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Spectrum of SN 1983n in NGC 5236 at maximum light

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Abstract. The spectrum of SN 1983n in NGC 5236 (M83) obtained at its light maximum is presented. The spectrogram was digitized and smoothed using optimal filter technique in Fourier space. The moonlight background was subtracted after smoothing. Though the specturm conforms to type I classification, it is peculier in that the characteristic 6150 Å absorption is very weak and the helium lines are seen in emission. The peculiarity probably owes to the fact that the supernova was underluminous : The identifiable absorption features of He I, O I, Fe II, S II, Si II and Ca II yield an expansion velocity of 12350 ± 1910 km s^{-1}, a value consistent with other type I supernovae.

Key words : supernovae, optical spectroscopy—digital analysis

1. Introduction

Supernova 1983n in NGC 5236 (M83) was discovered by the Australian amateur astronomer Reverend Robert Evans on July 3, about 20 days before maximum light (Thompson 1983). The premaximum spectrum was monitored with IUE by Wamsteker (1983) who found the supernova to be of type I. Though Wamsteker found the continuum to be flat between 260 and 120 nm, EXOSAT (1983) did not detect any flux in the x-rays at 0.1–40 KeV on 1983 July 5. Richtler & Sadler (1983, hereinafter RS) monitored the optical spectrum between 3900–5900 Å during 1983 July 3–13. Jenkins *et al.* (1984) obtained high-resolution spectra around Ca II H, K and Na I D on July 10 and found multiple components of interstellar lines in the range ± 100 km s^{-1} with respect to the systemic velocity of NGC 5236. Sancher *et al.* (1983) observed significant excess in the near-infrared.

NGC 5236 is a prolific producer of supernovae, with four earlier detections (1923a, 1950b, 1957d, and 1968*l*). Of these, only the first and the last were observed in some details. The peculiar supernova 1923a reached a maximum of m_{pg} = 14.0 whereas 1968*l* reached $V = 11.9$. At the relatively nearby location of NGC 5236, a type I supernova is expected to be brighter than 10 mag at maximum; but SN 1983n reached only about $V = 12.5$. The supernova is clearly underluminous in the optical. On the other hand, SN 1983n is the only type I supernova to be detected in the radio region (Weiler 1984). These two peculiarities, as also its peculiar optical spectrum, nondetection in x-rays and excess in the infrared, are all possibly interrelated (Chevalier 1984) and may imply a precursor rather different from the other well-observed supernovae.

2. Observations

Though the skies were generally cloudy at Kavalur observatory, an attempt was made to observe the supernova when the clouds had slightly thinned down for a short period on 1983 July 18. A dispersion of 875 Å mm^{-1} was obtained in the wavelength range of 4000–7500 Å, using an image-tube spectrograph at the Cassegrain focus of Kavalur 1.02m reflector. A spectrum of Stone (1974) spectrophotometric standard star BD + 25° 3941 was obtained when the sky thinned down again a few hours later. Both the spectra were recorded on Kodak IIaD emulsion and were calibrated for relative intensities. The spectrum of moonlight scattered by thin clouds was found superposed on the supernova spectrum. Yet, since the published spectra of SN 1983n did not contain information on the red region, an attempt was made to separate through digital analysis the supernova spectrum from the background.

3. Reductions

The spectra of the supernova, moonlight background and the standard star, as also the calibration plate were digitized with an automated microdensitometer (Viswanath 1980). The microdensitometer set up digitizes at an interval of 8μm. A total of 1024 points ($\sim$ 8.2 mm) were used in the analysis, which included the entire spectrum recorded.

The spectra were smoothed by applying a filter in Fourier space. An IBM fast Fourier transform (FFT) routine was employed (Gray 1976). The technique employed was based on Brault & White (1971) and Ardeberg & Virdefors (1973). Third-degree polynomial fits to the spectra were first subtracted to reduce the power at low frequencies. The polynomials were added back to the data after smoothing. The data sets were multiplied by a cosine-bell function to avoid abrupt changes at the ends of data string. The smoothed power spectrum of each data set was estimated by the segmental averaging technique. The length of 1024 points was divided into seven sets of 256 points each, with an overlap of 128 points in adjacent sets. Raw logarithmic power spectra of all these sets were co-added to obtain the smoothed power spectrum (figure 1).

The noise power (P_N) and signal power (P_S) as a function of frequency (ν) were estimated by model fitting. The noise power was estimated as a least-squares fit between ν and log P in the range of points 30-80 where the contribution due to signal is insignificant. Beyond point 80, the power spectrum is dominated by truncation errors in raw data. (The photographic transmission was digitized to only three decimal digits). The signal power was estimated by fitting another

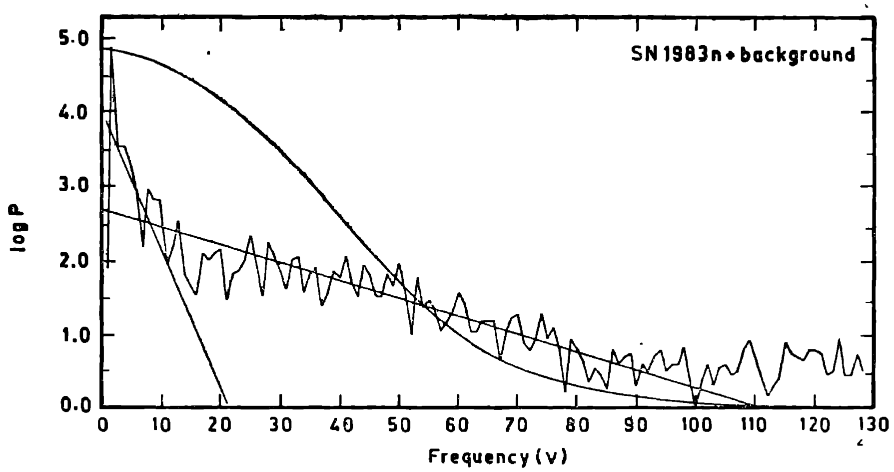

Figure 1. The raw power spectrum (log P + const) of the spectrum of SN 1983n + background moonlight. Seven data segments of 256 points each were employed in deriving the average power spectrum. The straight lines are estimates of signal power (steeper) and noise power (flatter). The highest frequencies are dominated by truncation noise. The curve represents the optimum filter, on arbitrary linear scale.

straight line between points 3–15 after subtracting the contribution due to noise power estimated already. The optimum filter was constructed as

$$\Phi(\nu) = \frac{P_S(\nu)}{P_S(\nu) + P_N(\nu)} \cdot$$

The derived signal and noise spectra as well as the optimum filter are shown in figure 1 for the spectrum of SN 1983n + background.

The Fourier transform of 1024 data points was multiplied by the optimum filter. Note that the filter shown in figure 1 is derived using 256 points and so needs to be enlarged along the frequency axis by a factor of 4. The inverse transform then gave the smoothed spectrum. The smoothed spectra of SN 1983n + background, and of background alone were converted to relative intensities using the calibration curve derived as a straight-line fit between logarithmic intensities and Baker densities. The spectrum of background was then subtracted from the spectrum of SN + background to obtain the uncontaminated spectrum of the supernova. Here, the zero order was used to establish the zero points of individual spectra.

The wavelength scale was established using the neon comparison spectrum and identifiable features in the spectrum of the standard star as well as atmospheric absorption bands. The correction for the wavelength response of the instrument was made using the observations of the standard star. The correction at each wavelength was determined by cubic spline interpolation between standard wavelengths. No attempt was made to correct for the differences in the resolution of Stone (1974) and present observations. A mean correction was applied for atmospheric differential extinction. The supernova and the standard star were observed at a zenith angle separation of Δ sec $z = 0.6$ in widely different sky conditions. Hence the shape of the continuum in the derived spectrum is somewhat uncertain.

The final spectrum of SN 1983n is displayed in figure 2. Though it resembles a typical type I spectrum, the characteristic dip at 6150 Å is inconspicuous. The emission features at 4600 Å, 5300 Å and 5900 Å resemble the spectra of recent type I supernovae like SN 1980n in NGC 1316 and SN 1983g in NGC 4753 (Prabhu 1981, 1983). The 4600 Å emission bands allow comparison with the spectra obtained by RS between 1983 July 3–13. Since the last observation of RS, both these features have sharpened, and possibly continued to move redward. The steady increase in the strengths of emission features, seen in the spactra of RS, continues. He I 4471 Å emission appears similar, whereas He I 5876 has increased in strength.

The interpretation of SN I spectra is an extremely difficult task. Attempts have been made in the past to explain the observed spectrum as a superposition of absorption lines over continuum, as P Cygni profiles, or purely emission features with or without continuum (*cf.* Branch 1980 and references therein), RS tried to identify blueshifted absorption features in the spectrum of SN 1983n but could not obtain a consistant expansion velocity for the shell. However, large scatter in the derived velocities is possible due to blending of lines and also since there may coexist different systems of velocities with different excitation and ionization in the exploding shell. Thus one may probably justify the exercise of identification of absorption features, even if it does not lead to highly consistent expansion velocity.

We have listed in table 1 all the absorption features seen in our spectrum of SN 1983n. The stronger dips are shown in bold (except for atmospheric absorption

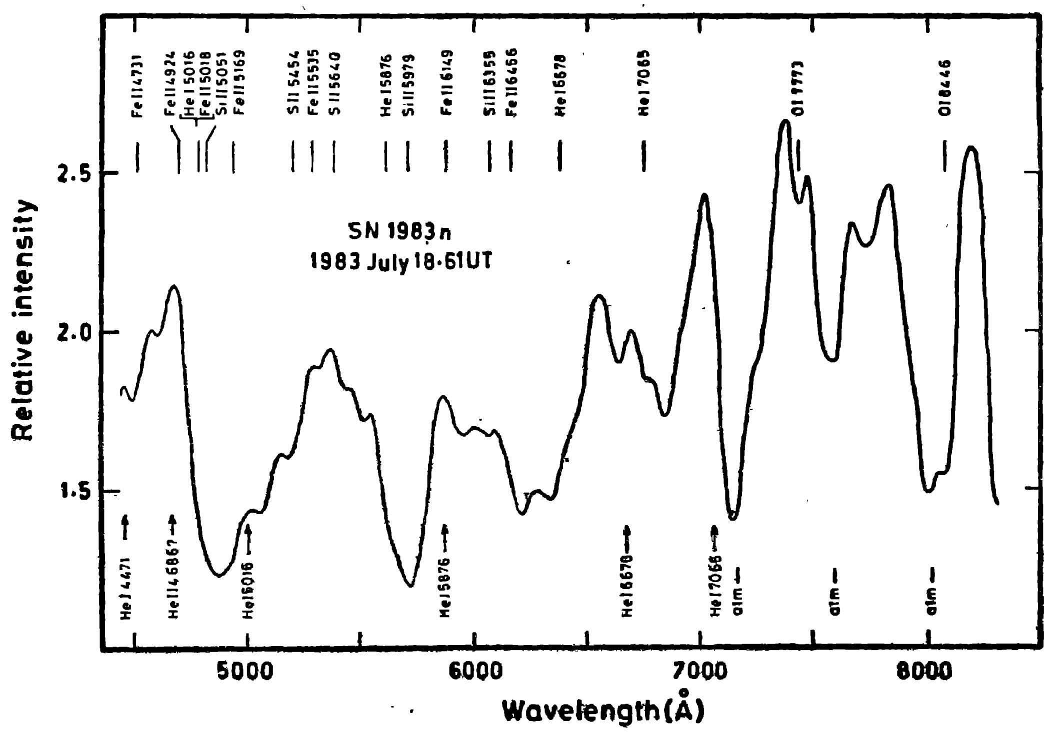

Figure 2. The spectrum of SN 1983n on 1983 July 18.6 UT. Stellar absorption features are marked above, and the atmospheric absorption bands are indicated below. The He I emission features are marked below by arrows.

Table 1. Identifications of absorption dips in SN 1983n

Obs Å	Identification Å	V_{exp} km s^{-1}
4519	Fe II 4731	13440
4636[(a)]	H 4861 ?	
(4754)	Fe II 4924	10360 :
4878	He I 5016	10950 :
	Fe II 5018	
	Si II 5051	
	Fe II 5169	
5071[(a)]	—	
5188	S II 5454	14630
5326	Fe II 5535	11330
5450	S II 5640	10110
5526	—	
(5609)	He I 5876	13630
5719	Si II 5979	13050
5974[(c)]	Fe II 6149	8540
6078	Si II 6355	13080
6223	Fe II 6456	10870
6360	He I 6678	14290
6650[(d)]	—	
6767	He I 7065	12650
7450	O I 7773	
(7553)	Mg II 7896	13020
7753	—	
7926	—	
8015	O I 8448	15380
	Mean $\langle V_{exp} \rangle$	12350 ± 1910

[(a)] Spurious dip due to He II 4686 Å emission to its redward side?
[(b)] Spurious dip due to He I 5016 Å emission to the blue side?
[(c)] Low velocity resulting from filling in by He I 5876 Å emission to the blue side?
[(d)] Spurious dip due to He I 6678 Å emission to the red?

bands of O_2 6867 Å, and of H_2O 7168 and 8228 Å). The faintest suggestion of absorption as a point of inflexion on rising or falling intensity, is indicated by parentheses. The identifications were made by comparing with the identifications of Patchet & Wood (1976) for SN 1974g in NGC 4414 and of Branch & Patchet (1973) for SN 1937c in IC 4182, as also with the synthetic spectrum of Branch *et al.* (1982) for SN 1981b in NGC 4536. Following the observation of He I 4471 Å emission by RS, both the emission and absorption due to other helium lines were looked for.

There is a clear evidence in our spectrum for unshifted emission at He I 4471, 5016, 6678 and 7065 Å. He II 4686 Å emission is also possibly present. The average expansion velocity of the shell is 12520 ± 1880 km s^{-1}. The velocities are significantly higher for Ca II than for Fe II. O I and He I lines also give slightly higher velocities. These deviations may arise both from ionization and excitation stratification, while an abundance gradient in the atmosphere is also possible (Branch *et al.* 1982).

Patchet & Wood (1976) found Balmer lines in SN 1974g. We have hence looked for the absorptions due to H_α and H_β. The evidence is not conclusive, though dips exist at the expected positions of these lines.

The presence of helium lines in emission suggests that the precursor of the supernova had a helium-rich envelope. As RS point out, we may be witnessing here a binary progenitor with an accreting white dwarf (Nomoto 1984).

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