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Research Note

Optical spectrum of supernova 1989 B in NGC 3627

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Abstract. Spectra of SN 1989 B in NGC 3627 were recorded photographically on three nights near maximum and two nights near 7 weeks from maximum. The spectrum and its evolution bears a close resemblance to a typical type Ia spectrum. The expansion velocity of the envelope decreased with time as observed in other supernovae. The velocity evolution is similar to that of SN 1981 B, but the magnitude is 10% smaller. Early velocities are comparable to those of SN 1986 G, but the latter evolved faster. Early spectroscopic evolution was faster than SN 1981 B, but compares well with SN 1986 G. It is proposed that the rate of spectral evolution, as judged from the epoch at which S II 545.4, 546.0 nm lines disappear and Na I D, Fe II 492.4, 521.5 nm become prominent, is inversely correlated with the velocity of the envelope: faster envelopes evolve slower.

Key words: supernovae: general – supernovae: individual: SN 1989 B – spectroscopy – galaxies: general – galaxies: individual: NGC 3627

1. Introduction

Supernova 1989 B was discovered by Evans (1989) on 1989 January 30.5 at 15 arcsec west and 50 arcsec north of the galaxy NGC 3627. From the discovery brightness of $m_{vis} \sim 13$, the supernova brightened to $m_{vis} \sim 12$ before the decline set in. Visual estimates (see Fig. 1) and a few V and R magnitudes published in the *IAU Circulars* suggest that the maximum light was attained on 1989 February 10.

NGC 3627 (= M 66) is an SABb galaxy, the brightest member of Leo Group G 9, which is a subgroup of Leo I cloud (de Vaucouleurs, 1975). It forms a triplet with galaxies NGC 3623, 20 arcmin away, and NGC 3628, 36 arcmin away. It was included in the list of peculiar nuclei exhibiting sharp change in the luminosity profile by Sérsic (1973), who assigned it a "hot spot?" class. On the other hand, the nuclear region does not contain bright H II complexes (Prabhu, 1980) while the continuum surface brightness is very high (Keel and Weedman, 1978). The mean of all observed velocities of NGC 3627 is $723 \pm 46\,\mathrm{km\,s^{-1}}$ (Palumbo et al., 1983). The mean velocity of the Leo group with respect to the local group is $670\,\mathrm{km\,s^{-1}}$ (Helou, 1984) implying a distance of 13.4 (h/50) Mpc. SN 1989 B was situated at the northern end of the bar of NGC 3627, whereas the type II supernova 1973 R was in a spiral arm (*cf.* Ciatti and Rosino, 1977).

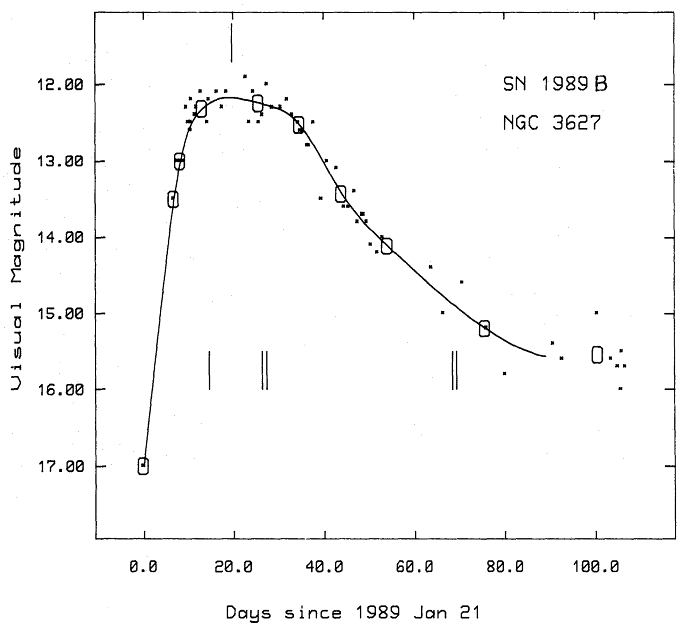

Fig. 1. Light curve of SN 1989 B. Visual estimates (·), and their local means (O), are plotted based on the data published in *IAU Circulars*. The curve is a spline fit to the mean visual magnitudes. Vertical bar on top is the estimated date of maximum (February 10), whereas the lower ones denote the dates of spectroscopic observations

2. Optical spectrum and its evolution

Low-resolution spectra (dispersion $40\,\mathrm{nm\,mm^{-1}}$) of SN 1989 B were recorded at the Vainu Bappu Observatory (VBO), Kavalur, on 1989 February 4.82, 16.70, 17.70, March 30.69 and 31.67, using 1-m reflector, Cassegrain spectrograph, Varo single-stage image

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intensifier, and Kodak IIa-D plates. The spectrograms were digitized on a PDS microdensitometer and reduced using an updated version of the RESPECT software (Prabhu et al., 1987) with the VAX 11/780 computer at VBO. In addition to the usual reductions, the image-tube background on all the days, moonlight background on February 17, and galaxy background on March 30, 31 were subtracted in the intensity domain. The instrumental response correction was made using the standard stars BD +8°2015 and Hiltner 600 (Stone, 1977). Correction for atmospheric bands was applied using templates made from standard stars. Flux calibration was made by computing zero-point corrections based on published V and R photometry (*IAU Circular* Nos 4742, 4743, and 4780). All raw spectra were smoothed by a low-pass filter with cutoff frequency 15 cycles mm^{-1} in Fourier domain. The spectra on adjacent days were averaged. The spectrum on March 30, 31 which had very poor signal-to-noise ratio, was further smoothed by 0.001 cycles nm^{-1} after flux and wavelength calibration. The wavelength scale was corrected for the velocity of NGC 3627. The resultant spectra shown in Fig. 2 are limited in accuracy due to poor signal-to-noise ratio, photographic response, and image-tube non-uniformities.

The spectra on February 4 and 17 form a smooth sequence with the CCD spectra recorded by Bolte et al. (1989) on February 3.4, 8.5, 9.5, 11.4, and 14.5. The spectrum on February 4 matches with the maximum time spectra of other SN Ia, particularly of SN 1981 B (Branch et al., 1983). The absorption dips attributed to Si II, S II and O I are fairly strong. By February 17, the S II lines almost disappeared, Si II lines became weaker, and lines of Na I and Fe II gained in strength. The spectrum now resembles that of SN 1981 B, 20 days from maximum. The spectrum of March 31 resembles that of SN 1981 B, 49–64 days from maximum. By this time the Si II lines have also disappeared, and the unidentified line at 677 nm has become prominent.

The observed absorption features, their identifications based on Branch et al. (1983) and Gordon (1980), and deduced expansion velocities, are listed in Table 1. The estimated errors in velocities are $\pm 300\,\mathrm{km\,s^{-1}}$ in February and $\pm 600\,\mathrm{km\,s^{-1}}$ in March. The values that are uncertain either because the wavelength scale was extrapolated beyond comparision lines, or due to poor signal-to-noise ratio, or because of blending are marked by a colon. We infer from Table 1 that the mean expansion velocity of the envelope decreased from $10000\,\mathrm{km\,s^{-1}}$ on February 4, through $9000\,\mathrm{km\,s^{-1}}$ on February 17 to $8000\,\mathrm{km\,s^{-1}}$ on March 31. The Si II absorption velocity of $11000\,\mathrm{km\,s^{-1}}$ on February 4 follows the trend noted by Bolte et al. (1989): 10900 (February 9), 10730 (February 11) and 10670 (February 14) $\mathrm{km\,s^{-1}}$, beginning with the value of $11350\,\mathrm{km\,s^{-1}}$ inferred for January 31 (*IAU Circ.* No. 4727).

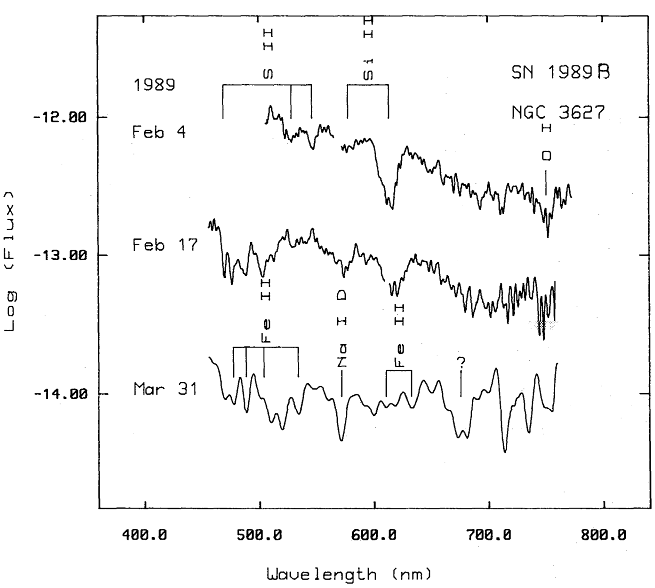

Fig. 2. Spectra of SN 1989B. Flux in units of $\mathrm{erg\,cm^{-2}\,s^{-1}\,Hz^{-1}}$ is only approximate. A bias of one unit has been added to the spectrum on February 4. Blemishes have been blanked out on February 4 and 17. Blue-shifted absorption features of important lines are marked

3. SN 1989 B among other I a supernovae

Barbon et al. (1973), Pskovskii (1977, 1984), and Branch (1981) have shown that intrinsic differences exist among type I a supernovae with respect to their light curves, expansion velocities, and absolute luminosity at maximum. The basic parameter appears to be the rate of decline of the blue light curve (β in magnitudes per 100 days), other parameters being correlated with this: supernovae with slower light curves reach higher luminosities at maximum, and exhibit higher expansion velocities (Pskovskii-Branch effect). A recent compilation of the evolution of photospheric velocity indicated by Si II 635.5 nm (Branch et al., 1988), shows that the magnitude of the velocity generally decreases with time, and there are significant intrinsic differences in the time rates of the decline. However, in the mean the observations are consistent with the theoretically-deduced variation corresponding to the law, density in the envelope $\propto$ (velocity)$^{-n}$ leading to $V_{\exp} \propto t^{-2/(n-1)}$, with a favoured value of $n = 7$.

Though no blue light curve has yet been published for SN 1989B, the visual light curve in Fig. 1 suggests that the supernova was not as slow as SN 1981 B ($\beta = 8.8$: Phillips et al., 1987). The rate of decline in visual light is 6 mag/100 days. Following Pskovskii (1977) this implies $\beta = 11$. The velocity at maximum is estimated to be $10600\,\mathrm{km\,s^{-1}}$ after correcting for the rotation of NGC 3627 (Bolte et al., 1989). This suggests $\beta = 10 \pm 2$ following Branch (1981).

Figure 3 compares the evolution of absorption velocity of Si II 635.5 nm feature in SN 1989B with SN 1981 B and SN 1986G (Phillips et al., 1987). The zero point of time is assumed to be 20 days before maximum (cf., Branch et al., 1988). The three curves resemble each other though SN 1986G declined considerably faster. In particular, SN 1989 B matches well with SN 1981 B if its timescale is stretched by a factor 1.5 and velocities increased by a factor 1.05. Alternative to scaling the time coordinate is to fix the zero point of time for SN 1989B as 30 days before maximum. Pskovskii (1977, 1984) found that faster supernovae have longer rise times. However, the effect is small, the difference being only a few days from the fastest to the slowest supernovae.

Least-squares fits $V \propto t^{-2/(n-1)}$ to the observations in Fig. 3 yield $n = 10.7$ (SN 1989B), 9.2 (SN 1981 B), and 6.6 (SN 1986G). These values do not appear to be correlated either with the velocity at maximum or the rate of decline ($\beta \sim 10 - 11$ for SN 1989B; 9 and 12, respectively, for SN 1981 B and SN 1986G following Phillips et al., 1987), but the trends in Fig. 3 suggest that they are correlated with the expansion velocity at the outburst. On the other hand, the correlation between the rate of decline and expansion velocity is best seen after maximum.

Both SN 1981 B and 1989 B exhibit a sharp drop in velocity: after 17 days from maximum in SN 1981 B, and after 4 days from

Table 1. Absorption features in the spectra of SN 1989B

Identification (nm)	Absorption wavelength (nm)		(Exp. vel. km s^{-1})
	1989 Feb 4	1989 Feb 17	1989 Mar 31
S II 481.5		469.9 (7230):	470.0 (7170):
Fe II 492.4		476.6 (9630)	477.7 (8960)
Fe II 501.8		487.0 (8858)	488.5 (7950)
–		500.0	501.7
Fe II 521.5		511.0 (6610):	511.0 (6610)
–			519.7
S II 545.4	528.9 (9080)	529.5 (8750)	
Fe II 553.5		541.0 (6780)	535.0 (10030)
S II 564.0	547.0 (9040)		
–		556.9	559.5
Na I 589.2		574.4 (7540)	571.2 (9170)
Si II 597.2	575.9 (10700)	574.4 (11450)	
–			596.0
Fe II 620.0			610.3 (4690)
Si II 635.5	612.2 (11010)	616.7 (8880)	
Fe II 647.9			632.9 (6950)
–	649.5	650.0:	650.7
–	661.0	661.7	663.9
'680.0'		{669.6	663.9
		{679.7	676.7
–	692.9 }	701.9:	{698.9
–	711.7 }		{713.9
O I 777.3	751.8 (9840):	748.0 (11310):	751.1 (10110):
Mean vel. (km s^{-1})	9930 ± 910	8920 ± 1380	7990 ± 1690

All values are corrected for a recession velocity of 725 km s^{-1}.

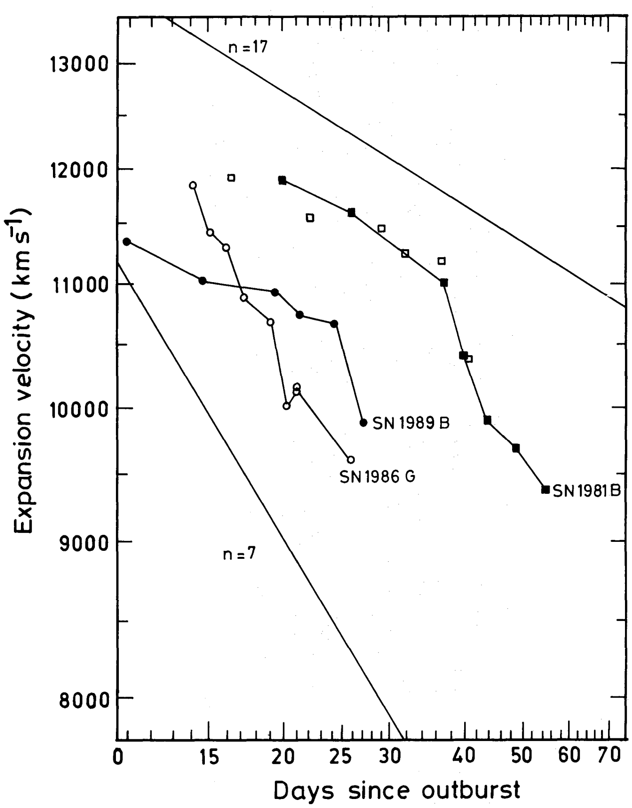

Fig. 3. Evolution of the photospheric velocities are compared for SN 1981B, SN 1986G and SN 1989B. Zero of time is taken to be 20 days before maximum. Open squares denote SN 1989B with timescale stretched by a factor 1.5 and velocities increased by a factor 1.05. Slopes of $V \propto t^{-2/(n-1)}$ are shown for $n = 7$ and 17

maximum in SN 1989B. A similar drop may be present in SN 1989G close to the maximum light, not easily distinguishable due to the overall fast decline of velocity. The sharp decline is accompanied by the weakening of S II lines and strengthening of Fe II and Na I lines. Taking day 17 of SN 1981B as standard, one may estimate the time at which other type Ia supernovae reached this stage. SN 1989B passed this stage between February 14 (Bolte et al., 1989) and February 17: i.e., ~day 6. SN 1986G was just entering this stage on day 4 (Phillips et al., 1987). SN 1960F ($V_{max} = 11300$ km s^{-1}; $\beta = 10$) in NGC 4496 crossed this stage between days 12 and 19 (Bloch et al., 1964). SN 1974G ($V_{max} = 9200$ km s^{-1}; $\beta = 10$) in NGC 7619, the stage appears to have been reached near maximum itself (Assousa et al., 1976). Clearly the spectral evolution is faster for supernovae with lower expansion velocities near maximum (see also Phillips et al., 1987 for a comparison between 1986G and 1981B).

4. Conclusions

The spectra of SN 1989B are typical of a type Ia supernova. Its photospheric expansion velocities after maximum are lower than those of SN 1981 B, and slightly higher than those of SN 1986G. The rate of decline of velocities is slightly slower compared to SN 1981B, but much slower than SN 1986G. Furthermore, spectral evolution of SN 1989B was considerably faster than that of SN 1981 B, but marginally slower than SN 1986G. The spectral evolution is thus seen to correlate with the velocity evolution: higher velocity envelopes evolve more slowly. These observations add to the growing evidence that SN Ia are not all alike (Pskovskii, 1977, 1984; Branch, 1981, 1987; Phillips et al., 1987).

No detailed models exist that explain the differences in SN Ia conclusively (see Branch, 1987; Graham, 1987; Canal et al., 1988). On the other hand, spectral evolution of most supernovae has not been monitored continuously. Some order may emerge among the variety of SN Ia when spectra become available for a good number of them at daily intervals beginning from a couple of weeks before maximum and extending to several weeks after maximum.

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