# Supernova 1987A: one year old

**On 23 February 1987, Supernova 1987A exploded in the Large Magellanic Cloud (LMC), about 55 kpc away. A brief flash of neutrinos, signifying the formation of a neutron star, has been followed during last year by emission from the expanding remnant in every part of the electromagnetic spectrum. The only radiation not seen was the burst of gravitational waves from the explosion; none of the detectors which might have seen it was operating.**

**Many of the observations and their theoretical implications could uncharitably be described as routine. The number and energy of the neutrinos conformed with models of the explosive energy release. When, after some confusion, the progenitor star had been identified as the blue supergiant Sk-69 202, the luminosity and radio emission around peak magnitude fitted well with complex hydrodynamical calculations of the core collapse and outburst. The subsequent exponential decline of the light curve was ample demonstration that decay of $^{56}$Co was the energy source.**

**But minute scrutiny of astrophysical theories is rare, and the wealth of new and detailed data from SN1987A has allowed already successful models to be refined by orders of magnitude. Twenty neutrinos on magnetic tape are worth any number of particle fluxes calculated by computer. Monitoring the light curve to unprecedented accuracy over many magnitudes allows exact deduction of the quantity of $^{56}$Co synthesized, and of the presence or absence of secondary energy sources.**

**Now, as the expanding remnant thins and the core becomes visible, entirely new observations become possible. The $\gamma$-ray and infrared lines recently detected would not have been seen from a more distant supernova, and will allow astronomers, during the coming year, to watch the cooling remnant turn to gas and dust.**

**By following the day-to-day evolution of this supernova nebula, we will learn not only about the fate of one star, but about local conditions in the LMC, about interstellar matter between ourselves and the LMC, and with greater certainty about supernovae in distant galaxies, of which two have already been spotted this year.**

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telescope optics, the shape of the single-source fringe pattern is not known *a priori*, but must be determined by observing a fiducial star known to be a point source. A difference between the fringe pattern of the source of interest and that of the fiducial star is then evidence for structure in the source. Of course there will always be statistical differences, and if the fiducial star and the source do not follow sufficiently similar paths through the atmosphere and telescope optics, there could be systematic differences as well. These might be misconstrued as evidence for a spurious faint second source (which would produce only a small modulation of the fringes of the brighter source).

The observational technique (speckle interferometry) which discovered the speck is more sophisticated than the simple two-hole system described above (the telescope is not masked at all), but the principles, and limitations, are the same. Although the technique is reliably used to measure the separations of close double stars, the many possibilities for systematic error are highlighted by occasional spurious discoveries (like the 'companion' to the star VB8, which inspired a whole conference before it was shown not to exist).

There is yet another way that SN1987A could have created a mirage: its light could have been deflected by a compact object between it and the Earth[4]. The mass required ranges from about 10 solar masses ($M_\odot$) if in our Galaxy, to about $10^5$ $M_\odot$ if near the supernova's galaxy. The numbers of such hypothetical compact objects are, however, constrained by the known total masses of the galaxies, and the probability of producing a second image of the supernova in this way is less than $10^{-6}$. The reported colour difference between speck and supernova is a further problem for this model. If the speck was real, it must have shone by reflecting the light of SN1987A or by emitting a line spectrum (from rarefied gas), a nonthermal continuous spectrum (from relativistic particles) or a thermal continuous spectrum (from dense gas or a hot solid). People are circulating preprints invoking all these mechanisms, but only the thermal spectrum is consistent with the observations as reported, except in implausible situations.

Our view of interstellar space is obscured by small grains of condensed refractory elements. A large cloud of these (perhaps the disk of an inchoate companion star) could survive heating by the light pulse of SN1987A and reflect some of its light. Difficulties arise, however, because dynamical arguments and the observed asymmetry make it unlikely that the cloud could cover more than one-tenth of the sky of SN1987A. An uncomfortably high bulk albedo is thus required. The problem is even worse if the reported colours of the speck[1] are accepted. Grains scatter more blue light than red in the forward direction, so it is hard to believe that a cloud in front of the supernova reflects three times more red light than blue, as indicated by the observations. Light scattered through the cloud can be red enough, but would be too faint. If the cloud were behind SN1987A, blue light would penetrate deeper into the cloud and be absorbed. A disk or grains with conventional properties thus reflects about 30 per cent of the incident red light, but only about 22 per cent of the blue. But were the cloud behind the supernova, scattered light arriving at Earth 30 days after the explosion would have to have been emitted by SN1987A less than 15 days after the explosion, when it was much fainter and bluer. The cloud would have to reflect almost all of the incident red light, but only 2–17 per cent as much of the blue light, and no plausible fiddling of grain parameters can produce these bulk albedos.

Line emission[5] is excluded by high-resolution spectra[6]. Speckle observations show that in the 100-Å band around the hydrogen H$\alpha$ emission the speck was one-tenth of the brightness of SN1987A. If the speck's one-tenth of the light in this 100Å band were concentrated in a line less than 40-Å wide, it would easily be recognized in the combined spectrum; careful fitting could identify even broader lines. In its first day, SN1987A probably emitted a pulse of about $4 \times 10^{46}$ erg of ionizing radiation (refs 7, 8 and D. Arnett, preprint) which could ionize a dust-free gas cloud. Models of this sort, invoking the recombination of ions with electrons, are hard pressed to produce the observed H$\alpha$ luminosities[9]. The mass of ionized gas required is of the order of $M_\odot$, and the expected linewidth is only about 0.4 Å (caused by Doppler broadening by speeds of 20 km s$^{-1}$). Even with an ionizing pulse orders of magnitude larger than expected (so that the ionized cloud becomes thick to Compton scattering[9]), or using shock waves to do the ionization, it does not seem possible to get the line wider than

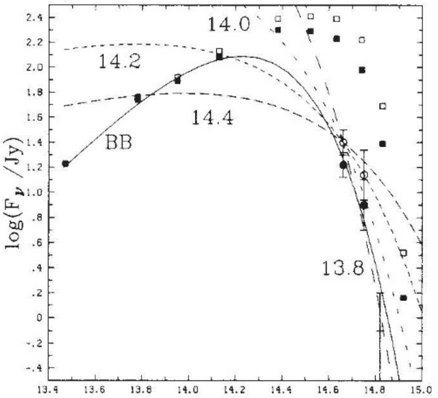

**Fig. 2** Spectrum of SN1987A plus speck (squares) and speck alone (circles) 30–37 days after the explosion. Filled points are as observed[1,6]; open points have been de-reddened assuming the the relative extinction of blue and visible light ($E_{B-V}$) is 0.2, and the extinction curve is that of the Large Magellanic Cloud[14]. Dashed curves, single-particle synchrotron emission curves with critical frequencies as labelled. Note that no synchrotron spectrum is simultaneously compatible with the total flux measurements in both the infrared and ultra-violet. The curve labelled BB, emission from a 3,000 K black body, is marginally consistent with the total flux in the infrared.