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Spectrophotometry of type Ib/c SN 1997X: HeI lines near maximum light

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Abstract. Low resolution B&C+CCD (range 3600 Å – 1.0 μm) and high resolution Echelle+CCD (range 5800–8100 Å) spectrophotometry of type Ib/c SN 1997X near maximum light is presented and discussed. The supernova is notheworthy in having presented absorption lines of He I at early phases (at an expansion velocity of 11000 km sec^{-1}). From the interstellar NaI D lines a reddening of E_{B-V}=0.18±0.02 mag has been derived, which arises in the host galaxy. From the emission lines of the underlying H II region, a density of $N_e \leq 100$ and a velocity of RV$_\odot$=1098±3 km sec^{-1} are obtained.

Key words: Individual supernovae: SN1997X – Interstellar medium

1. Introduction

SN 1997X has been discovered by Aoki (1997) on Feb 1.76, 1997 (UT), at 8 arcsec to the east of the nucleus of NGC 4691. On Feb 4.3 Covarrubias (1997) obtained V=13.71, B-V=+1.04 and V-I=+0.86. According to spectra secured at the same time (between Feb 4.3 and 4.47) by Suntzeff (1997), Garnavich & Kirshner (1997) and Benetti et al. (1997) SN 1997X was a type Ic caught about one week past maximum light, with an expansion velocity of ∼10,000 km sec^{-1}, strong FeII and CaII lines, HeI possibly present in blend with NaI D and lack of hydrogen features with an overall similarity to the spectrum of SN 1987M (Filippenko 1992).

Since the introduction of SNe Ib/c as a separate subclass from SNe Ia (Wheeler & Levreault 1985; Elias et al. 1985), their nature is still a matter of debate. There are basically two reasons for this, i.e. their rareness and faintness. Cappellaro et al. (1997) estimate that only 40% of type I SNe turn out to be SNe Ib/c. Piemonte (1997), re-examining a complete sample of SNe Ib/c and disregarding parent galaxy absorption, found $M_B = -16.80 \pm 0.94$, about two magnitudes fainter than SNe Ia.

The classification of SNe is based on spectra near maximum light, but in the SNe Ib/c case this can be misleading if one tries to separate the Ib (He-rich) class from the Ic (He-poor) one. Already Clocchiatti et al. (1996) showed evidence for He lines in some SNe previously classified as Ic (namely SN 1994I, SN 1987M and SN 1988L). Moreover, examining the sample extracted from an updated version of the Asiago SN Catalog (Barbon et al. 1989; see also http://athena.pd.astro.it/~supern/) Piemonte (1997) found evidence for objects that do not match the classical paradigm which assigns the SNe with strong He lines to the Ib class and those with faint (if any) He features to the Ic class. Particularly striking is the case of SN 1990W (see also Wheeler et al. 1994), where the behaviour of the He/Na D feature resembles that of SN 1994I, with the He line emerging after the maximum light. Also the large dispersion found for the photometric parameters like lightcurve slopes and maximum absolute magnitudes, put growing evidence toward a heterogeneous nature for these objects, which can be a natural consequence of the articulated progenitor scenarios proposed by several authors (see Filippenko 1997 for a review).

The favoureable brightness of SN 1997X and its partnership to a galaxy displaying peculiar features (e.g. high infrared luminosity and a complex inner region, c.f. Rodriguez–Espinosa et al. 1987, Devereux 1989, Garcia–Barreto et al. 1995) prompted us to secure spectroscopic data on SN 1997X. The results are here presented and discussed.

2. Observations

An Echelle+CCD spectrum has been obtained at the Asiago 1.82 m telescope on Feb 18.1 1997, covering the range 5800-8100 Å and with a resolution of $\lambda/\triangle\lambda \sim$17,000 at Hα (estimated from the FWHM of the comparison spectrum lines). The exposure has been 70 minutes with a 1.″5 wide slit rotated

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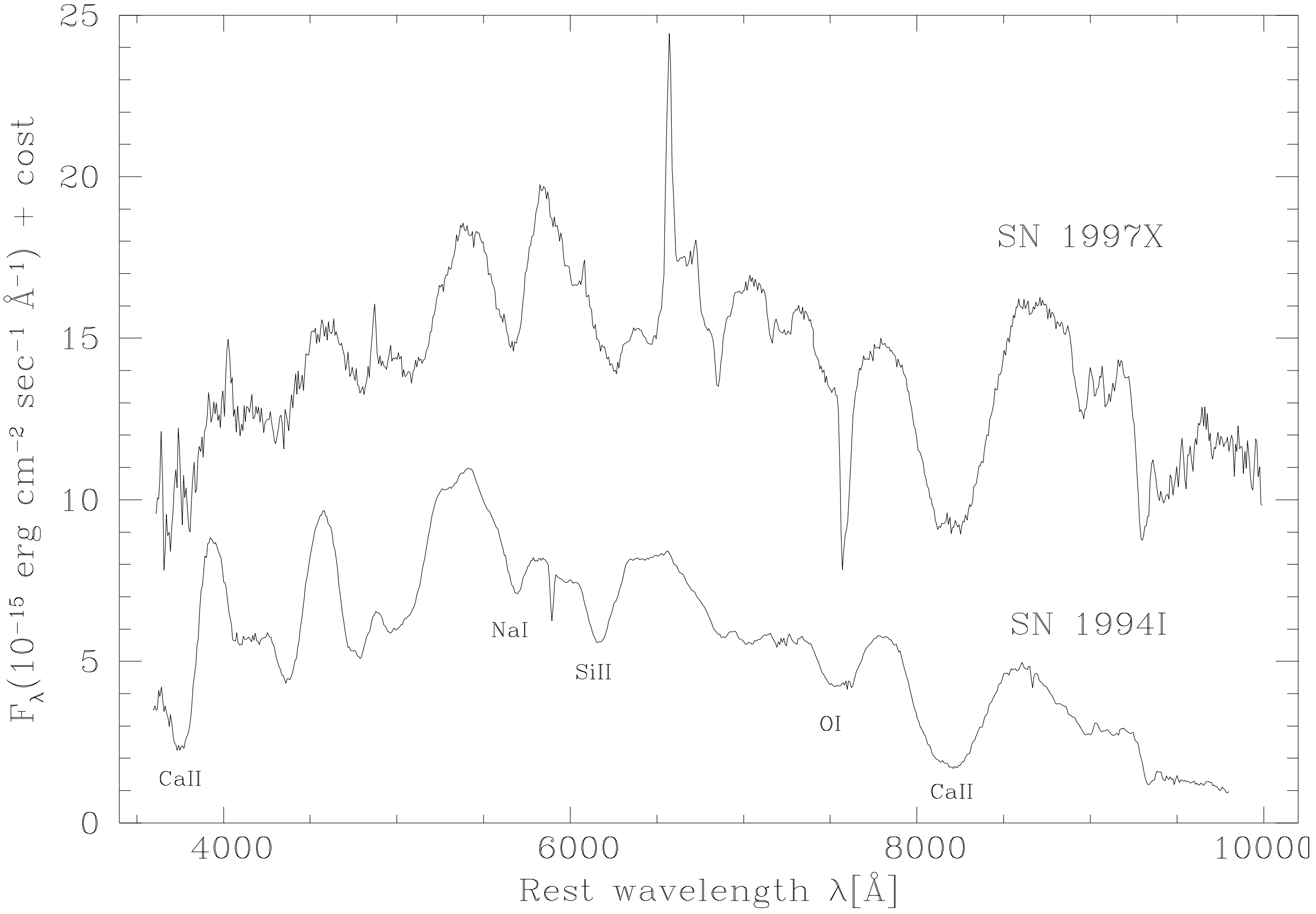

Fig. 1. Spectrum of the He poor SN 1994I at maximum (from Turatto and Zanin 1994) compared to that of SN 1997X arbitrarily shifted on the flux scale. The lines identifications for SN 1994I follow those of Clocchiatti et al (1996). The telluric absorptions have not been filtered out and no reddening correction has been applied.

North-South (at nearly 90° away from the bright galaxy nucleus). The background (sky + galaxy) has been evaluated over a region 2 arcsec in length on both sides of the SN at 3 arcsec distance from the latter.

Low resolution spectrophotometry of SN 1997X has been secured on Feb 7.1 (range 3600–7400 Å, 25 min. exposure) and Feb 8.1 (range 6800–10000 Å, 35 min. exposure) 1997 with the B&C+CCD spectrograph mounted on the Asiago 1.82 m telescope. The spectrograph slit was set to 1.″5 width and rotated North-South. The sky and galaxy backgrounds have been evaluated from a detailed fit extending over the whole recorded slit height (∼1 arcmin). Absolute flux calibration has been achieved by observations of a few spectrophotometric standard stars from Hamuy et al. (1994). Their intercomparison suggests that the error of absolute flux scale should not exceede 10% except for the very borders of the recorded wavelength range.

All data reductions have been performed in a standard fashion with the IRAF package running on a Pentium under the Linux operative system. The B&C+CCD spectrum is presented in Figure 1, with an expanded view around some HeI lines given in Figure 2. Selected portions of the Echelle+CCD spectrum are given in Figure 3.

Table 1. $UBV(RI)_C$ photometry of SN 1997X. Values for Feb 4.3 are from Covarrubias (1997) who assigned them a ±0.05 mag error. Our data from absolute spectrophotometry (Feb 7.1 and 8.1) should be accurate to 0.05 mag in B, V, R, 0.07 mag in I and 0.12 mag in U.

date	U	B	V	R_C	I_C
Feb 4.3		14.75	13.71		12.85
Feb 7.1	15.6	14.73	13.78	13.11	
Feb 8.1					12.73

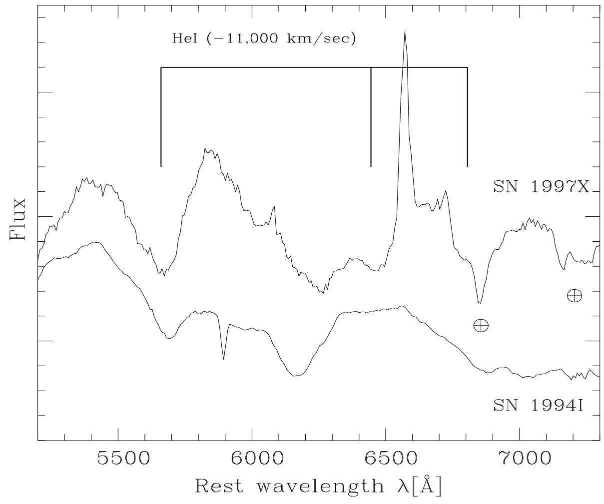

Fig. 2. Expanded view of the Figure 1 spectra of SN 1994I and SN 1997X around the region of the λλ 5876, 6678 and 7065 Å HeI lines. Telluric absorptions are marked.

3. The optical low–resolution spectrum

Our low resolution, combined spectrum of the supernova (epochs Feb 7.1 and 8.1 1997) is shown in Fig. 1 together with the maximum light spectrum of SN1994I (from Turatto and Zanin 1994). From the comparison of the two spectra, and according to IAUC No. 6552 and 6554, our spectrum of SN1997X may be assumed to have been obtained close to maximum light. Absorptions due to CaII (*H*, *K* and the IR triplet), OI λ7773 Å and SiII are clearly visible. Expansion velocities deduced from these lines range between $10,000 \leq V_{exp} \leq 14,500$ km sec^{-1}. He I absorption lines are not as conspicuous as they were seen in the type Ib SN 1984L (Harkness et al . 1987), nevertheless they are visible in the spectrum. In Figure 2 the excellent coincidence of absorption features with λλ 5876, 6678 and 7065 Å HeI blue-shifted by 11,000 km sec^{-1} is marked (NaI is quite probably contributing to the feature centered at 5660 Å). Such velocity is consistent with the findings by Benetti et al. (1997) and within the velocity range of the "bona fide" supernova absorptions identified in Figure 1. For comparison, the velocity deduced from the (transient) HeI lines in SN 1994I and SN 1987M are about 17,000 km sec^{-1} (Clocchiatti et al.1996). Assuming the same amount of total kinetic energy (10^{51} ergs) it seems to imply more ejected He mass in SN 1997X than in SN 1994I and SN 1987M.

SN 1997X therefore shows, to the contrary of the prototypical SN 1994I, presence of He already at early phases.

4. *UBVRI* magnitudes

$UBV(RI)_C$ magnitudes have been computed by convolving the absolutely calibrated spectrum in Figure 1 with the band transmission curves. We have used the following sources for the transmission curves: Lamla (1982; Vilnius Observatory reconstruction) for the U and B, and Bessell (1979) for the V, R_C, I_C bands. The results are given in Table 1.

There is a very close match with the BVI data secured by Covarrubias (1997) three days earlier, suggesting a leisure decline rate, if any at all, and therefore confirming that spectrum in Figures 1 and 2 has been secured close to maximum light. From the below derived E_{B-V}=0.18 and adopting a standard Savage & Mathis (1979) extinction law, the intrinsic colors of the supernova at the time of our absolute spectrophotometry are:

$$(U-B)_\circ = 0.75$$
$$(B-V)_\circ = 0.77$$
$$(V-R_C)_\circ = 0.58$$
$$(V-I_C)_\circ = 0.16$$

Table 2. Heliocentric radial velocities, equivalent widths (for absorptions, in Å) and integrated flux (for emissions, scaled to F(Hα)=1.0) of selected lines in the Echelle+CCD spectrum of SN 1997X on Feb 18.1.

	$\lambda_\circ$	$RV_\odot$	E.W.	Flux
NaI D	5889.9	1129	0.354	
	5895.9	1141	0.371	
Hα	6562.8	1103		1.000
[NII]	6548.1	1105		0.098
	6583.6	1097		0.281
[SII]	6717.0	1089		0.172
	6731.3	1098		0.126

5. Reddening

Interstellar lines are visible in the Echelle+CCD spectrum of SN 1997X. Munari & Zwitter (1997) have calibrated accurate relations between reddening and equivalent widths (E.W.) of the interstellar lines of NaI D and λ 7699 Å KI. Our Echelle+CCD spectrum is quite noisy in the KI line region, and we could only measured an upper limit of E.W.(KI)≤0.07 Å, if any KI line is actually present. There are no NaI D interstellar lines at radial velocities compatible with our Galaxy at a sensitivity level of $E_{B-V} \leq 0.02$ (i.e. $A_B \leq 0.09$). The strong NaI D doublet at

$$RV_\odot(NaI) = 1135 \pm 4 \quad km\ sec^{-1} \tag{1}$$

originates in the host galaxy as the reddening affecting the supernova. Using the Munari & Zwitter (1997) relations and the E.W. in Table 2, the reddening affecting SN 1997X is found to be

$$E_{B-V} = 0.18 \pm 0.02 \quad mag \tag{2}$$

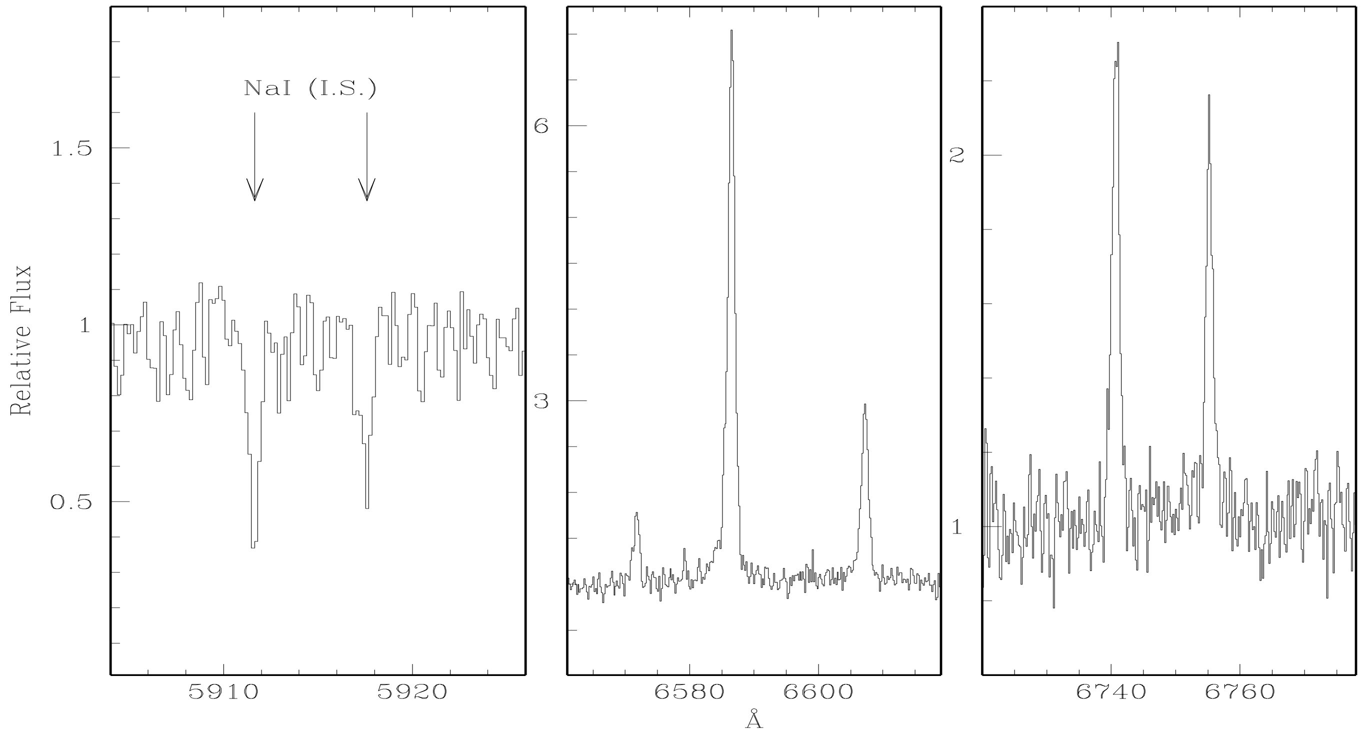

Fig. 3. Portions of the Echelle+CCD spectrum of Feb 18.1. *Left:* region around the NaI doublet. The arrowed lines are the interstellar NaI D lines arising in the host galaxy. *Center :* Hα and [NII] doublet from the H II region spatially not resolved from the supernova. *Right :* the same for the [SII] doublet.

The corresponding E.W. for interstellar KI according to Munari & Zwitter (1997) is 0.05 Å, fully consistent with the above upper limit.

Adopting the NGC 4691 distance modulus ($m-M=31.76$ for $H=75$) and galactic absorption (A_B=0.02 ≡ E_{B-V}=0.005 mag) from Tully (1988) we obtain M_B=–17.05 as the absolute magnitude of SN 1997X, which brightens to M_B=–17.77 once absorption in the parent galaxy is taken into account. These values are consistent with the mean $M_B=-16.80\pm0.94$ derived by Piemonte (1997) for a sample of SNe Ib/c with $(m-M)\leq 32$ and ignoring correction for reddening in the host galaxies. The coincidence further strengthens the idea that we observed SN1997X close to its peak optical brightness.

6. The H II region

The spectrum of a H II region appears superposed on that of the supernova. The major emission lines from the H II region recorded in our 5800–8100 Å Echelle spectrum are the Hα/[NII] complex at 6548–84 Å and the [SII] doublet at 6717–31 Å. They are plotted in Fig. 3. $RV_\odot$ and integrated fluxes are presented in Table 2, from which it can be derived

$$RV_\odot(H\ II) = 1098 \pm 3 \quad km\ sec^{-1} \tag{3}$$

with a clear kinematical separation from the diffuse interstellar medium responsible for the NaI D absorption lines (cf. eq. 1). The FWHM of the emission lines (corrected for instrumental broadening) is ∼55 km sec^{-1}. The flux ratio of the [SII] lines suggests very low electron density in the H II region for any reasonable adopted electron temperature (cf. Osterbrock 1989):

$$[SII]\frac{\lambda 6717\ \text{Å}}{\lambda 6731\ \text{Å}} = 1.37 \quad \longrightarrow \quad N_e \leq 100 \tag{4}$$

The ratio

$$[NII]\frac{\lambda 6584\ \text{Å}}{\lambda 6548\ \text{Å}} = 2.9 \tag{5}$$

is very close to the theoretical 3.0 ratio. Unfortunately, the auroral [NII] line at 5755 Å lies outside the recorded λ range of our spectrum and therefore we cannot proceed to use the [NII] lines to estimate the electron temperature in the H II region.

It is worth noticing that for SN1997X to have erupted close or inside a star forming region is in agreement with the common interpretation that these objects originate from massive stars.

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References

Aoki M., 1997, IAU Circ. 6552

Barbon R., Cappellaro E., Turatto M., 1989, A&AS 81, 421
Benetti S., Turatto M., Perez I., Wisotzki L., 1997, IAU Circ. 6554
Bessell M.S., 1979, PASP 91, 589
Cappellaro E., Turatto M., Tsvetkov D. Yu., Bartunov O.S., Pollas C., Evans R.,Hamuy M., 1997, Astron. Astrophys. in press
Clocchiatti A., Wheeler J.C., Brotherton M.S., Cochran A.L., Wills D., Barker E.S., 1996, ApJ 462, 462
Covarrubias R., 1997, IAU Circ. 6552
Elias J., Matthews K., Neugebauer G., Persson S.E., 1985, ApJ 296, 379
Devereux N.A., 1989, ApJ 346, 126
Filippenko A.V., 1992, ApJ 384, L37
Filippenko A.V., 1997, in: Canal R., Tuiz-Lapuente P., Isern J. (eds.) Thermonuclear Supernovae. Kluwer, p. 795
Garcia-Barreto J.A., Franco J., Guichard J., Carrillo R., 1995, ApJ 451, 156
Garnavich P., Kirshner R., 1997, IAU Circ. 6552
Hamuy M., Suntzeff N.B., Heathcote S.R., Walker A.R., Gigoux P., Phillips M.M., 1994, PASP 106, 566
Harkness R.P., Wheeler J.C., Margon B., Downes R.A., Kirshner R. P., Uomoto A., Barker E.S., Cochran A.L., Dinerstein H.L., Garnett D.R., Levreault R.M., 1987, ApJ 317, 355
Lamla E., 1982, in: Schaifers K., Voight H.H. (eds.) Landolt-Börnstein Series 2b, Springer, Berlin, p. 51
Munari U., Zwitter T., 1997, A&A 318, 269
Osterbrock D.E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei, Univ. Science Books
Piemonte A., 1997, SN 1987A. In: Phillips M.M., Suntzeff N.B. (eds.) Ten Years After. (in press)
Espinosa R.J.M., Rudy R.J., Jones B., 1987, ApJ 312, 555
Savage B.D., Mathis J.S., 1979, ARA&A 17, 73
Suntzeff N.B., 1997, IAU Circ. 6552
Tully R.B., 1988, in: Nearby Galaxies Catalogue. Cambridge Univ. Press
Turatto M., Zanin C., 1994, IAU Circ. 5971
WheelerJ.C., Har4kness R.P., Clocchiatti A., Benetti S., Brotherton M.S., DePoy D.L., Elias J., 1994, ApJ 436, L135
Wheeler J.C., Levrault R., 1985, ApJ 294, L17

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