Chapter 17 **A Big Star Falls Hard**

The bigger they come, the harder they fall—Robert Fitzsimmons, prizefighter

On January 28, 1986, shuttle *Challenger* exploded on its way toward orbit. The rubber O rings that were supposed to seal the joints in the solid-propellant rocket boosters failed, allowing exhaust to burn a hole in the fuel tanks. Seven astronauts were killed almost instantaneously, including Christa McAuliffe, NASA's first "teacher in space". Prior to the launch children around the USA watched Christa McAuliffe explain the science teaching experiments that she was prepared to demonstrate. A mere 73 seconds after liftoff, 8.9 miles above the Atlantic Ocean, her life ended before the eyes of many an idealistic child. Ten years later National Public Radio was to conduct interviews with those children, now in their twenties, and we heard their reactions--first confrontations with death, first doubts of NASA or of the US government, first awareness that life can end in an instant. It was indeed a great tragedy. But one thing is clear. There was from the first, on every shuttle launch, a chance of disaster. The one certain thing that Americans had to confront was our cherished hope in infallibility. Collateral damage affected me; namely, that disaster also delayed the launch of NASA's *Compton Gamma Ray Observatory.* I am sometimes asked what we missed by its not getting up on schedule in 1987. We missed the astronomical event of the century—Supernova 1987A (*SN1987A*).

What we all feared while preparing GRO for launch was not a shuttle disaster but that no supernova would occur sufficiently nearby during its mission to provide an observable flux of gamma rays from the radioactivity. Their rate of arrival at earth declines as the inverse square of the distance to the supernova. Standard astronomical estimates are that a supernova occurs in our Milky Way Galaxy about every thirty years, although unpredictably spaced in time. Therefore the most likely outcome was that during a five-year mission we would have no suitable supernova within our Galaxy. We could live with those odds because young supernova remnants will still emit detectable gamma-ray lines for a decade at least. Then, as if by miracle, fate arranged that such a star would explode at just the right time.

Explosion may not be the best word to suggest that its bright visual display actually happened as consequence of its central mass falling onto itself because of the strong gravitational pull of its own mass. Its core collapsed onto itself, leaving a gravitationally bound neutron star or a black hole at the center and expelling the remainder. Nineteen neutrinos observed over about ten seconds after the collapse of SN1987A attest to the ferocity of that core collapse. It is amusing to be reminded that SN1987A actually exploded about 170,000 years ago, during pre-human prehistory, in the Large Magellanic Cloud, a small satellite galaxy attached to our Milky Way; but its gamma rays, traveling at the speed of light for 170,000 years to cover the 170,000 light years of distance to the Large Magellanic Cloud, reached Earth in the very year scheduled by a maturing mankind for the launch of *Compton Gamma Ray Observatory*. That cosmic coincidence is the irony. I often joked, "God was kind to arrange this. But a leaky O ring fouled it up!" Gamma Ray Observatory would not be launched until April 5, 1991, more than four years after the light from supernova 1987A reached earth.

The most intense predicted radioactivity was that of ^{56}Co, which is produced when the radioactive but short lived ^{56}Ni decays to it. The ^{56}Ni nuclei are the nuclei created by the explosion. The supernova is a dense ball, more massive and thicker than the sun, so those gamma rays cannot escape from the deep interior in the early months. The radioactivity is initially imbedded too deeply within the explosively expanding mass. One can no more detect it immediately than one can detect gamma rays from natural uranium decaying in the center of the Earth. But the exploding supernova is, unlike the Earth, flying apart at speeds near 5000 km/sec, or 3000 miles per second. That is fast! According to calculations, that expanding mass would become thin enough for the cobalt gamma rays to emerge after about one year, which would have been in early 1988, near the time of our scheduled launch. So the timing had indeed been almost perfect! We expected[1] the ^{56}Co gamma rays, especially those having energies of 847 keV and 1238 keV, to be visible for about three years. But as the *Challenger* hearings were unfolding, it became apparent that we would not get up in time to seek them. I felt deep disappointment. The gamma ray detection would have provided the first unambiguous proof that the iron of our world had indeed been created as radioactive fallout from ancient supernovae. Fortunately, that proof would emerge from observations of supernova 1987A by other research groups.

But there was a second, more subtle, loss associated with our being grounded in 1987. We could have measured details of the structure and mass of the exploding envelope above its collapsed core. By the year 1987 most astronomers no longer needed proof that the elements were synthesized in supernova explosions. They accepted that. The circumstantial evidence for that belief had mounted since the 1960s. Detecting the gamma-ray lines would, in that regard, simply prove it. Nor was it so pressing to demonstrate that iron was ejected in the form of radioactive nickel rather than as iron itself. Stable, rather than radioactive, iron isotope production and ejection had been championed during two decades, 1946-1966, by Hoyle and Fowler. The correctness of radioactive ^{56}Ni as nature's parent for ^{56}Fe had grown gradually more secure. In the first place, supernova theory demanded it unless our ideas were wrong. Secondly, the 77-day halflife of ^{56}Co matched very well the halflife for the decay of the optical brightness of one specific class of supernova, the so-called Type Ia supernovae. It also matched the halflife of the decay of the brightness of supernova 1987A. It had become apparent that supernovae would become dark after their first week were it not for radioactivity reheating the cooling interior and thereby keeping it shining. That 77-day match for SN1987A was in the last analysis a surprising and fortuitous result of the particular kind of supernova that SN1987A was. Being twenty times more massive than the sun, its precursor star had aged in just such a way as to be compact and blue at the time of its collapse. If it had been distended and red, as most supernovae of this type are, the visible effect of the radioactivity on the light output would not have been so clear. But this was not (all) known at the time when both the star and the *Challenger* exploded and when *Gamma Ray Observatory* was therefore held back.

The reorientation in my 1974 paper[1] had emphasized measuring *the structure* of the exploding stars with the gamma rays. In that work the rate of rise of the gamma ray intensity as the object expanded was argued to be more informative than its intensity after maximum, because the rise time measures where the radioactivity is located within the exploding object. A new goal would measure the star's radioactive structure with gamma rays, using not only the many strong lines from ^{56}Co decay but also lower energy ones that were emitted following ^{57}Co decay, which is the parent of the mass-57 isotope of iron, ^{57}Fe. The less abundant ^{57}Co would become the brighter of the two gamma-ray emitters after two years. Differing gamma-ray lines have different transparency within the supernova owing also to their different energies. In the energy region of about one MeV, the more energetic the gamma ray, the more penetrating it is. Those from ^{57}Co were less able to penetrate the supernova mass, so their breakout was retarded somewhat in time relative to those from ^{56}Co, which emits more energetic gamma rays. Likewise the strength of the 847 keV line from ^{56}Co would be seen to have been retarded with respect to that of the 2599 keV line, even though both are emitted at the same rates and from the same locations. The supernova structure could be mapped in this way. A rather poor analogy might be the use of X rays in medicine to map the interior of the human body. I began to advocate that interior mapping as another strong reason in support of gamma-ray spectroscopy of supernovae. These opportunities were lost in 1987 because *Compton GRO* was not up.

I suspected that mixing of the radioactivity into overlying portions of the expanding star should cause the gamma ray intensities to be detectable sooner than would be observed in unmixed models. I found it likely that the violent explosion would send fingers of radioactivity outward, penetrating through the overlying matter. This was to prove to be the case in supernova 1987A. But our inability to launch frustrated each hope to measure these effects myself, using the good time dependent precision that GRO could have provided.

For all of these reasons and more, the *Challenger* fireball was not only a national tragedy but also wrecked some of my personal scientific goals. Had my own observations with the *OSSE* team of the gamma light curves been able to confirm and utilize my own predictions and motivations from 13-28 years earlier, it would have been the luckiest outcome of my lucky scientific life. The issues are dramatic and fundamental for the natural philosophy of our material world. But slight frustration over this is of no consequence for science, and is truly of no concern to the scientist. For the most part, the desired understanding was achieved anyhow, by other observations. What is exciting to me is that we scientists did reach, during the supernova 1987A event, a profound new level of understanding of supernova nucleosynthesis and structure. That supernova spawned a flurry of theoretical papers looking intensely into the explosion mechanism of Type II supernovae. It continues unabated to this day.

It was just prior to SN1987A that Nancy and I decided to take my last sabbatical leave from Rice University. Waiting out the *Challenger* inquiry was no fun, except for the exciting brilliance of my hero from the 1960s, Richard Feynman.