THE ASTRONOMICAL JOURNAL VOLUME 114, NUMBER 5 NOVEMBER 1997

OPTICAL SPECTRA OF RECENT SUPERNOVAE OF TYPE Ia: SN1995AL, SN1997Y, SN1997BP

G. C. ANUPAMA
Indian Institute of Astrophysics, Bangalore 560 034, India
Electronic mail: gca@iiap.ernet.in

Received 1997 July 14; revised 1997 July 31

ABSTRACT

Optical spectra of three recent supernovae of type Ia: SN1995al in NGC 3021, SN1997Y in NGC 4675, and SN1997bp in NGC 4680 are presented. Comparing the spectra with those of other normal type Ia supernovae, the epoch since maximum is estimated for each of the supernovae. Based on the blueshift of the Si II 6355 Å feature, and its location in the galaxy, it appears that SN1997Y belongs to the older, bulge population of the galaxy. © *1997 American Astronomical Society.* [S0004-6256(97)01511-2]

1. INTRODUCTION

The discovery of several bright supernovae in the recent years has evoked a great deal of interest in these objects (e.g., Filippenko *et al.* 1992; Ruiz-Lapuente *et al.* 1992; Leibundgut *et al.* 1993; Prabhu *et al.* 1995; Gomez *et al.* 1996). A majority of the type Ia supernovae (SNe Ia) belong to a fairly homogeneous class, in both their photometric as well as spectroscopic properties (Branch *et al.* 1993), while some like SN1986G, SN1991T, and SN1991bg show spectroscopic as well as photometric pecularities. The peak absolute magnitudes of SNe Ia in the B, V, and I bands correlate with the decline rate of the immediate post-maximum light curve (Phillips 1993; Hamuy *et al.* 1996a; Hamuy *et al.* 1996b), giving a photometric sequence from luminous blue events with relatively slow decline of the light curve (e.g., SN1991T) to the subluminous red events with a rapid decline of the light curve (e.g., SN1991bg). Branch *et al.* (1993) find that when arranged in the photometric sequence, SNe Ia also form a spectroscopic sequence. This has interesting implications on the explosion models of SNe Ia. Although a majority of the SNe Ia are normal, some spectral inhomogeneities exist. At a given phase there is a spread among the absorption blueshifts as well as minor differences in the line strengths (Branch & van den Bergh 1993, hereinafter BB93), which could be related to the properties of the progenitor. It is hence important to study individual SNe events.

In this paper, post-maximum spectra of three recent SNe Ia—SN1995al in NGC 3021, SN1997Y in NGC 4675, and SN1997bp in NGC 4680—are presented. The spectra are compared with the well studied, normal SNe Ia 1981B and 1989B and time elapsed since maximum and the expansion velocities based on the absorption minima are estimated.

2. OBSERVATIONS

SN1995al was observed on 1995 December 14 and 15 using the Boller & Chivens spectrograph at the cassegrain focus of the 2.34 m VBT (Vainu Bappu Observatory, Kavalur) in the wavelength range 3600–8200 Å with a resolution of 4.5 Å pixel^{-1}. SN1997Y was observed on 1997 February 25 and SN1997bp on 1997 April 19, both using the new OMR cassegrain spectrograph at the VBT (Prabhu *et al.* 1997) in the wavelength range 3800–8200 Å with a resolution of 5.3 Å pixel^{-1}.

All spectra were bias subtracted, flat-field corrected and extracted in the standard manner using the IRAF[1] reduction package. The spectra were flux calibrated using spectrophotometric standards observed on the same night. SN1996al and SN1997Y were oberved under good sky conditions while SN1997bp was observed through clouds. All fluxes are on a relative scale.

3. DISCUSSION

3.1 SN1995al

This supernova was discovered at a visual magnitude of $m_v = 13.0-13.5$ on 1995 November 1.04 (Pesci & Mazza 1995). The supernova is located 15 arcsec west and 2.9 arcsec south of the nucleus of the galaxy NGC 3021 (Pollas 1995). Early spectra obtained on November 3.88 and 4.77 (Wei *et al.* 1995; Ayani & Kawakita 1995) showed absorption features of Si II 6355 Å, S II 5454 Å, Mg II 4481 Å, and complex absorptions of Si II and S II shortwards of 5000 Å. Balmer lines were absent with Si II 5972 Å still weak, indicating the supernova belonged to the type Ia in the maximum phase. The spectrum resembled that of SN1981B in the maximum phase. The Si II 6355 Å absorption line was found to be blueshifted with respect to the galaxy by 14000 km s^{-1} with a FWHM of 6900 km s^{-1} on November 4.77.

From the V light curve of SN1995al, based on magnitude estimates by Tanabe *et al.* available from the variable star network (VSNET) the maximum appears to have occurred around 1995 November 9 with $V_{max} = 13.25$. Comparing with the template V light curve of SNe Ia, the supernova is estimated to have been at a magnitude of ~14.5 on 1995 December 15, about 36 days past maximum. The average spectrum of the supernova is shown in Fig. 1. The spectrum

[1]IRAF is distributed by National Optical Astronomy Observatories.

 0004-6256/97/114(5)/2054/4/$10.00

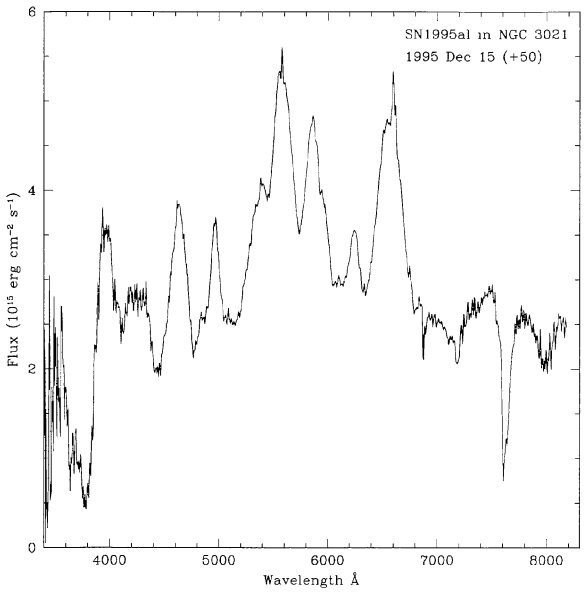

FIG. 1. Spectrum of SN1995al in NGC 3021. The phase (in days) estimated for the spectrum is indicated. Wavelength scale is in the observer's frame, not corrected for the redshift of the parent galaxy.

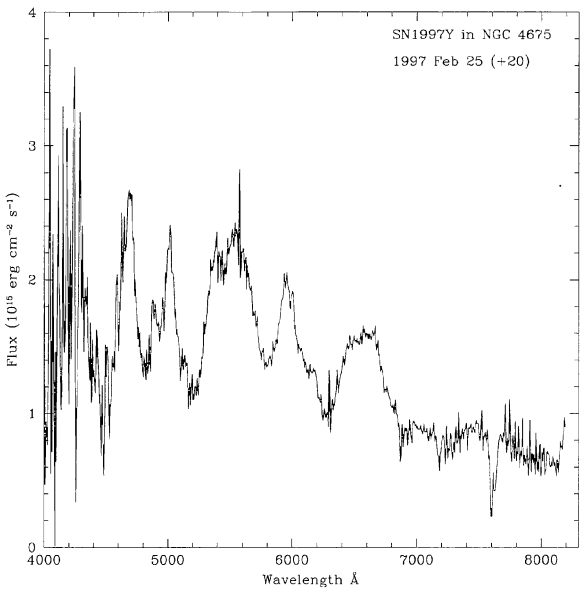

FIG. 2. Spectrum of SN1997Y in NGC 4675. The phase estimated for the specturm is indicated. Wavelength scale is in the observer's frame.

compares well with those of SNe Ia 1981B between 49 and 64 days past maximum (Branch *et al.* 1983, hereinafter B83) and 1989B, 52 days past maximum (Barbon *et al.* 1990, hereinafter BBCRT).

3.2 SN1997Y

This supernova was discovered by the Beijing Astronomical Observatory's supernova survey on CCD images obtained on 1997 February 2 and February 7 (Li *et al.* 1997). The supernova brightened from a magnitude of 14.8 on February 2 to 14.4 on February 7. Spectra of the object obtained on 1997 February 9 (Filippenko *et al.* 1997; Garnavich & Kirshner 1997) indicated the supernova to be of type Ia, close to maximum brightness, quite similar to the spectrum of SN1981B. Prominent Na I D interstellar absorption was present indicating the supernova is significantly reddened. The supernova is located 3.5 arcsec west and 1.7 arcsec north of the nucleus of the galaxy NGC 4675.

The spectrum of the supernova obtained on 1997 February 25 is shown in Fig. 2. Comparing with the spectra of SN1981B (B83) and SN1989B (BBCRT), the spectrum of SN1997Y is similar to SN1981B 20 days past maximum and in between the spectra of SN1989B 11 and 22 days past maximum.

3.3 SN1997bp

This supernova was discovered by R. Evans on 1997 April 6.52 at a magnitude of 13.8 (Marples 1997). Early spectra obtained on April 7 (Phillips 1997; Schlegel 1997; Filippenko & Leonard 1997; Wang & Wheeler 1997a; Garnavich *et al.* 1997) indicated the supernova belonged to the type Ia, very close to maximum. Strong, broad Si II and Ca II absorptions were present. The supernova is located 14.1 arcsec west and 19.8 arcsec south of the nucleus of the galaxy NGC 4680 (Williams 1997). Spectropolarimetry of the supernova on April 7.2 (Wang & Wheeler 1997b) showed variation in the polarisation of $>0.5\%$ across the Si II 6355 feature, indicative of intrinsic polarization.

The spectrum of SN1997bp obtained on 1997 April 19 (see Fig. 3) resembles the early post-maximum spectra of SNe Ia. Comparing with the spectra of SN 1981B (B83), SN1997bp appears to be in a phase 0–17 days. The Si II absorption feature is very similar to that of SN1981B 6 days past maximum. Comparing with SN1989B (BBCRT), the

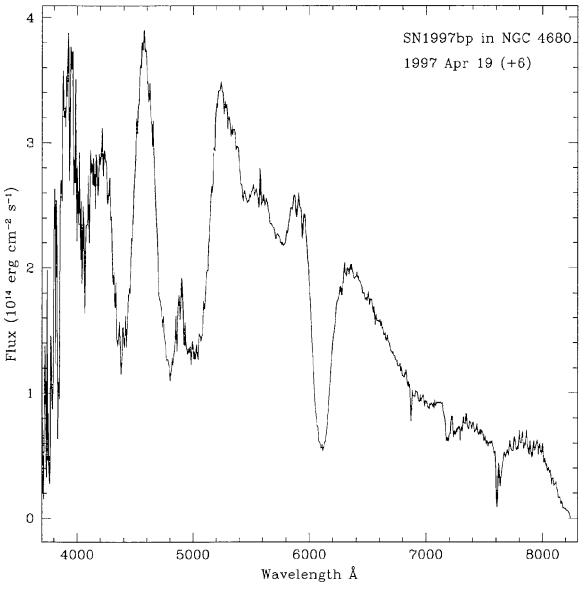

FIG. 3. Spectrum of SN1997bp in NGC 4680. The phase estimated for the spectrum is indicated. Wavelength scale is in the observer's frame.

TABLE 1. Absorption features and blueshift velocities.

	Obsd. wavelength and velocity[a]					
	SN1995al		SN1997Y		SN1997bp	
Feature	λ	velocity	λ	velocity	λ	velocity
Ca II 3945	3758	14250	···	···	3807	10555
Fe II 4220	4109	7905	···	···	4025	13830
Mg II 4481	···	···	4317	10980	···	···
Fe II 4568	4420	9690	4429	9129	4343	14790
Fe II 4635	···	···	4527	6964	···	···
Fe II 4924	4746	10860	4745	10920	4757	10150
Fe II 5018	4845	10330	4868	8962	···	···
Si II 5051	···	···	···	···	4815	14076
Fe II 5172	···	···	5016	9022	···	···
Fe II "5215" [b]	5091	7095	···	···	4955	14970
Fe II 5276	···	···	5124	8644	···	···
Fe II 5535	5327	11289	5364	9245	···	···
Unidentified	5420	···	···	···	5424	···
Na I 5893	5708	9390	5698	9866	5664	11610
Si II 5972	···	···	···	···	5725	12400
Fe II 5991(?)	···	···	5852	6933	···	···
Fe II 6200	6032	8129	6033	8090	···	···
Si II 6355	6102	11940	6179	8300	6058	14000
Fe II 6479	6306	8008	···	···	···	···
Mean vel.	···	9900	···	8920	···	12930
Galaxy vel.	1541		4806		2492	

[a]Corrected for recession velocity of the galaxy.
[b]Fe II 5125: blend of 5172 and 5276 complexes.
Velocities in km s^{-1}.

spectrum is similar to the spectrum of SN1989B 6 days past maximum.

3.4 Absorption Velocities

The observed absorption features identified based on B83, BBCRT, and Prabhu & Krishnamurthy (1990) and the resulting expansion velocities for each of the supernovae are listed in Table 1. The velocities are corrected for the recession velocity of the host galaxy using the values $V_{3021} = 1541$ km s^{-1} for SN1995al, $V_{4675} = 4806$ km s^{-1} for SN1997Y, and $V_{4680} = 2492$ km s^{-1} for SN1997bp (NED[2]). The mean absorption velocities are -9900 ± 2100 km s^{-1} in SN1995al, -8920 ± 1290 km s^{-1} in SN1997Y, and -12930 ± 1800 km s^{-1} in SN1997bp. These velocities fall in the range of velocities generally observed in SNe Ia.

The Si II 6355 Å absorption velocity in SNe Ia is found to correlate with the Hubble type of the host galaxy, with lower velocites occurring in SNe Ia in early-type galaxies, indicating the latter supernovae belong to the oldest stellar population (Filippenko 1989; BB93). Based on these findings, BB93 also suggest that lower expansion velocities may be expected in the nuclear bulges of spirals. The Si II velocity in the three supernovae presented here are compared with those of other SNe Ia from the data available in BBCRT, Leibundgut *et al.* (1993) and BB93. The blueshifted Si II velocity in SN1995al reduced from 14000 km s^{-1} around maximum to about 10000 km/s nearly 50 days past maximum. These velocities are higher than those observed in SNe 1981B and 1989B, although the rate of decline appears to have been similar (BBCRT: Fig. 6). The Si II blueshifted velocity in SN1997bp is 14000 km s^{-1} about 6 days past maximum, similar to SN1995al. Both these supernovae have velocities quite consistent with the Hubble type of their parent galaxies: NGC 3021, a starburst galaxy, in which SN1995al occurred is of type SA(rs)bc, while NGC 4680 in which SN1997bp occurred is listed as peculiar in NED. The Si II velocity in SN1997Y which occurred in NGC 4675 a galaxy of type SBb:, is 8300 km s^{-1} about 20 days past maximum. This value is much lower than what is normally found in SNe Ia in spirals, at the same phase. It is, however, quite similar to the velocities seen in SN1979B, which also occurred in a spiral galaxy NGC 3913, Sd: (BBCRT; BB93) and in SNe Ia in early-type galaxies. Although the velocity is low, the spectra of SN1997Y show no pecularities and are very similar to normal SNe Ia. Based on the normal spectral features, low Si II expansion velocity and the proximity of the supernova to the center of the galaxy, it appears that SN1997Y occurred in the bulge of the galaxy and belongs to the older stellar population.

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration (USA).

[2]NASA/IPAC Extragalactic Database.

REFERENCES

Ayani, K., & Kawakita, H. 1995, IAU Circ., No. 6256

Barbon, R., Benetti, S., Cappellaro, E., Rosino, L., & Turatto, M. 1990, A&A, 237, 79 (BBCRT)

Branch, D., Fisher, A., & Nugent, P. 1993, AJ, 106, 2383

Branch, D., Lacy, C. H., McCall, M. L., Sutherland, P. G., Wheeler, J. C., & Wills, B. J. 1983, ApJ, 270, 123 (B83)

Branch, D., & van den Bergh, S. 1993, AJ, 105, 2231 (BB93)

Filippenko, A. V. 1989, PASP, 101, 588

Filippenko, A. V., *et al.* 1992, ApJ, 384, L15

Filippenko, A. V., & Leonard, D. C. 1997, IAU Circ., No. 6613

Filippenko, A. V., Leonard, D. C., Gilbert, A. M., & Ho, W. C. G. 1997, IAU Circ., No. 6557

Garnavich, P., Challis, P., & Kirshner, R. 1997, IAU Circ., No. 6613

Garnavich, P., & Kirshner, R. 1997, IAU Circ., No. 6557

Gómez, G., López, R., & Sánchez, F. 1996, AJ, 112, 2094

Hamuy, M., Phillips, M. M., Schommer, R. A., Suntzeff, N. B., Maza, J., & Avilés, R. 1996a, AJ, 112, 2391

Hamuy, M., Phillips, M. M., Suntzeff, N. B., Schommer, R. A., Maza, J., Smith, R. C., Lira, P., & Avilés, R. 1996b, AJ, 112, 2438

Leibundgut, B., *et al.* 1993, AJ, 105, 301

Li, W.-d., Qiu, Y.-l., Qiao, Q.-y., & Hu, J.-y. 1997, IAU Circ., No. 6556

Marples, P. 1997, IAU Circ., No. 6613

Pesci, S., & Mazza, P. 1995, IAU Circ., No. 6255

Phillips, M. M. 1993, ApJ, 413, L105

Phillips, M. 1997, IAU Circ., No. 6613

Pollas, C. 1995, IAU Circ., No. 6255

Prabhu, T. P., & Krishnamurthy, A. 1990, A&A, 232, 75

Prabhu, T. P., *et al.* 1995, A&A, 295, 403

Prabhu, T. P., Anupama, G. C., & Surendiranath, R. 1997, Bull. Astron. Soc. India (in press)

Ruiz-Lapuente, P., Cappellaro, E., Turatto, M., Gouiffes, C., Danziger, I. J., Della Valle, M., & Lucy, L. B. 1992, ApJ, 387, L33

Schlegel, D. J. 1997, IAU Circ., No. 6613

Wang, L., & Wheeler, J. C. 1997a, IAU Circ., No. 6613

Wang, L., & Wheeler, J. C. 1997b, IAU Circ., No. 6622

Wei, J.-y., Li, W.-d., Qiu, Y.-l, & Hu, J.-y. 1995, IAU Circ., No. 6256

Williams, G. V. 1997, IAU Circ., No. 6617