactions in the core of a supergiant star prevent it from collapsing under the force of its own tremendous gravity.
2. When the nuclear fuel is used up, the core collapses into a neutron star. A shock wave rebounds from the core in a huge explosion, leaving a brightly glowing and expanding cloud.



TIME Diagrams by Joe Lertola

The Fate of the Sun

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
*And would suffice.**

Robert Frost wrote *Fire and Ice* in 1923, some four decades before astrophysicists were able to fathom how the sun—and thus the earth—would die. Nonetheless, he was basically correct: first fire, then ice. The fire will not be an explosion like the one now brightening the Large Magellanic Cloud; the sun is thought to have only about a tenth of the mass necessary to become a Type II supernova and has no stellar companion to contribute the mass necessary to turn it into a Type I blast. But that will be of little comfort to whatever creatures exist on earth when the sun is in its death throes; the final solar convulsions, while feeble compared to those of a supernova, will wipe out all life on the planet.

Fortunately for the earth's current inhabitants, the sun is enjoying a stable middle age, about halfway between its formation some 4.5 billion years ago and its demise about 5 billion years hence. Its radiation may fluctuate by a few hundredths of a percent here and there (data from the Solar Max satellite indicate that the sun's radiation declined from 1980 through 1985). But solar behavior has never been erratic enough to threaten all terrestrial life with extinction.

The real trouble will begin as the sun nears the 10 billion-year mark, when the thermonuclear fires that have been burning since its birth have fused all the hydrogen fuel in the solar core into helium. As the fuel runs out, the nuclear fire will die down, and the now largely helium core—which has been kept distended by the heat—will begin to contract under its own gravitational pull.

As the core contracts, however, its internal pressures will rise, forcing the temperature rapidly back up again until the intense heat ignites the unfused hydrogen gas surrounding the core. The interior of the sun will now be hotter than ever, a dense core of incandescent helium surrounded by a thin shell of hot, fusing hydrogen. Over the next few hundred million years, heat from the core will drive surface layers of the sun so far outward that they will cool to about two-thirds of the current 6,000° C surface temperature, and redden. The sun will have become a red giant, so large that it will engulf the planet Mercury, perhaps extending to encompass the orbit of the earth. Even if the swollen sun stretches no farther out than Mercury, however, the heat reaching earth will be from 500 to 1,000 times as great as it is today. Oceans will boil, and life will be incinerated.

Finally, after a cycle of contraction and re-expansion, the sun's surface gravity will be so low the outer layers will boil off into space, leaving behind only the naked core, a lump of matter about as big as the earth, but with 60% of the sun's original mass, glowing blue-hot at perhaps 120,000° C. That stage will mark the end of the sun's active life; its nuclear fires will never again turn on. Slowly it will cool until it is first a white dwarf, still glowing, then a cold black dwarf, a cinder. In the blackness of space, as in *Fire and Ice,* the lifeless earth will pass into an eternal deep freeze.

*Reprinted from *The Poetry of Robert Frost* by permission of Henry Holt and Co.

—THE STOCK MARKET

Astronomer Fritz Zwicky recognized supernovas (he coined the name) as a class of exploding star fundamentally different from ordinary novas. With Colleague Walter Baade, he began formulating the modern theory about how supernovas explode and launched the first systematic search for them. While the average galaxy has only an occasional supernova, Zwicky reasoned, there are so many distant galaxies visible through large telescopes, astronomers should have no trouble finding the great explosions popping out all over the universe. At first Zwicky's colleagues thought the idea ridiculous, but over the four decades that followed, he and his team found nearly 300 supernovas, about 30 times as many as appear in all of recorded history prior to 1885; the contributions of other astronomers have pushed the total to more than 600.

Armed with a growing number of examples, theorists refined their views of stellar evolution in general and of how, for some stars, an inevitable violent death occurs. The basic theme: a star performs a continual balancing act between its own immense gravity, which tries to pull all of its matter in toward the center, and the intense thermonuclear energy radiating from its core, which pushes the matter outward, keeping the star in the form of a distended ball of hot gases. For most of a star's lifetime, these forces are in equilibrium.

When the nuclear fuel is exhausted and the fusion reactions stop, however, gravity takes over. Without the outward pressure needed to keep it "inflated," the core of the star begins to collapse like a deflating balloon, its matter crushing down toward the center. For a star about the size of the sun, the collapse stops after several intermediate steps when the stellar material is compressed so much that its atoms virtually touch, forming what physicists call degenerate matter; what prevents further collapse is the tendency of the atoms' negatively charged electrons to repel one another. The star has become a white dwarf. Says David Branch, an astrophysicist at the University of Oklahoma: "It's the size of the earth but has the mass of the sun."

Degenerate matter is so resistant to further compression that nothing much can happen to a white dwarf unless, as is common in the Milky Way, it is part of a binary star system. If it is, the white dwarf's powerful gravity can draw gaseous matter away from its companion. In some cases, as the dwarf becomes bloated with its companion's substance, gravitational pressure triggers a fusion reaction in the captured gases, which are blown off in the explosion, resulting in a garden-variety (nonsuper) nova. According to Astrophysicist Branch, about 50 novas are observed flaring up each year in the Milky Way.

If the captured matter fails to ignite, however, the dwarf's mass increases until it approaches the point—known as Chandrasekhar's limit, for University of Chicago Astronomer Subrahmanyan Chandrasekhar, who first characterized it—at which its own gravity will overcome even the powerful repulsive force between electrons. When the dwarf's mass reaches about 1.4 times that of the sun (the exact figure depends on the star's makeup), the star suddenly begins to collapse again, heating up so violently that its core ignites in a sudden thermonuclear fire. The result: a supernova. "It takes half a second for the flame to cross the whole white dwarf," says Santa Cruz's Woosley. "So much energy is released that the entire star is disrupted. It blows itself to smithereens." Such an exploding star is known as a Type I supernova; historical accounts of the rate at which Brahe's and Kepler's supernovas dimmed suggest to modern astronomers that both were probably Type I.

Even if a star begins life with as much as eight times the mass of the sun, it has more than likely ejected so much matter from its outer layers in the course of evolving it ends up with a mass below Chandrasekhar's limit. Hence it will become a white dwarf and a candidate for either stable, long-term cooling or, if it has a close companion, nova- or supernova-hood. In fact, since a white dwarf has inevitably lost its outer, hydrogen-rich layers (no matter what its original size), the lack of detectable hydrogen in a supernova explosion typically identifies it as a Type I.

If the stellar mass exceeds eight times that of the sun, however, the star has a short, spectacular life, turning into a red supergiant and ending its life by exploding as a Type II supernova. Says Woosley: "Big stars burn the candle at both ends, and they go out in style." After only 7 million years of existence, according to Woosley, the fast-burning star has probably fused all its hydrogen into helium and begins to contract. The compression drives the temperature up to 180 million degrees Celsius, more than high enough to begin fusing helium atoms and releasing more energy. The star then expands again, remaining stable for about 600,000 years, until all the helium atoms have been fused into carbon and oxygen. Then, in successively shorter intervals and with ever higher temperatures, the star expands and contracts, its fires dying down, then blazing hotter, gradually fusing lighter elements into heavier ones, until in just one day, its silicon is fused into iron.

And that is the end of the line. The structure of iron atoms prevents them from being fused into a heavier element under those conditions. At this point the star resembles an iron-cored onion, with an outermost shell of hydrogen and nested inner shells of some 20 other elements, including silicon, sulfur, calcium, argon, chlorine, potassium, neon, magnesium, aluminum and phospho[rus].

But not for long. The instant the [re]maining silicon in the core is fused in[to] iron, the thermonuclear reactions stop. Without enough radiation pressure to sustain it, the now all-iron core, hidden under the star's outer layers, begins its final, catastrophic collapse. In the incredibly short time of just 1 second, according to University of Arizona Astrophysicist Adam Burrows, the core is compressed to more than the density of an atomic nucleus. "It's as if the earth had suddenly collapsed to the size of New York City," says Burrows. "At this point the rest of the star is oblivious. It doesn't know the core has collapsed and that it's doomed."

Now it is not just the atoms that are touching, as in a white dwarf, but their nuclei. Under the immense pressure, the electrons, no longer able to repel one another, are squeezed into the nuclei, which ordinarily contain just protons and neutrons. In about a thousandth of a second, the negatively charged electrons combine with positively charged protons to form additional neutrons; the process also produces the ethereal neutrinos, which effortlessly zip through the star's outer layers and into space. Under these circumstances, there is a limit to how much the neutrons can be compressed. As gravity tightens its grip further, the neutrons, in what Hans Bethe, Cornell University's Nobel laure-

A Super Stargazer

If Las Vegas made book on which amateur astronomer would be the first to spot the next supernova, the odds-on favorite would have to be Robert Evans, 50, a Uniting Church minister from New South Wales, Australia. True, the skies were cloudy overhead on Feb. 23, and Evans missed the chance to be acclaimed the discoverer of spectacular 1987A. But four days later he was the first to sight the much dimmer, more distant 1987B, the year's second supernova. According to Brian Marsden of the International Astronomical Union, that was only the 18th visual discovery of a supernova by an amateur stargazer in this century. Yet 15 of those stellar explosions have been found by Evans, most of them on a homemade telescope and all since 1981.

By day Evans tends his flock in the rural parish of the Lower Blue Mountains. By night, sometimes all night, he scans the heavens with a telescope set up in his driveway. His education in astronomy began when he was a schoolboy, with pointers from his father, a lab assistant in the botany department at the University of Sydney, and with binoculars borrowed from his uncle. In the late 1950s he began hunting for supernovas with a 5-in. reflecting telescope. In 1967 he built a 10-in. reflector to improve his chances of finding new spots of brightness in distant galaxies. But, says Evans, "I didn't have any success." The problem, he recalls, was that he did not have the proper charts or photographs of the galaxies he was looking at. "I couldn't really tell when a new object appeared," he says, "because there was nothing to compare it with."


JAMES POZARIK

Evans: supernova superstar

In 1980 he got a series of sky charts from a member of the Astronomical Association of Queensland, and things began to happen. He found two supernovas in 1981, four each in 1983 and 1984, one in 1985, three in 1986 and one so far this year. He has compiled this formidable record by spending between 20 and 30 hours a month at his telescope.

Indeed, Evans has so often viewed the hundreds of galaxies he scans each month that he has now become quite familiar with their positions and characteristics. As a result, he explains, "I can look at a lot of galaxies fairly quickly, locate and examine them in perhaps half a minute. Then, if there's anything suspicious, I check the chart. Usually a supernova is fairly obvious." Evans' most scientifically significant supernova find was 1986G, located in a galaxy known as Centaurus A. The supernova was right behind an unusual "belt" of interstellar dust that appears to bisect the galaxy. Professional astronomers have since been analyzing the nature and composition of the belt by determining which wavelengths of light from the supernova are blocked by the dust and which pass through it.

After finding his eleventh supernova, in 1985, Evans retired his aging 10-in. scope. The replacement, a new 16-incher, was given to him by the Commonwealth Scientific and Industrial Research Organization, Australia's national science organization, under a program that donates equipment to top-notch amateurs who are capable of making important contributions to science. Evans remains unaffected by the recognition and acclaim. "It's a humbling experience," he says, "looking at something so awesome."

physicist, has called the "moment of ximum scrunch," recoil ferociously. The resulting shock waves spread outward through the core, enter the star's still unsuspecting outer layers, and hours later reach the surface, spewing the star's laboriously made elements into space in a mammoth explosion. All that is left behind is the neutron core, the strange entity that astronomers call a neutron star.

There is another possible scenario: if a star is a minimum of 30 to 40 times as massive as the sun, its gravitational collapse could be so violent that it may never become a supernova at all. Instead of bouncing back at the instant of maximum scrunch, the core continues its collapse indefinitely, forming a bizarre object of infinitesimal size and nearly infinite density, with a gravitational field so intense that light itself cannot escape—a black hole. In effect, the entire, tremendous mass of the star has gone down a cosmic drain.

These are the theoretical scenarios. And at first 1987A seemed to be following the rules: it jumped from near invisibility to respectable brightness literally overnight, and while its wave-front speed was high, its spectrum revealed the unmistakable hydrogen-bearing signature of a Type II. But when the International Ultraviolet Explorer satellite reported a rapid drop in ultraviolet light, scientists began to wonder. Says Robert Kirshner, of the Harvard-Smithsonian Center for Astrophysics: "The spectrum we're seeing in the ultraviolet resembles the spectrum of a Type I. That's a puzzle." Admits Texas' Wheeler: "There are some funny features in this supernova."

Another question that troubled some astronomers was why 1987A stopped brightening. To be sure, some previously observed supernovas have leveled off in brightness for a time, then shot up to the expected brilliance. In fact, last week southern hemisphere observatories reported that the supernova's magnitude, which had remained relatively constant for almost two weeks, showed signs of increasing slightly, from 4.5 to 4.25. But even if 1987A stays "subluminous," it will be important because it may point to the existence of a previously unknown class of stellar explosion.

What does it all mean? "There will be as many notions of what's going on as there are astronomers," says Woosley. "It's what you might call organized scientific chaos. When it's all over, we'll have a better idea of what causes a supernova, but the one rule now is that you shouldn't trust the theoreticians. Expect the unexpected."

Still, the theoreticians could crow that in at least one way 1987A had performed according to the script. Minutes after hearing about the supernova but before they learned of any neutrino data, Astrophysicist Bahcall and two Israeli colleagues began working on a paper predicting the number of supernova neutrinos that should have been recorded by various detectors on earth; their paper was published in last week's *Nature*. If the neutrinos had been recorded—and especially if they arrived before the supernova was seen—it would be a dramatic confirmation of current supernova theory.

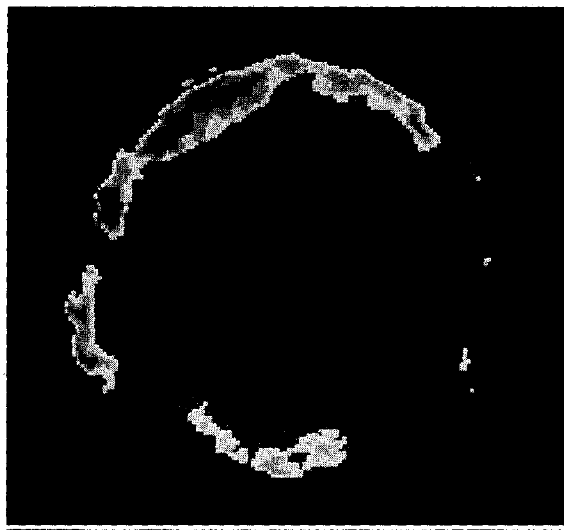
Sure enough, a check of the Kamiokande II detector in Japan disclosed that a burst of eleven neutrinos, with the predicted range of energies, arrived in a span of 13 seconds on Feb. 23, about three hours before light from the supernova was first observed. And data provided by the IMB (Irvine-Michigan-Brookhaven) detector under Lake Erie showed a burst of eight neutrinos in six seconds at the same time as the Japanese reading. Says Physicist Frederick Reines, of the University of California, Irvine: "One observation by one team is not sufficient; it has to be confirmed by an independent group. But together, the results from the IMB detector and the Kamiokande II detector are hard to disbelieve."

Both the Mont Blanc and Mount Elbrus detectors also picked up neutrino bursts at the crucial time, but scientists are still puzzling over another burst recorded at Mont Blanc some 4½ hours earlier. They will examine the data further this week at a meeting in Wisconsin. In any case, Bahcall is ecstatic. "I think this is almost surrealistic," he says. "It's hard to believe I'm actually awake." Agrees University of Chicago Astronomer W. David Arnett: "There have been smoking guns, but we've never seen the act committed before."

The neutrino bursts could help pin down theoretical models not only about how stars die but also about how the universe might expire. A debate is raging over how much "dark matter"—stuff invisible to astronomers—exists in the universe. If there is sufficient dark matter, its gravity will be enough to force the universe, still expanding from the Big Bang, to slow, stop and fall together again in a "Big Crunch." If the necessary matter does not exist, the universe will expand forever.

One proposed candidate to provide the needed matter is the neutrino—if it has mass and exists in the universe in such profusion that it could fill the bill. But 1987A may yet pour cold water on that idea: by coming in ahead of the light and in such short bursts, the neutrinos must have been traveling at or nearly at the speed of light. If they moved at the speed of light, according to Einstein, they have no mass. And if they traveled a bit more slowly and have mass, says Bahcall, that mass "is probably so small that the neutrino can't contribute noticeably to the problem." In other words, if the universe eventually crunches, it will almost certainly not be the neutrinos' fault.

Another report in last week's *Nature*, while not dealing with 1987A, provided further insight into Type II supernovas. A group led by Chemist Edward Anders and Physicist Roy Lewis, both of the University of Chicago, revealed that they had discovered an abundance of submicroscopic diamonds in a meteorite that fell in Mexico in 1969. While the impact of a meteor slamming into the earth creates enough pressure to crystallize carbon into dia-



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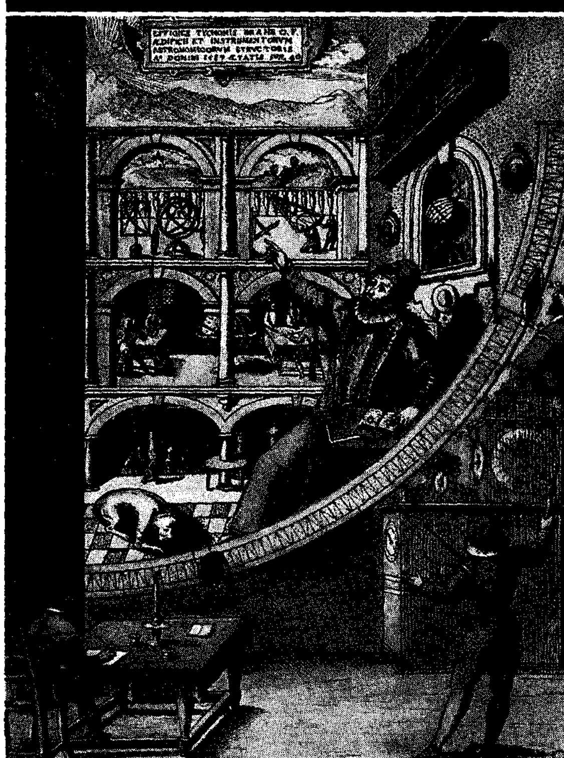


THE GRANGER COLLECTION

Tycho Brahe studied the 1572 starburst. Above: a radio image of what that supernova left behind.

monds, the tiny samples found by the Chicago team apparently resulted from an ancient supernova. The evidence: they contained atomic forms of the gas xenon different from the kind found on earth or detected in the sun.

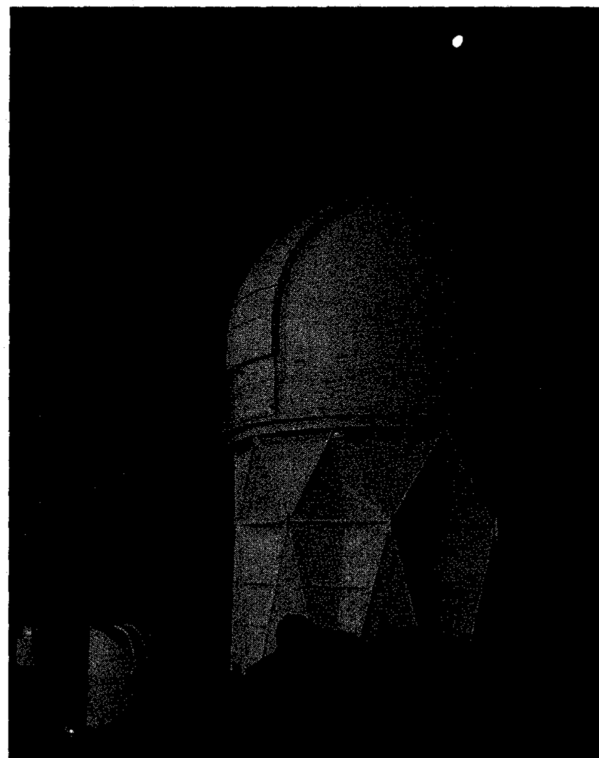
The diamonds, Anders suggests, came from red supergiant stars that threw off their outer coats, forming a gas shell. As the star's shell expanded outward and cooled, the carbon in it condensed and crystallized, forming diamonds. Later, when the star exploded, it created xenon that shot from the star's outer layers and caught up with the diamonds. "It's like the tortoise and hare," says Anders. "The xenon atoms overtake the diamonds and shoot right through them, becoming very securely locked up."

If shock waves from an ancient supernova sparked the creation of the sun and planets, Anders concludes, "it's very likely that the material from which our solar system was formed was contaminated with these diamonds. The diamonds on earth may well be a mixture of those loaded with xenon and those without it."

Still, it was the big diamond in the sky, 1987A, that was getting most of the attention last week. While the supernova shines in southern hemisphere skies, most of the world's astronomers are in the northern half of the world, and they are scrambling to find ways of viewing 1987A directly rather than vicariously through the reports of others. Says Laurence Peterson, of NASA's astrophysics division, host of the brainstorming meeting at Goddard: "Hundreds of scientists are working on ideas." One proposal: temporarily base NASA's Kuiper Airborne Observatory, which is aboard a customized Lockheed C-141 StarLifter, south of the equator. Flying at 40,000 ft., above most of the murk of the atmosphere, the Kuiper can turn its 36-in. infrared telescope on the supernova. It can be equipped with nearly a dozen other instruments that will enable scientists to determine with precision how cool the supernova's envelope is becoming, and how the dust from the blown envelope is condensing.

Another idea: use sounding rockets to boost detection equipment up 100 miles, allowing a five-minute viewing window of the southern skies before falling back to earth. A third: "Everyone who has got an instrument in his closet is digging it out and petitioning NASA for support to go to Australia and fly it in a balloon," says Marvin Leventhal, a physicist with AT&T's Bell Labs. Leventhal and his collaborator Crawford MacCallum, a physicist with the Sandia Corp., already have their balloon, a plastic monster so huge (600 to 700 ft. tall) that its material could be used to cover the Washington Monument.

University of Iowa Radio Astronomer Robert Mutel is spearheading a drive to fly advanced imaging equipment to seven observatories in the southern hemisphere that lack the sophisticated instruments. Mutel already has several offers from groups around the world to lend some of their own equipment. Indeed, his group has already decided to cannibalize its North Liberty Radio Observatory near Iowa City. Says Mutel: "I'm trying to get the NSF [National Science Foundation] to see if it can free up some money. It will be interesting to see how quickly a big bureaucracy can react."



SHAMBROOM—PHOTO RESEARCHERS

When will another supernova glow? On average, starbursts visible to the naked eye happen only four times a millennium.

Some astronomers are in less of a hurry, figuring that the best is yet to come. Says Woosley: "Once the photosphere [the supernova's luminous surface layer] is gone, that's when it gets interesting." When that shell thins out, months or years from now, astronomers will be able to look inside and "see" the newly born, rapidly spinning neutron star, but with a radio telescope rather than the optical kind.

The problem, explains Princeton Physics Professor Joseph Taylor, is not that a neutron star emits no light but that it is only ten miles across. "If you were close enough," he says, "you'd see a very bright light. But over interstellar distances, it wouldn't be visible." The solution is suggested by the name astronomers gave to known neutron stars: pulsars. The spinning neutron stars have intense magnetic fields generating precisely spaced electromagnetic pulses that can be picked up by radio telescopes. Some 440 pulsars have been discovered so far, all of them thought to be remnants of Type II supernovas. The youngest found to date sits right at the center of the Crab nebula, site of the great supernova of 1054.

How long it takes for a pulsar to develop is one puzzle 1987A may help answer. In addition, says Taylor, scientists would like to learn what kind of supernovas make pulsars. "We have a good idea that stars between eight and 15 times the mass of the sun are in the right range," he says, "but that is still somewhat speculative."

Although many scientists now lean toward the theory that dinosaurs were wiped out 65 million years ago by the impact on earth of a large comet or asteroid, some experts until recently were suggesting that radiation from a nearby supernova might have been the culprit. No evidence exists that a supernova has ever flared close enough to earth to destroy life. Still, if one should go off within ten to 20 light-years away, says Radio Astronomer Gerrit Verschuur, "we would have a problem. Everything would be destroyed by blasts of X rays, ultraviolet radiation and cosmic rays." Radiation from an expanding supernova even as distant as 50 light-years, he says, would pack a tremendous wallop, probably destroying the atmosphere's protective ozone layer and causing harmful mutations. Such a supernova could alter the course of biological evolution, perhaps wiping out entire species.

As astronomers survey the nearest stars, however, they see no apparent candidates for an imminent supernova. One favorite in the supernova category is Betelgeuse, the red supergiant clearly visible at the shoulder of the constellation Orion, the Hunter. That monster star is 650 light-years away, out of harm's way, but should provide a spectacular show when and if it expires.

Indeed, although the experts consider it unlikely, Betelgeuse may have already died of gravitational collapse—around the time of Columbus, for example, or Galileo or Napoleon. If so, the light generated by that explosion is on its way, well along on its 650-year journey to earth, bearing evidence that the red supergiant has been consumed in a cosmic catastrophe. But for now, astronomers aiming their sophisticated instruments into the night sky would be no more aware of the event than their primitive ancestors were of 1987A, when, 170,000 years ago, they stared fleetingly at the Large Magellanic Cloud. ***—By Michael D. Lemonick. Reported by J. Madeleine Nash/Chicago, Gavin Scott/Santiago and Dick Thompson/Washington***