SN 1987A (continued)

The far southern declination of Supernova 1987A (−69°.5) means that it is "circumpolar" – always above the horizon – at all of the major astronomical observatories in the southern hemisphere. Observations have therefore continued every night since the discovery in February.

Since the last reports about SN 1987A in this journal (**49,** pages 25 and 32–34), the comprehensive Proceedings of the ESO Workshop on SN 1987A have been published, giving an in-depth account of the first four months of intensive observations. Details about this king-size book and how to obtain a copy are given in the box.

The Proceedings of the ESO Workshop on

SN 1987A

which took place at Garching from 6 to 8 July 1987, have been published. The price for this 688-page volume, edited by I. J. Danziger, is DM 50.– and has to be prepaid.

Payments have to be made to the ESO bank account 2102002 with Commerzbank München or by cheque, addressed to the attention of:

ESO
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Please make certain that your full address and the title of the volume are indicated.

Two contributions from ESO are included in this issue of the Messenger. The first concern observations of the infrared spectrum with the 3.6-m telescope and IRSPEC. These data are unique and it has therefore been decided to print the preliminary list of observed lines in its entity. Another contribution provides information about recent speckle observations.

Hard X-rays from SN 1987A were detected already in August, but this was only announced in late September, because of problems in separating the SN signal from that of the nearby X-ray source, LMC X-1. X-rays in the 20–130 keV energy region were observed with HEXE, a German-built instrument on the Kvant module of the Soviet Mir station. The SN was also detected at energies up to 350 keV by the Soviet "Pulsar X-1" instrument, and also with the Japanese Ginga satellite. The observed spectrum was very hard; this explains why no radiation was registered by earlier experiments in the low-energy range. For instance, a rocket was launched on November 14 from Woomera, Australia, with a detector in the soft X-ray range from 0.75–2 keV, but no signal was detected.

It is not yet clear whether the observed hard X-rays originate in the expanding shell, as diffused emission from decaying Cobalt-56 atoms, or whether the source is a neutron star (pulsar) at the centre. Continued observations may be able to tell which of these two hypotheses is correct, since the flux from a neutron star is thought to remain largely constant, whereas radiation from Cobalt will slowly decrease.

The visual brightness continues to decrease slowly in an exponential way, and accurate measurements indicate that the corresponding "decay-time" lies between 106 and 115 days. This is very near the 111-day mean life of Cobalt-56 and is indicative of this radioactive element being the main source of energy during the present phase. It was thought in late October that a more linear decline in brightness might have begun, but this was soon refuted by continued, accurate photometry in South Africa and in Chile.

The magnitude in late November was about 6.0. This means that it is now becoming too faint to be seen with the unaided eye.

The Editor (November 30, 1987)

A 1–5 μm Infrared Spectrum of SN 1987A

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An infrared spectrum of SN 1987A covering the atmospheric windows between 1 μm and 5 μm was obtained at R = 1,500 with the IRSPEC spectrometer on the ESO 3.6-m telescope during the period 5–8 October 1987. Unfortunately, the observations had to be spread over several nights due to the presence of cirrus clouds which made it necessary to observe and calibrate separately at each of the ≃ 50 grating positions used. Nevertheless the result is instructive in demonstrating that, with the advent of array detectors, infrared observations do not necessarily have to stop as soon as the clouds appear!

The complete spectrum is reproduced in Figure 1 and, as three enlarged sections, in Figure 2 where the fainter lines are more visible and the main features are also identified. A strikingly large number of emission lines are now present and Table 1 represents our first attempt at identification. Many of these features have not previously been reported in astronomical spectra, several remain unidentified and some of the suggested identifications (mainly amongst the neutral atoms) must be considered uncertain. All the lines are broad, with typical FWHM ≃ 3,000 km s^{-1}. Their profiles range from highly symmetrical to pronounced P Cygni but, in all cases, the emission peaks are redshifted by 400–1,500 km s^{-1} compared with the ≃ 270 km s^{-1} expected for the LMC. Actual values for the "cleanest" and most securely identified lines are given in Table 1. Neither the "excess" redshifts nor their large spread can be attributed to wavelength measurement errors because the positions of H and CO lines in the observed comparison stars confirm the accuracy of the IRSPEC calibration (with a neon spectral line lamp) to better than one pixel (typically < 200 km s^{-1}). Within the observed velocity spread however there do not appear to be systematic differences between species or amongst lines with different optical depths. It should also be noted that visible spectra reveal the Hα emission to be redshifted by

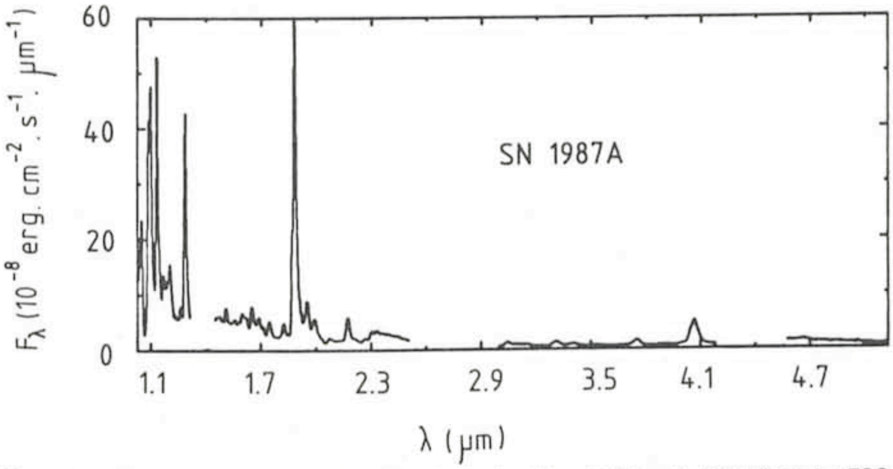

Figure 1: *1–5 µm spectrum of SN 1987 A obtained at R ≃ 1,500 with IRSPEC at the ESO 3.6-m telescope during the period 5–8 October 1987.*

1,000 km s^{-1} at this time. At present we do not know how to resolve this apparent contradiction between evidence for an expanding gas shell around the SN and a bulk motion along the line of sight away from us. As there has been very little time for interpretation between the data reduction and the deadline for this article, the other conclusions reached so far are also presented here somewhat tentatively.

H and He

Around 20 hydrogen recombination lines are present and, allowing for possible flux errors estimated at ~ 20 % due to the clouds, the relative intensities of the 12 cleanest lines are close to those expected for a case B recombination spectrum. However, lines arising from levels $n > 7$ appear to be somewhat enhanced (~ 30 %) while Pfβ (H7-5 at 4.66 µm) is too faint by a factor ~ 3 – a result of particular significance because the CO fundamental band emission in this region appears to be similarly weak as discussed further below. Both the He lines detected at 1.083 µm and 2.058 µm have metastable lower levels, are the brightest lines expected and exhibit P Cygni profiles whereas the H lines do not (as observed also in some WR stars).

Fe

In addition to the isolated [Fe II] (1.257 µm) line, the excess strength of the 1.644 µm feature relative to the neighbouring hydrogen Brackett lines is consistent with the presence of [Fe II] (1.6435 µm) blended with H 12-4. Two lines in the visible, at 5530 Å and 7160 Å, can also be identified with [Fe II]. Their line intensity ratios are consistent with thermal populations ($n_e \geqslant 10^7$ cm^{-3}) at $T_e \sim 4,000$ K in which case the 1.257 µm line luminosity corresponds to an estimated Fe^+ mass of ≃ 0.04 $M_\odot$. Assuming all the Fe is singly ionized (L. Lucy, private communication), this implies an Fe mass function of ~ 0.004 for a 10 $M_\odot$ envelope. Given the uncertainties in this determination and in the expected LMC abundance, it is too early to claim that this is abnormally high.

Neutral Atoms

The line at 1.132 µm is one of the brightest in the spectrum. Its identification with O I (1.1287 µm) is believed to be reasonably secure because the upper level of this transition has an energy

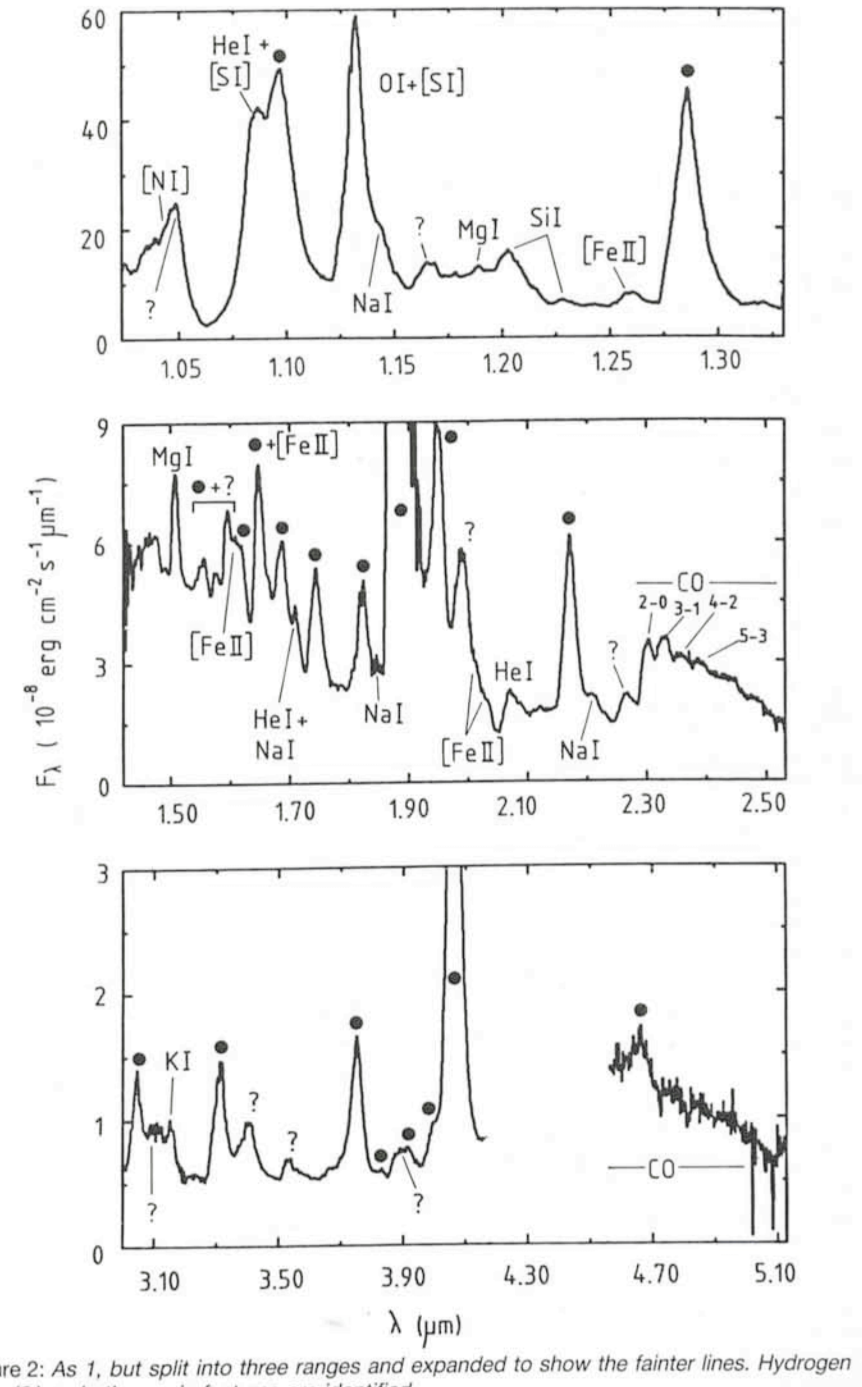

Figure 2: *As 1, but split into three ranges and expanded to show the fainter lines. Hydrogen lines (●) and other main features are identified.*

$\lambda^{(1)}_{OBS}$	I$^{(2)}$	identification$^{(3)}$	$\lambda^{(4)}_0$	$\Delta v^{(5)}$
1.047	~20	?		
		[N *I*] $^2D^0 - {^2P^0}$	1.040	
1.086	~30	He *I* $2s\,^3S - 2p\,^3P^0$	1.08294	800
		[S *I*] $^3P_2 - {^1D_2}$	1.08210	
1.096	~40	H 6-3	1.09379	600
		([Si *I*] $^1D_2 - {^1S_0}$)	1.09913	
1.132	53	O *I* $3p\,^3P - 3d\,^3D^0$	1.1287	900
		[S *I*] $^3P_1 - {^1D_2}$	1.13058	
1.143		Na *I* $3p\,^2P^0 - 4s\,^2S$	1.139	
1.162	~3	?		
1.18	~5	K *I* $4p\,^2P^0 - 3d\,^2D$	1.173	
		Mg *I* $3p\,^1P^0 - 4s\,^1S$	1.182818	
		Ca *II* $5s\,^2S - 5p\,^2P^0$	1.187	
1.202	~4	Si *I* $4s\,^3P^0_1 - 4p\,^3D_2$	1.1984	
		Si *I* $4s\,^3P^0_0 - 4p\,^3D_1$	1.1991	
		Si *I* $4s\,^3P^0_2 - 4p\,^3D_3$	1.2032	
1.228	0.6	Si *I* $4s\,^3P^0_1 - 4p\,^3D_1$	1.2104	
		Si *I* $4s\,^3P^0_2 - 4p\,^3D_2$	1.2227	
1.260	2.4	[Fe *II*] $a\,^6D_{9/2} - a\,^4D_{7/2}$	1.25666	800
		(K *I* $4p\,^2P^0 - 5s\,^2S$)	1.248	
1.285	54	H 5-3	1.28179	700
1.444	0.5	[Fe *I*] $a\,^5D_4 - a\,^5F_5$	1.44294	
1.46	~2	H n-4 (Bracket) limit	1.45799	
1.488	0.1	Mg *I* $3d\,^3D - 4f\,^3F^0$	1.487	
1.505	3.2	Mg *I* $4s\,^3S - 4p\,^3P^0$	1.503	400
		([Fe *I*] $a\,^5D_2 - a\,^4F_4$)	1.49820	
1.528	0.1	H 19-4	1.52603	
		K *I* $3d\,^2D - 4f\,^2F^0$	1.5166	
1.55	1.4	[Fe *II*] $a\,^4F_{9/2} - a\,^4D_{5/2}$	1.53345	
		H 18-4	1.53416	
		[Fe *I*] $a\,^5D_3 - a\,^5F_5$	1.53510	
		H 17-4	1.54387	
		H 16-4	1.55562	
		CO 3-0 band-head	1.558	
1.573	0.5	H 15-4	1.57004	
		Mg *I* $4p\,^3P^0 - 4d\,^3D$	1.575	
		CO 4-1 band-head	1.578	
1.60	6.2	H 14-4	1.58803	
		Mg *I* $3d\,^3D - 5p\,^3P^0$	1.5885	
		Si *I* $4s\,^1P^0 - 4p\,^1P$	1.58884	
		CO 5-3 band-head	1.5990	
		[Fe *II*] $a\,^4F_{7/2} - a\,^4D_{3/2}$	1.59945	
		[Si *I*] $^3P_1 - {^1D_2}$	1.60679	
		H 13-4	1.61091	
1.644	6.5	H 12-4	1.64070	
		[Fe *II*] $a\,^4F_{9/2} - a\,^4D_{7/2}$	1.64353	
		[Si *I*] $^3P_2 - {^1D_2}$	1.64453	
1.684	3.5	H 11-4	1.68063	600
1.705	0.8	He *I* $3\,^3P^0 - 4\,^3D$	1.70029	
		Na *I* $3d\,^2D - 5p\,^2P^0$	1.7031	
		Mg *I* $4s\,^1S - 4p\,^1P^0$	1.71087	
1.740	5.4	H 10-4	1.73619	700
1.820	5.3	H 9-4	1.81738	500
1.851	0.8	Na *I* $3d\,^2D - 4f\,^2F^0$	1.847	
1.881	110.	H 4-3	1.87507	900
1.948	9.6	H 8-4	1.94453	500
		(Ca *I* $4p\,^3P^0_0 - 3d\,^3D_1$)	1.93092	
		(Ca *I* $4p\,^3P^0_1 - 3d\,^3D_2$)	1.94530	
		(Ca *I* $4p\,^3P^0_1 - 3d\,^3D_1$)	1.95057	
1.989	6.0	?		
		(Ca *I* $4p\,^3P^0_2 - 3d\,^3D_3$)	1.97768	
		(Ca *I* $4p\,^3P^0_2 - 3d\,^3D_2$)	1.98622	
		([Fe *I*] $a\,^5F_5 - a\,^3F_4$)	1.98045	
2.03		[Fe *II*] $a\,^4P_{1/2} - a\,^2P_{1/2}$	2.00667	
		[Fe *II*] $a\,^2G_{9/2} - a\,^2H_{9/2}$	2.01510	
		[Fe *II*] $a\,^4P_{5/2} - a\,^2P_{3/2}$	2.04598	
2.068	1	He *I* $2s\,^1S - 2p\,^1P^0$	2.05810	1500
2.172	9.8	H 7-4	2.16550	900
2.207	0.3	Na *I* $4s\,^2D - 4p\,^2P^0$	2.207	
2.264	0.6	?		
2.303	~1	CO 2-1	2.294*	1100
2.330	~1	CO 3-2	2.322*	1000
2.36		CO 4-3	2.353*	1000
~ 2.4	35*	CO first overtone band		
3.048	2.2	H 10-5	3.03833	900
3.12	3.6	?		
		K *I* $3d\,^2D - 5p\,^2P^0$	3.149	
3.311	3.5	H 9-5	3.29604	1400
3.402	2.1	?		
		(Mg *I* $3d\,^1D - 4p\,^1P^0$)	3.3963	
3.531	0.7	?		
3.659	0.2	K *I* $5p\,^2P^0 - 6s\,^2S$	3.649	
3.747	4.5	H 8-5	3.73948	600
		(K *I* $5p\,^2P^0 - 4d\,^2D$)	3.721	
3.827	0.1	H 16-6	3.81836	
3.89	1.3	?		
		(H 15-6)	3.90643	
4.02		H 14-6	4.01971	
		K *I* $4f\,^2F^0 - 5g\,^2G$	4.01584	
4.064	25	H 5-4	4.05109	1000
4.66	~2	H 7-5	4.65244	~500
~4.7	50*	CO fundamental band		

Notes to table

(1) Observed wavelength in μm. The line center has been defined as the average of the 4 highest points. Center positions of broad features and lines in crowded regions are given with 2 significant digits.

(2) Observed line intensity, in units of $10^{-10}\ erg\,cm^{-2}s^{-1}$

(3) Identification. Transitions which are unlikely to give a substantial contribution to the observed feature are given within brackets.

(4) Rest wavelength of the identified transition. The number of significant digits is given according to the wavelength spread of the multiplet.

(5) Velocity shift in km/s between the observed and the line rest wavelengths. Given only for bright and clearly identified lines. Positive values are for red shifts. Typical uncertainity is 200-300 km/s

TABLE 1. *Line identifications.*

coincident, within 15 km s^{-1}, with that of Lyβ and is connected to the ground state by a strong UV transition. A large fraction of the Lyβ photons can, therefore, be "transformed" into O I transitions (1.1287 μm + 8447 Å + 1304 Å) provided that the optical depth in Hα is large enough to inhibit the competitive process which transforms Lyβ photons into Hα + Lyα. It is not clear at present whether the observed line ratio Hα/Pβ can be accounted for by $\tau(H\alpha) \sim 500$, as required in the case of cosmic O I/H I abundance. Also, we cannot determine how much [S I] 1.1306 contributes to the observed 1.132 μm feature. We expect, however, that the O I line should vary more rapidly than the H lines due to its dependence on the optical depth of Hα and Lyβ. Future spectra should, hopefully, be able to confirm (or exclude) the O I identification and to determine the O I/H I abundance ratio.

Other lines have been identified on the basis of wavelength coincidence with atomic transitions between low lying states which may be collisionally populated at T ~ 5,000 K. Some of these identifications are further strengthened by the presence of several transitions (e.g. Na I, Mg I). In general, however, these identifications must be treated with caution at this stage.

CO

The fundamental band of carbon monoxide at 4.6 μm appears to dominate the emission in the M window (4.5–5 μm) and its first overtone band the emission between 2.3 and 2.5 μm. As noted already, the CO emission is redshifted by the same amount as the atomic and ionic lines and is thus apparently associated with the SN ejecta rather than ambient material. Several of the individual $\Delta v = 2$ bands are resolved in the 2.3–2.4 μm region and their relative strengths lead to a crude temperature estimation of $T \simeq 2{,}000$ K and a CO mass of $\sim 4 \cdot 10^{-4} M_{\odot}$. Relative to the first overtone, however, the emission in the fundamental band is a factor ~ 3 too weak (the same as observed for Pfβ). This cannot be a calibration effect (because the flux levels in our spectrum are consistent with lower resolution CVF observations made slightly later by P. Bouchet) and therefore implies the importance of strong radiation transfer effects in the envelope. In this case the strength of the fundamental and first overtone bands can be expected to vary at different rates in the future.

Summary

The infrared spectrum is dominated by emission lines from a gas of low ionization degree (including molecular CO) and, apparently, relatively normal abundances. Whereas the symmetry and widths of the lines are generally consistent with an envelope expanding at ~ 1–2 × 10^3 km s^{-1} however, the emission in virtually all lines appears to be dominated by gas receding along the line of sight at a few × 10^2 km s^{-1} relative to the systemic velocity of the LMC.

IR Speckle Interferometry

Infrared (IR) speckle observations performed in early May and in June do not show the mystery spot – whose infrared detection has been erroneously mentioned in the summary of the ESO Workshop on SN 1987A. With the separation observed in visible light, the mystery spot must be, at 3.8 microns, at least 4 magnitudes fainter than the supernova to escape detection. But beginning from mid-June, our observations show a barely resolved structure appearing in this band and lying at the limit of detectability, thus either extremely small or extremely weak. Further observations carried out on August 6 confirm that the supernova is definitely resolved in IR. A weak oscillation shows up in all visibilities obtained from 2.2 to 4.6 microns. The actual structure causing this, accounting for 2.5 to 3 per cent of the total flux, cannot be unambiguously derived until now: the presence of one or several IR spots at 0.35 arcsecond, as measured on the N-S and E-W axis, is as plausible as that of a ring-like structure of 0.42 arcsecond diameter, although the latter seems physically more realistic. Whatever the correct model is, the projected velocity of about 0.4 c clearly points to a light echo.

A.A. Chalabaev, C. Perrier and J.-M. Mariotti (Observatoire de Lyon)

Conference Report:

Astronomy from Large Databases: Scientific Objectives and Methodological Approaches

The conference on Astronomy from Large Databases: Scientific Objectives and Methodological Approaches took place in Garching on 12–14 October 1987.

Approximately 150 attended. The projects and missions represented included, amongst others, HST, IUE, IRAS, ROSAT, EXOSAT, EUVE, and Hipparcos. In the three days of the conference, 74 presentations were discussed. These were organized in sessions on Astrophysics from Large Databases, Object Classification Problems, Statistics, Pattern Recognition and Expert Systems, and Databases – Current Trends.

Half of the presentations were in the latter category and hence a comprehensive view of work in progress in this area of astronomy can be gleaned from the papers. The diversity of approaches in this area (for example, the range of database systems in use, generally customized) points to the need for coordination. This conference provided a good start in this direction.

In other sessions, discussion took place on the applications of new technologies to stored astronomical data. Some of the papers on expert systems and statistics will provide useful reference material – not easily available elsewhere – when considering the application of methods in these fields.

The proceedings will be published by the European Southern Observatory and are expected to be available around the end of January 1988.

F. Murtagh (ST-ECF, ESO), affiliated to the Astrophysics Division, Space Science Dept., European Space Agency.