SN 1987A at La Silla: The Early Days

John Danziger[1]
Patrice Bouchet[2]

[1] INAF – Osservatorio Astronomico di Trieste, Italy
[2] Observatoire de Paris, France

We first try to capture some of the response at ESO La Silla to the announcement of a bright supernova in the LMC – the excitement, the planning, and the discussion. Some of this was a result of the growing realisation that we were confronted with a unique event whose special aspects we describe. We conclude with very brief descriptions of the role of ESO astronomers in trying to unravel some of the mysteries in competition and collaboration with other observatories.

First news of a bright supernova

When astronomers at La Silla arrived for the ritual afternoon tea at 4 p.m. on 24 February 1987 after the previous night's clear observing, they were greeted by the news that a supernova had been detected in the LMC the previous night by Shelton at the neighbouring Las Campanas Observatory. This news, conveyed to La Silla by a telephone call from Mark Phillips at Cerro Tololo at tea-time, was met with only a fleeting skepticism because the source was recognised as impeccable. The tea-time ritual of groggy astronomers quietly sipping their tea and gazing out the windows to judge the prospects for the coming night by the quality of the sky was transformed, to be succeeded by flurries of excited, but still to some extent uncoordinated, planning. Nobody doubted for one second that the sky would be clear and there would be excitement galore in the days and nights ahead. And indeed there was!

Now on such occasions a large observatory such as La Silla can be considered like a naval fleet consisting of many ships of the line from torpedo boats to cruisers and even aircraft carriers. La Silla had them all. Fortunately, also present was the Admiral of the Fleet Lo Woltjer, otherwise known as the DG of ESO. An admiral has the ultimate power to define battle tactics, and therefore the roles of the various ships under his command, while leaving his individual captains the flexibility of initiative and manœuvre; and this was the course followed by our Admiral. All observers were encouraged to plan for observing SN 1987A by whatever means at their disposal. This was understood to mean abandoning scheduled observing plans. In fact there were even judicious changes of instruments, one being the immediate installation of IR equipment on the 1-m telescope, the rewards for which can be seen in the long history of IR photometry and low-resolution spectroscopy emanating from La Silla and its importance in determining the bolometric light curve, among other things.

There were also remarkable sociological effects witnessed at La Silla during this initial period. Although even after the first night astronomers were talking to one another at afternoon tea more than ever before, it was decided after the third night to have regular meetings of all observers at 4 p.m., naturally with the tea and cakes, but in a room in the 'Atacama Hilton' ample enough to accommodate both the sipping and munching and, more importantly, a lively report and discussion of what had transpired the previous night. Our Admiral was always present ready to give judgment on various delicate questions such as who should co-author the various papers that would inevitably appear and could this include collaborating colleagues (named in their original proposals) back in Europe. Not much room for Solomonic judgements there.

To add to all this excitement we began to receive advice on the internet on what to observe and how, and even offers to take responsibility in some yet to be constructed archive of all the data flowing in, not just from La Silla but from the other southern observatories as well. Separation by intercontinental distances made handling these matters relatively easy.

The observations commence

Spectral observations at the 3.6-m telescope were complicated because the supernova was too bright, not too faint. This necessitated the insertion of neutral density filters involving added calibration problems and very short exposures. It left little time for us to stand outside and admire the supernova with the naked eye. Appreciating by now that this was an historic occasion, we did however sneak outside occasionally to satisfy ourselves that it had not been an optical illusion. No breaks that night however for midnight lunch at least at the 3.6-m.

In the meanwhile the internet had been flowing with speculations about what type of supernova it might be even after spectra had been taken. There was in fact misinformation. Some of this speculation was undoubtedly biased by the knowledge, among supernova *aficionados*, that a Type II supernova had until that time never been recorded in a Magellanic-type irregular galaxy. Moreover in flux uncalibrated spectra – those you are likely to see first as a spectral observation is completed – the nature of P-Cygni profile of Hα does not exactly stand out particularly for an observer inexperienced in such matters. We soon knew that poor statistics had been responsible for any bias.

For these reasons, and for the more important reason of informing the community about observed facts and some measurable quantities, an *ESO communiqué* was sent in the form of IAU Circular No. 4326 agreeing with the classification of Type II made earlier in IAUC No. 4317 from Las Campanas and IAUC No. 4318 from CTIO. Identification and temporal behaviour of various lines were given. What was not remarked was how the velocity of the photosphere was decreasing so rapidly in the early stages as the photosphere receded into the ejecta that it could be seen online with each successive spectrum.

A somewhat tense atmosphere surrounded activity at the 1-m telescope because, as mentioned above, the removal of a spectro-polarimeter to be replaced with IR InSB photometer had been approved by our Admiral. There was worry whether this change could be accomplished rapidly enough to allow observations before SN 1987A reached a high enough air mass to impede a sufficiently accurate beam switching. Accurate optical alignment was also a major point of concern to establish the throw amplitude for the chopping in the complicated dense field of 30 Doradus. The final outcome, predicated on the strong signal from the supernova, was that the 1-m IR equipment was kept in place and scheduled, even for daytime, months ahead.

To add to this excitement (and tension) during that initial period was the news, informally propagating at that stage, but soon officially revealed in IAUC. Nos. 4323, 4338, 4340 that neutrino bursts had been detected, providing observational evidence that theory was on the right track, but also giving a precise time for the collapse of the core after the physicists had clarified which reported events were real. These neutrinos certainly played a part in giving an extra incentive push that we were on to something special, just as they may have provided a push to force the envelope off the collapsed core.

Uniqueness of the event

It is worth recalling just how unique this SN 1987A proved to be. Much of this uniqueness, though not all, was appreciated within the first week or ten days after the discovery and ESO observers played a part in elaborating some of those. Here we list some but probably not all. One general aspect, not listed but certainly unique, was the extent to which it has triggered a huge upsurge in studies of supernovae of all types, and the extent to which it, as a single object, has been studied over the past 20 years. Virtually all of these unique characteristics stem from its proximity in the LMC and of course were helped by the availability of modern instrumentation, eager observers and theoretical insight.

SN 1987A is the only naked eye supernova for 383 years. It was the first Type II recorded in a Magellanic type irregular galaxy. It was the first supernova whose progenitor was identified. It is the only supernovae from which neutrinos have been detected (marking the core collapse). It was the first supernova to be detected in gamma-rays, both line and continuum emission. The prompt intrinsically faint radio burst was the first of its kind. (Stronger radio emission started later at about the same time as X-ray emission.)

There was evidence of asymmetries in the expansion and shape revealed by means of the Bochum event, polarisation and later structures in emission line profiles. While spectral synthesis of both UV and optical photospheric spectra using Monte Carlo methods satisfactorily explained the main features, the enhanced lines of s-process elements identified at CTIO and later modelled at ESO proved something of a surprise.

And somewhat later direct observations of the masses of ^{56}Co and ^{57}Co were both confirmed by entirely independent methods. Also, with greater uncertainty, a determination of the increased mass of Fe albeit before all the ^{56}Co had decayed. The first light echoes from a supernova were detected. The unambiguous detection of dust formation in the expanding ejecta was also a major feature.

As a separate issue SN 1987A in the first days was bright enough that it acted as a background source observable at very high spectral resolution revealing interstellar lines and bands never before detected in the LMC.

As a further separate issue of uniqueness one might suspect that the increase in cost of IAUC telegrams announced in IAUC No. 4344 was a case of demand inflation whose immediate cause was SN 1987A.

The role of ESO in some of this

1. The progenitor. Astronomers were quick to identify the culprit as Sanduleak –69° 202, a blue supergiant, and ESO was well up in this competition with IAUC No. 4319. These results were later elaborated with a careful evaluation of the astrometry (West) in one of a series of papers to appear as a volume of A&A Letters, as were most of the other early results from ESO.

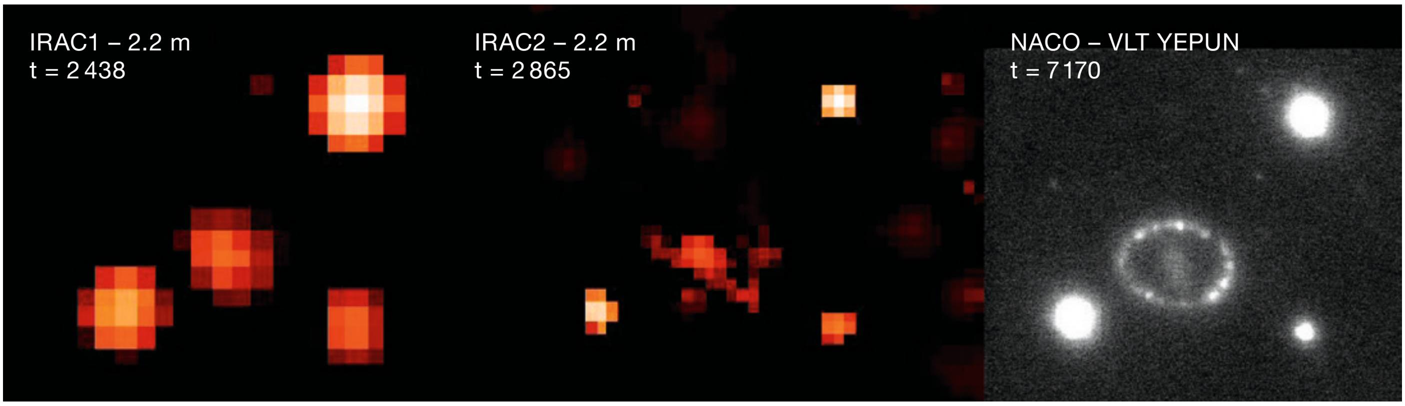
2. A long series of optical photometry was obtained with various filter systems at various smaller telescopes. These included *U*, *B*, *V* broad bands, the Walraven system and the Geneva system. In general the *U*, *B*, *V* observations were used (in combination with the IR) for defining the bolometric light curve. The most accurate proved to be the Geneva system photometry (Rufener) in which, to this day, one wonders about the reality or otherwise of small glitches seen occasionally, particularly in the *UV* band. With time, account had to be taken of the contamination from two neighbouring stars.

3. Broad-band IR photometry covering from *J* to *Q* bands was essential for establishing the bolometric light curve and therefore the energy budget of SN 1987A as a function of time (Bouchet). It had and has special relevance to the study of dust. It also had special relevance in demonstrating how much gamma-ray deposition occurred and therefore how much outward mixing of radioactive Cobalt was required in the models to reproduce the observations. An intriguing result of these observations has been the occurrence of an IR excess beyond two microns starting near day 40. There is still not complete agreement concerning its origin – early dust in the ejecta, heated dust in the circumstellar environment, free-free emission from the ionised gas in or around the ejecta. This photometry has now extended with unavoidable gaps over 20 years (Bouchet) and still produces new insights, as can be seen in Figure 1.

4. Early reports of measurements of polarisation were given by other observatories in IAUC Nos. 4328 and 4337 neither of which demonstrated that there was a component intrinsic to SN 1987A. With IAUC No. 4339 from ESO, it was established that polarisation varied strongly across PCyg features thus establishing an intrinsic component. Subsequent observations (Schwarz) have shown that with time the polarisation increased.

5. The early low resolution optical spectroscopy from ESO provided, as did most other spectroscopy, a means of measuring the expansion rate of the envelope (Danziger). The availability of IUE spectra allowed the creation of a

Figure 1: Then – first IR images obtained at the 2.2-m with IRAC1 on 26 October 1993 (left) and IRAC2 on 27 December 1994 (middle). And now – with NACO at the VLT Yantun on 9 October 2006 (right). All images have been acquired through the *H* filter.



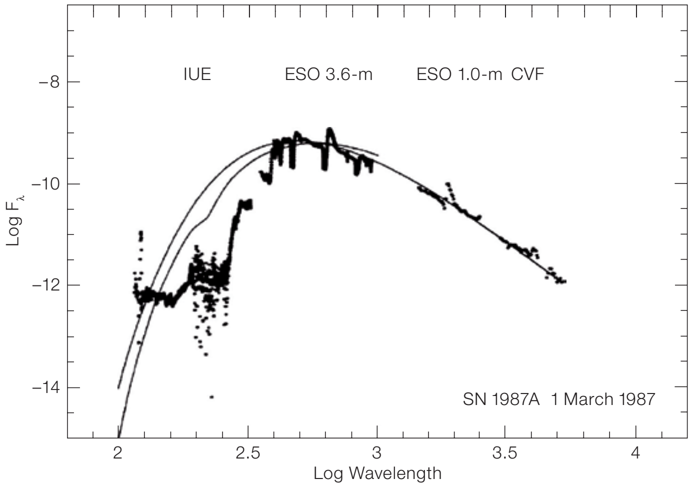


Figure 2: A combination of the UV, optical and infrared spectra for 1 March 1987. The axes are logarithmic in units of erg cm^{-2} s^{-1} nm^{-1}. Overplotted is a 6 000 K black-body, both unabsorbed and with an extinction corresponding to E(B–V) = 0.22, all normalised to 550 nm.

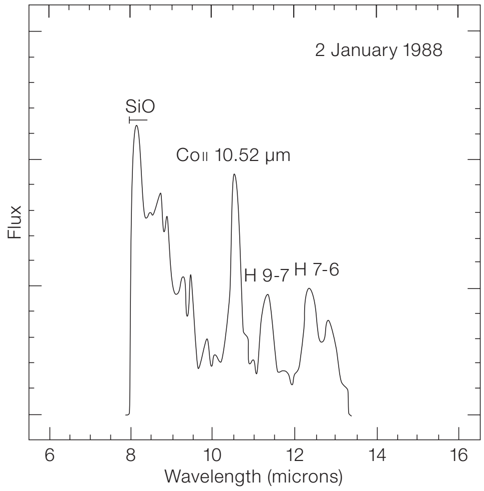


Figure 3: CVF Spectrum obtained at the 1-m on day 314.

composite spectrum from 1500 Ångstroms to 5 microns for 1 March 1987 observations shown in Figure 2. But its ready availability at ESO provided the means of spectrophotometric modelling using Monte Carlo techniques (Lucy). Arguably the best reproduction up to that time of a SN spectrum virtually from first principles, this modelling helped to establish the identity of major absorption features in the early spectra (Fosbury). Early IUE UV spectra were also well reproduced at ESO, immediately allowing one to identify the main sources of opacity in the UV. The Bochum event was seen in the beautiful regularly spaced low-resolution spectra taken with the scanner on the Bochum telescope at La Silla (Hanuschik). It can be described as a structural bump appearing after 15 March 1987 and growing in contrast on the blue wing of the Hα emission and gradually decreasing in velocity. Another bump appears on the red side of Hα perhaps a bit later. There seems no way of avoiding an asymmetry near the line-forming region to adequately account for this. Such effects, though less well documented have appeared in spectra of subsequent supernovae.

6. Low-resolution IR spectra were obtained with the CVF starting very early. As the supernova expanded it gradually became optically thin at various wavelengths in various lines. Apart from the more conventional lines of hydrogen being present and detected, the less conventional molecular emission bands of CO (fundamental and first overtone) and silicon monoxide (SiO) (fundamental only half visible owing to atmospheric cutoff) were identified (Bouchet). Subsequent higher-resolution spectra obtained with IRSPEC led to the first estimate of the mass of CO (Oliva) not so different from later more sophisticated modelling of this emission. Probably the most important result of this IR spectroscopy has been the detection and temporal variation of the fine structure line of Co II at 10.52 microns. This line is insensitive to temperature, most of the Co was singly ionised, and the line was in a clear atmospheric window without serious blending. Simple nebular theory, after it became optically thin, has

therefore led to the most direct determination of the mass of Cobalt in SN 1987A. Its temporal behaviour was also consistent with the radioactive decay of ^{56}Co, but leaving at later times a residual that could be safely ascribed to 57Co whose decay rate is much longer (Danziger). Figure 3 shows a CVF spectrum with the prominent [Co II] 10.52-micron line. Observations from space and the bolometric light curve are entirely consistent with these conclusions. One can add to this story that the estimate of the mass of Fe determined with IRSPEC spectra (Oliva) suggested an increase consistent, within the uncertainties, with what would be expected from the Cobalt decay.

7. Echoes were expected if one reads the literature. In fact the first report of echoes appeared in IAUC No. 4561, March 1988. Here we refer to optical echoes and not the dubiously named IR echoes. However a close inspection of Schmidt plates taken at ESO revealed the presence of echoes as early as 16 August 1987. An analysis of spectra showed that the reflecting medium lay at two discrete distances on the near side of the supernova reflecting light emitted near maximum (Gouiffes).

8. Interstellar lines of Ca II and Na I at high spectral resolution were detected with the CES at La Silla during the first week when the supernova acted as a bright background source (Vidal-Madjar). The forest of Ca II absorption lines showed a complex interstellar structure in the LMC, while the Na I/Ca II ratios were different in the LMC from those in the halo. The presence of diffuse interstellar bands in the LMC (the first in an external galaxy) was also reported and elaborated on later (Vladilo). This work was nicely complemented by detection of hot coronal gas in the LMC, the [Fe X]6375 Ångstrom line in absorption, using the same instrument early on, and supplemented with AAT data (D’Odorico). All of these results suggest, but do not prove, that SN 1987A could hardly lie on the near side of the LMC. After some misleading starts, all of the relevant high-resolution spectra were combined to provide a stringent upper limit on the strength of the interstellar lithium line near 6 708 Ångstroms (Baade).

9. Other observations included attempts to detect a central pulsar presumed to have formed at the time of core collapse. All attempts at ESO, both early and later, have failed to demonstrate a convincing detection (Ogelman).

This account of the early period of observational results from ESO is by its nature highly biased. This is shown not only through the selection of topics but through our method of referencing results, namely by quoting only the name of the first author of any paper that we have used to write this. We hope that all those who contributed to the enterprise of observing and understanding SN 1987A, including the Chilean staff, will understand and be tolerant of this relaxed style.

Photographic image of the Large Magellanic Cloud, before (left) and after (right) the explosion of SN 1987A. The supernova is visible on the right image just below the Tarantula nebula, in the upper part of the irregular galaxy. (ESO PR Photo 08b/07)