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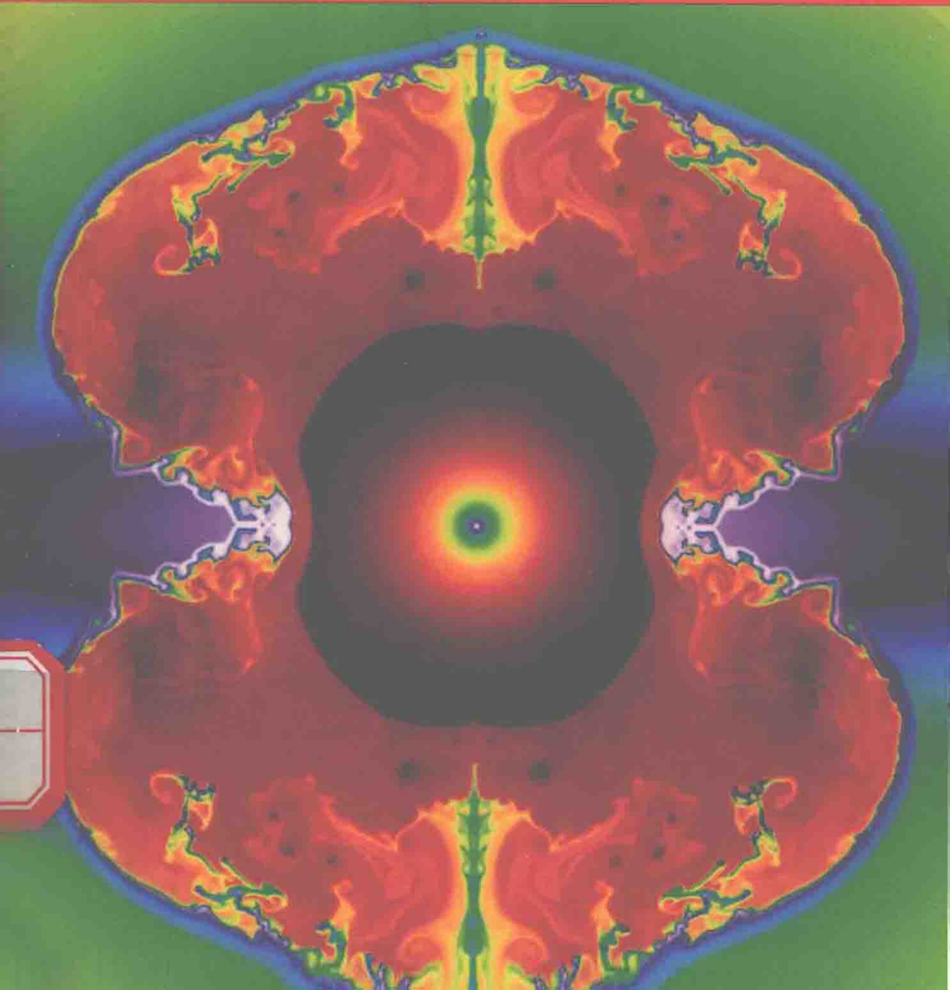

THE SUPERNOVA STORY

LAURENCE A. MARSCHALL

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To Emma, Geoffrey,
and Ellen

Preface (1994)

In the preface to the first edition of *The Supernova Story* I expressed the hope that, along with telling the story of exploding stars, I might give the reader some appreciation of how astronomy was done. Rereading what I had written there, six years later, I realize that doing science was what the book was about in the very first place. Conventional wisdom in science is so fluid that any account of a particular discipline is dated almost as soon as it reaches the bookseller's shelves. But the overall enterprise of science is much more enduring. You may never be able to step twice into the same river, yet you still know it's a river you've stepped into. While some of the facts, figures, and interpretations I cited in 1988 have changed since I wrote them down, I still feel satisfied that this book presents a reliable account of the process of research in one of the most exciting fields of modern astronomy.

Having said that, I am struck with how little has actually changed despite all that has happened. In most respects, Supernova 1987A has developed about as we expected. The overall decline in its light output, the appearance of gamma rays from its radioactive by-products, the interaction of its outrushing debris with the surrounding interstellar gas, have all proceeded pretty much on schedule. Several hundred new supernovae, most of them very faint, have been observed since 1988, and the brightest of the new crop, which appeared in March 1993, caused almost as much excitement as its predecessor. That one, Supernova 1993J, was enough like Supernova 1987A to show us what we got right in the first place, and enough different to lead us into fascinating new realms of inquiry.

In recent years, new telescopes in space and on the ground have helped us discover new pulsars and supernova remnants. And a number of clever and diligent theoretical astrophysicists have come up with sparkling new computer models that highlight the fine details of supernova explosions. The skeleton picture of a supernova we had in 1988 now has much more flesh on its bones. But its overall shape is very similar to what it was back then.

For that reason I have resisted the urge to tinker with the original text, and have not endeavored to bring each fact and figure up to date. By the time you read this, science will surely have moved on again. There may be a dozen new pulsars or three hundred faint supernovae not mentioned here, along with a host of novel theories that confirm or deny possibilities I have raised. While I have tried to clarify ambiguous passages and correct outright misstatements of fact, the body of the first edition stands pretty much as it did when I wrote it. It should serve as a trustworthy guide to our knowledge of supernovae at the time of Supernova 1987A.

Still it is fascinating, after some passage of time, to return to the scene of an event and learn what has happened to its principal characters. I have, accordingly, added an epilogue to the original edition, so that the reader can find out what has happened to Sanduleak -69 202 since 1988. I have also included a section on recent advances in supernova research in that chapter and a few additional references in the bibliography so that the reader may follow further developments in the field with an intelligent eye.

The preparation of this new edition benefited from the work of many besides myself. I would particularly like to thank Stan Woosley for his careful reading of the original text and his many helpful suggestions for improvements. Greg Aldering, John Blondin, Alex Filippenko, Janet Mattei, Dick McCray, Mike Richmond, Brian Schmidt, Michael Seeds, and Nick Suntzeff contributed information and data on late-breaking developments. Shawn Baker provided invaluable help in library research. I have also incorporated revisions proposed by a number of readers and reviewers over the years. Finally, I would like to thank Trevor Lipscombe at Princeton University Press, without whose efforts this paperback version would not have been produced.

Laurence A. Marschall

Gettysburg, Pennsylvania

Preface (1988)
A Blaze in the Sky

The annals of the Benedictine monastery of St. Gallen in Switzerland record the following entry for the year 1006. "A new star of unusual size appeared, glittering in aspect, and dazzling the eyes, causing alarm. . . . It was seen likewise for three months in the inmost limits of the south, beyond all the constellations which are seen in the sky." Chinese court astronomers saw it too, shining with a brilliance that rivaled the moon; several years passed before it faded from sight.

Monks and mandarins had witnessed a rare and wonderful event, not properly a "nova stella" or new star, but the last self-destructive burst of a dying star, an event known to modern science as a supernova. The supernova of 1006 was the brightest in recorded history, one of the very few such explosions to have occurred close enough to our sun to be visible to the naked eye. Fewer than a half-dozen naked-eye supernovae have been recorded since that time, and recent research in the field has largely had to make do with an examination of ancient records, along with analyses of the faint light from supernova explosions in galaxies beyond our Milky Way. Until 1987, not one nearby supernova had been caught *in extremis* by the tools of 20th century astrophysics.

That situation has changed abruptly. Late in the afternoon of February 23, 1987, in a tunnel deep beneath Kamioka, Japan, a dozen flashes of light occurred in a sealed 3000-ton tank of water. No human eye saw them, but all around the tank an army of ultrasensitive photodetectors converted the feeble flashes to faint electrical signals, passing them on to a computer for storage and analysis. Simultaneously, in a salt mine under Lake Erie, a similar apparatus recorded flashes in another giant tank of water. In both cases, the faint glitter marked the passage of a flood of neutrinos, subatomic particles that are released in the decay of the nuclei of atoms. Because a neutrino can pass through a planet like sunlight through glass, even a dozen flashes—a handful of neutrinos snagged in flight—marks a signal of considerable intensity. On February 23, Earth was washed by a great wave of neutrinos, like a torrent from a broken dam. It was the blast from a nearby supernova.

At first neither Japanese nor American physicists were aware of what their apparatus had detected. But by the next night astronomers worldwide were jubilantly passing the word of a brilliant stellar explosion. Ian Shelton, an observer working for the University of Toronto on a mountain in Chile, had photographed a new star, clearly visible to the naked eye, in the southern sky. Located in the Large Magellanic Cloud, a neighbor galaxy to our Milky Way, the exploding star was so bright that when the instruments on some large telescopes were first directed at it, they were saturated with light and unable to measure it properly. One telescope in Chile observed the supernova with its dome partly closed to reduce the level of light falling on its detectors. With all Astronomy in a frenzy over the new discovery, the neutrino physicists checked their data and found, on records made less than a day before Shelton's sighting, the signature of the neutrino pulse.

The burst of light and neutrinos from SN 1987A, named for the date of its arrival at our planet, had been on its journey from the Large Magellanic Cloud for 160,000 years, a long time in the history of humanity. Had the explosion gone off 100 light-years nearer to us, the brilliance would have reached Earth 100 years sooner, arriving in an age when telescopes in space weren't even a dream, when photography was in its infancy, when the analysis of spectra was just beginning to be applied to the study of the sun. Yet, by a great stroke of fortune, the light reached Earth during a time of great technological proficiency, a golden age for astronomy.

Contrast the current sighting with its counterpart a thousand years earlier, and you can appreciate how times have changed. In 1006, the supernova was a blaze in the sky, a portent, a sign from the heavens. Emperors, fearing perfidy, consulted court astrologers; euphoric monks saw visions of the Cross in the sky. The 1987 supernova, considerably farther away, was bright only to astronomers; to the untrained eye it appeared as just one of the many featureless

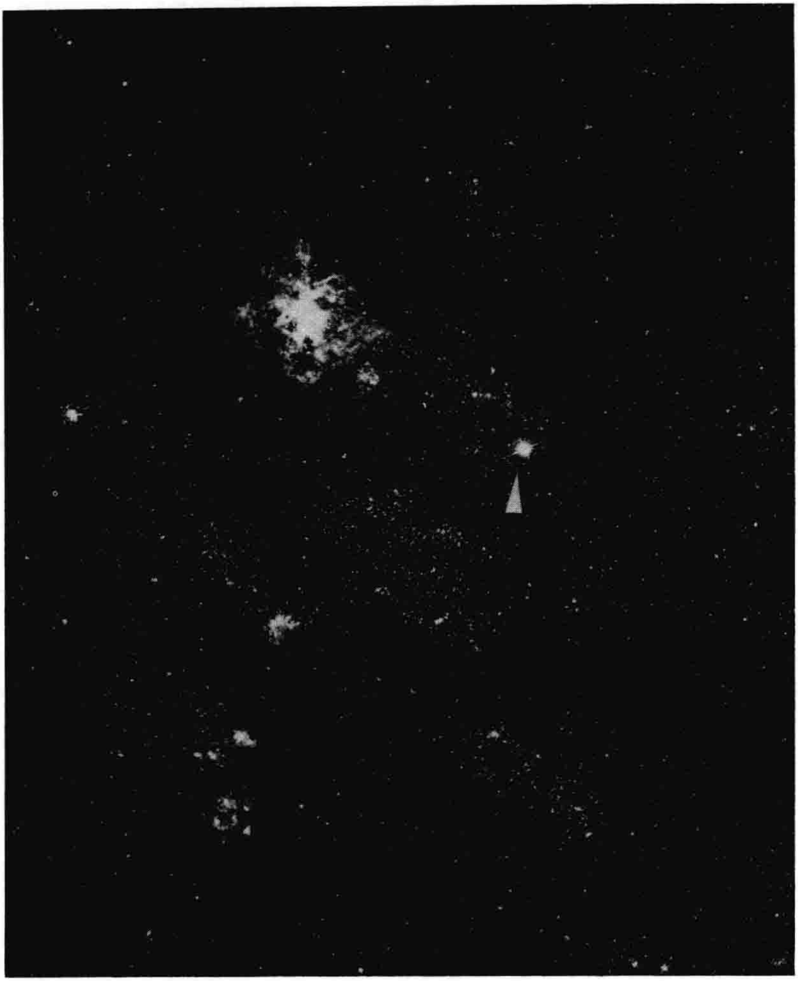

FIGURE 1: Supernova 1987A is indicated by an arrowhead in this photograph of a portion of the Large Magellanic Cloud taken on February 25, 1987 by Wendy Roberts of the Harvard–Smithsonian Center for Astrophysics using the wide-field Schmidt telescope at Cerro Tololo Inter-American Observatory near La Serena, Chile. The 30 Doradus Nebula, a large gaseous nebula (a gas cloud), is to the upper left. (National Optical Astronomy Observatories.)

specks in the dark night sky. Yet in its own fashion, SN 1987A was as much a public event as the supernova in 1006. It even was accorded a place of honor on the cover of *Time* magazine.

Why all the fuss? Historically speaking, there was nothing new about the 1987 supernova but its name. Medieval and Renaissance astronomers had witnessed such things several times. They called any star that appeared where none had been before a "nova stella," a "new star." Nowadays, astronomers use the old terminology, "nova" for short, but they recognize two sorts: common novae and supernovae. Common novae, as the name implies, are relatively frequent. Supernovae, especially bright supernovae, are exceedingly rare. I will use all three terms. In discussing the early history of astronomy, an era when no one distinguished between common novae and supernovae, I will use the term "nova" to refer to any new star, whatever its nature. In most cases, however, especially where confusion might arise, I shall use "common nova" and "supernova" as appropriate.

Few would have taken notice had the new star of 1987 been a common nova. As we understand them, common novae are explosive outbursts that occur among close pairs of stars when one of the pair accumulates material from the other. A critical mass of this surface debris may abruptly ignite, giving a distant observer the impression that a new star is appearing from nowhere. An exceedingly bright common nova went off in 1975 among the stars of the constellation of Cygnus. At maximum it appeared brighter than the supernova of 1987. Yet it received scant mention in the press. Even among astronomers, common novae are something of a curiosity, of interest only to a few specialists. Were supernovae just upscaled nova explosions, they would merit little attention.

Supernovae, their name notwithstanding, represent a phenomenon fundamentally distinct from common novae. Compared to a supernova, a common nova sends out faint sputters of light and feeble puffs of gas. A supernova rends a star to pieces, pushing the laws of nature to the limit. Supernova explosions mark a climactic stage in the lives of stars, and play a central role in the formation of the elements, the shaping of the galaxies, and the evolution of life. Some astronomers suggest that formation of our sun may have been triggered by a supernova, and few doubt that most of the atoms in our bodies originated in the outward rush of matter from one of these exploding stars. Thus, the story of supernovae, ancient and modern, touches on the foundations of biology, physics, cosmology, and astronomy, and draws on the resources of historians, anthropologists, and geologists as well.

In the chapters that follow, we shall trace the threads of that story, from the first sightings of new stars in ancient times, to the latest findings from Supernova 1987A. I shall try to make clear why supernovae generate so much excitement, even though so few of us—astronomers included—have ever seen one with our own eyes. I also hope, along the way, to give you some appreciation of how astronomy is done, and why so many people who do it find it a source of endless amusement and edification.

Laurence A. Marschall

Brookline, Massachusetts

Acknowledgments

Anyone who writes a popular science book inevitably finds it necessary to seek the advice of many others. It could not be otherwise. Science has become so specialized that even in a narrow field like supernova research, which is itself a subfield of astronomy, there are few, if any, who have a total grasp of the entire subject. Even when discussing the same phenomenon, the theoreticians often understand it quite differently from the observers.

I am an observational astronomer—one of those who still use telescopes. My research deals with young stars, not dying ones, though I have had a nonprofessional interest in supernovae for many years. One of the greatest pleasures in writing this book has been discussing supernovae with those whose experience and knowledge is far greater than mine. It has also been a pleasure to work with many others, not just astronomers, who have offered support and criticism, or who have helped obtain illustrations for the book.

Those who have been generous in supplying help and information include Tom Bania, David Devorkin, Oscar Duhalde, Ron Eastman, Andrew Fraknoi, Robert Garrison, Russell Genet, Martha Hazen, Lewis Hobbs, Dorrit Hoffleit, Kenneth Janes, Robert Jedrzejewski, Albert Jones, Steve Kent, Charles Kowal, Donald Lamb, Stephen Maran, Brian Marsden, James Matthews, Richard McCrosky, Peter Nisenson, Bernard Pagel, Costas Papaliolios, Jay Pasachoff, Carl Pennypacker, Rudy Schild, Ronald Schorn, Michael Seeds, Fred Seward, Ian Shelton, Larry Sulak, Victor Thoren, Alan Uomoto, and Nolan Walborn. Special thanks as well to Ken Brecher for many lively lunchtime discussions. And thanks to Jonathan Weiner, who warned me how much labor was involved in writing a book. He was right.

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My editors at Plenum Press, Linda Greenspan Regan and Victoria Cherney, ably saw the project through from start to finish; I could not and would not have done the book without them. Finally, my warmest thanks to the members of my family, who have helped this book in so many ways. My parents, Bernice and Frederic Marschall, gave me a love of learning that I hope I will never lose. My father, in addition, took several of the photographs and printed many of the illustrations that appear on these pages. My sister Claudia, who edits, teaches, and directs, has tolerated years of my dubious humor and contributed all of my best jokes. Last, but far from least, I thank my children, Emma and Geoffrey, who exercised extraordinary patience while I typed, and my wife, Ellen Friedman Marschall, who not only read each page, but who labored far harder than I to keep everything going.

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