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Upper limit for circumstellar gas around the type Ia SN 2000cx

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ABSTRACT

Context. The nature of the companion stars in type Ia Supernova (SNe) progenitor systems remains unclear. One possible way to discriminate between different scenarios is the presence (or absence) of circumstellar material, the left overs from the progenitor evolution that may be revealed by their interaction with the SN.

Aims. A new method to probe the circumstellar environment has been exploited for the normal type Ia SN 2006X, leading for the first time to the direct detection of material which escaped the progenitor system. In this paper we apply the same analysis to the peculiar type Ia SN 2000cx, with the aim of constraining the properties of its progenitor system.

Methods. Using multi-epoch, high-resolution spectroscopy we have studied the spectral region where narrow, time-variable Na ID absorption features are expected in case circumstellar material is present along the line of sight.

Results. No Na ID absorption is detected in the rest-frame of the host galaxy to a level of a few mÅ, setting a stringent upper limit to the column density of the absorbing material ($N(\mathrm{NaI}) \leq 2 \times 10^{10}$ cm^{-2}).

Conclusions. In this respect the peculiar type Ia SN 2000cx is different from the normal Ia SN 2006X. Whether this is to be attributed to a different progenitor system, to viewing-angle effects or to a low metallicity remains to be clarified.

Key words. stars: supernovae: general – stars: supernovae: individual: SN2000cx – ISM: general – galaxies: individual: NGC 524

1. Introduction

Due to their enormous luminosities and their homogeneity, type Ia Supernovae (hereafter SNe Ia) have been used in cosmology as standard candles, with the ambitious aim of tracing the evolution of the Universe (Riess et al. 1998; Perlmutter et al. 1999). Despite of the progresses made in this field, the nature of the progenitor stars and the physics which governs these powerful explosions are still uncertain. In general, they are thought to originate from a close binary system (Whelan & Iben 1973), where a white dwarf accretes material from a companion until it approaches the Chandrasekhar limit and finally undergoes a thermonuclear explosion. This scenario is widely accepted, but the nature of both the accreting and the donor star is not yet known, even though favorite configurations do exist (Branch et al. 1995; Parthasarathy et al. 2007; Tutukov & Fedorova 2007). A discriminant between some of the proposed scenarios would be the detection of circumstellar material (CSM). However, notwithstanding the importance of the quest, all attempts of detecting direct signatures of the material being transferred to the accreting white dwarf in normal SNe Ia were so far frustrated, and only upper limits to the mass-loss rate could be placed from optical (Mattila et al. 2005), radio (Panagia et al. 2006) and UV/X-Ray emission (Immler et al. 2006). Claims of possible ejecta-CSM interaction have been made for a few normal objects, namely SN 1999ee (Mazzali et al. 2005), SN 2001el (Wang et al. 2003), SN 2003du (Gerardy et al. 2004) and SN 2005cg (Quimby et al. 2006). In all those cases, the presence of CSM is inferred from the detection of high-velocity components in the SN spectra. However, it must be noticed that these features can be explained by a 3D structure of the explosion (Mazzali et al. 2005) and, therefore, circumstellar interaction is not necessarily a unique interpretation (Quimby et al. 2006). Furthermore, even if the high-velocity components were indeed caused by an ejecta-CSM interaction, it would not be possible to estimate the velocity or density of the CSM.

Two remarkable exceptions are represented by the peculiar SN 2002ic and SN 2005gj, which have shown extremely pronounced hydrogen emission lines (Hamuy et al. 2003; Aldering et al. 2006; Prieto et al. 2007a), that have been interpreted as a sign of strong ejecta-CSM interaction. However, the classification of these supernovae as SNe Ia has been questioned (Benetti et al. 2006), and even if they were SN Ia, they must be rare and hence unlikely to account for normal type Ia explosions (Panagia et al. 2006). As a matter of fact, the only genuine detection may be represented by the underluminous SN 2005ke (Patat et al. 2005), which has shown unprecedented X-ray emission at the 3.6σ-level accompanied by a large UV excess (Immler et al. 2006). These observations have been interpreted as the signature

⋆ Based on observations obtained at ESO-Paranal.

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of a possible weak interaction between the SN ejecta and material lost by a companion star (Immler et al. 2006). Interestingly, the SN has not been detected at radio wavelengths (Soderberg 2005).

A different approach has been recently proposed and tested on the normal SN Ia 2006X (Patat et al. 2007; hereafter P07). For SN 2006X, P07 detected material within a few 10^{16} cm from the explosion site. Based on the velocity, density and location of the CSM, P07 have concluded that the favorite companion star for the progenitor of SN 2006X is a red giant at the time of explosion. The method is based on the study of time variation of absorption lines (Na I, Ca II, K I) arising in the CSM. Since in SNe Ia the UV bluewards of 3500Å undergoes severe line blocking by heavy elements like Fe, Co, Ti and Cr (Pauldrach et al. 1996; Mazzali 2000), they are able to ionize any existing circumstellar material only within a rather small radius. Once the SN UV flux has significantly decreased in the post-maximum phase, the material that has a sufficiently high density recombines, producing time-variable absorption features. In particular, due to their strength, the high-resolution study of the evolution of Na I D lines offers a powerful diagnostic, capable of revealing very small amounts of material along the line of sight, without requiring direct interaction between the SN ejecta and CSM.

In order to investigate the existence of multiple channels to type Ia explosions and the possible presence of viewing angle effects (which are expected if the material is confined within a disk or a torus), a large sample of type Ia events needs to be studied. The drawback of the novel approach proposed by P07 is that it requires multi-epoch, high-resolution ($\Delta\lambda/\lambda \geq 40\,000$) and high signal-to-noise ratio ($SNR \geq 50$) data, making it feasible only with a large amount of integration time at large telescopes and for close-by objects only. This is also one of the reasons that make the data set of SN 2006X unique, at least in this respect.

A few type Ia SNe have been observed at high spectral resolution with the aim of detecting possible signs of interaction with CSM (Lundqvist et al. 2003, 2005; Sollerman et al. 2005; Mattila et al. 2005). In particular, searching the ESO-VLT Archive[1], we have found one object, namely the peculiar type Ia SN 2000cx (Li et al. 2001), that has been observed with VLT-UVES by two different groups, covering two pre-maximum epochs (discussed by Lundqvist et al. 2003) and two additional epochs at about two months past maximum (unpublished, see next section). SN 2000cx was discovered about ten days before maximum in the S0 galaxy NGC 524 (Yu et al. 2000) and was classified as type Ia based on its similarity to SN 1991T (Chornock et al. 2000). SN 2000cx may be as luminous as SN 1991T (see for example Mazzali et al. 2007), but it does not obey to the luminosity vs. light curve width relation (Li et al. 2001) and it is less peculiar from a spectroscopic point of view, since it does not show a Fe lines dominated spectrum at the earliest phases (Filippenko et al. 1992; Ruiz-Lapuente et al. 1992; Mazzali et al. 1995).

Multi-epoch photometry, low-resolution optical and near IR spectroscopy for SN 2000cx have been presented by Li et al. (2001), Rudy et al. (2002), Sollerman et al. (2004) and Branch et al. (2004). Here we focus on the analysis of the high-resolution spectroscopic data obtained for SN 2000cx on four epochs, ranging from day −7 to day +68 with respect to *B* maximum light.

The paper is organized as follows. In Sect. 2 we describe the observations and the data reduction, while in Sect. 3 we illustrate the properties of the host galaxy. The results are presented in Sect. 4 and discussed in Sect. 5. Finally, in Sect. 6 we summarize our conclusions.

[1] `http://archive.eso.org/`

Table 1. VLT-UVES observations of SN 2000cx used in this paper. Phase refers to *B*-band maximum light (July 26.7, 2000, Li et al. 2001).

Date (UT)	Phase (days)	Setup	Range (Å)	Exp. time (s)	Slit width (arcsec)
2000-07-20	−7	DIC1	3280–4510	2 × 2400	0.8
			4620–5600		
			5675–6650		
2000-07-25	−2	DIC1	–	3 × 3600	0.8
2000-09-17	+52	RED	4780–5760	2 × 5400	1.0
			5835–6810		
2000-10-03	+68	RED	–	2 × 5400	1.0

2. Observations and data reduction

The high-resolution data were obtained with the ESO 8.2 m Kueyen Telescope equipped with the Ultraviolet and Visual Echelle Spectrograph (UVES; Dekker et al. 2000) on several epochs, using different instrumental setups (DIC1 390+564, DIC2 437+860, RED 580). For our purposes we have selected DIC1 390+564 and RED 580, retaining only the data sets obtained on 2000-07-20, 2000-07-25, 2000-09-17 and 2000-10-03. The other epochs (2000-09-12, 2000-09-13 and 2000-09-14) were affected by bad weather and did not add significantly to the phase coverage. The main information on the data is recapped in Table 1.

The data were reduced using the UVES Data Reduction Pipeline (Ballester et al. 2000). Wavelength calibration was achieved using Th-Ar lamps, with a final rms accuracy of 0.15 km s^{-1}. The wavelength scale was corrected to the rest-frame adopting a host galaxy heliocentric recession velocity of 2353 km s^{-1} (Emsellem et al. 2004). To compensate for the Earth's motion, a heliocentric velocity correction was applied to the data. The atmospheric lines were identified using a spectroscopically featureless bright star (HR 3239) observed with the same instrumental setup as for the science data. The resolving power $\Delta\lambda/\lambda$ at 5900 Å is 54 000 (DIC1) and 42 600 (RED), corresponding to a full width half maximum (FWHM) resolution of 5.5 and 7.0 km s^{-1} for the two setups, respectively. Finally, in order to increase the signal-to-noise ratio, spectra obtained on the same night were combined. The resulting signal-to-noise ratios per pixel (0.017 Å) in the Na I D region are 90, 160, 70 and 50 for day −7, −2, +52 and +68, respectively.

The gas column densities relative to the detected absorptions were estimated using VPGUESS[2] and VPFIT[3].

3. Host galaxy properties and SN location

NGC 524 is classified as S0^{+}(rs) (de Vaucouleurs et al. 1991), and it shows a gaseous disk with some hint of spiral pattern in the nuclear region (Sarzi et al. 2006). Considering its low ellipticity ($\epsilon < 0.05$, Simien & Prugniel 2000), it shows very high velocities, with an amplitude that reaches ∼140 km s^{-1} at $r \simeq 20''$ (Emsellem et al. 2004). The metallicity index Mg *b*

[2] VPGUESS has been developed by J. Liske and can be freely downloaded at `http://www.eso.org/~jliske/vpguess/index.html`

[3] VPFIT has been developed by R.F. Carswell and can be freely downloaded at `http://www.ast.cam.ac.uk/~rfc/vpfit.html`

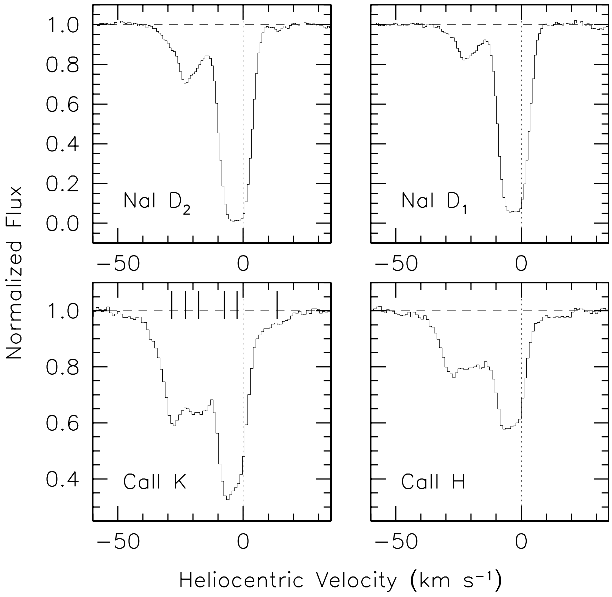

Fig. 1. Line profiles for the Galactic Ca II H&K and NaI D lines on day −2. The resolution is 5.5 km s^{-1} (FWHM). the vertical tickmarks on the Ca II K diagram indicate the positions of the main components.

presents regular gradients as in the case of the Hβ map, which shows a mild positive gradient (Kuntschner et al. 2006). The metallicity in the central part of the galaxy is estimated to be [Z/H] $\sim$ 0.15, while it decreases by about −0.35 per dex in $\log(r/r_{\rm eff})$ (H. Kuntschner, private communication).

SN 2000cx exploded at a projected distance of 111.7 arcsec from the nucleus of NGC 524 (Yu et al. 2000), corresponding to ~2.3 effective radii (Kuntschner et al. 2006). At a distance of 33 Mpc (H_0 = 72 km s^{-1} Mpc^{-1}), this corresponds to about 18 kpc. The velocity maps of NGC 524 (Emsellem et al. 2004) extend to about 35″ from the nucleus in the SW direction (where they reach a velocity of about −140 km s^{-1}) and therefore do not include the apparent position of the explosion site. Nevertheless, these maps suggest that the SN is projected onto the approaching side of the host galaxy. Preliminary results from GMOS observations of NGC 524 reaching out to about 2.5 times the effective radius are consistent with the extrapolation of the SAURON velocity maps, albeit indicating velocities of only ~−100 km s^{-1} at the position of SN 2000cx (M. Norris, private communication).

4. Absorption features

4.1. Milky Way

The Milky Way reddening along the line of sight to NGC 524 is A_B = 0.356 ($E(B-V)$ = 0.083, Schlegel et al. 1998) so that narrow absorption features are expected to be detectable. Indeed, the UVES data we present here clearly show strong Ca II H&K and Na I D lines at heliocentric velocities of 0–30 km s^{-1} (see Fig. 1). The global equivalent widths (EW) of these lines are 0.24 ± 0.01 Å (K), 0.14 ± 0.01 Å (H), 0.35 ± 0.01 Å (D_2) and 0.29 ± 0.01 Å (D_1), respectively. These features show no significant variation during the epochs covered by our data (see Table 2). The ratio of the color excess and the total equivalent width of Na I D lines is $E(B-V)/EW$(NaID) = 0.13, placing SN 2000cx on the lower slope relation between EW and $E(B-V)$ presented by Turatto et al. (2003).

Closer inspection of the line profiles shows a number of sub-components, better seen in the less saturated Ca II H&K lines. The main features correspond to +13.5, −2.4, −7.5, −17.7, −23.1 and −28.5 km s^{-1} (see Fig. 1), the most intense being the second and the third component. The total column density deduced from the Voigt profile fitting of the D_1 component gives $\log N$(NaI) = 13.1 ± 0.1. For a typical Milky Way dust mixture this would imply $E(B-V) = 0.24 \pm 0.03$ (Hobbs 1974), which is almost a factor 3 larger than the value reported by Schlegel et al. (1998). Even though the column density estimate is certainly hampered by line saturation ($EW(D_2)/EW(D_1) \sim 1.2$), we notice that the column density corresponding to $E(B-V)$ = 0.083 is log N(NaI) = 12.3, which can hardly account for the observed line depth.

Table 2. Equivalent widths of Ca II and Na I Galactic features.

Epoch (days)	Ca II K (Å)	Ca II H (Å)	Na I D_2 (Å)	Na I D_1 (Å)
−7	0.24 ± 0.02	0.14 ± 0.02	0.36 ± 0.03	0.29 ± 0.03
−2	0.24 ± 0.01	0.14 ± 0.01	0.35 ± 0.01	0.29 ± 0.01
+52	–	–	0.35 ± 0.02	0.29 ± 0.02
+68	–	–	0.36 ± 0.03	0.29 ± 0.03

4.2. Host galaxy

No trace of Na I absorptions at velocities near the recession velocity of the host galaxy is present in the data (Fig. 2, left panels). All the weak absorption features visible in the spectra are in fact identified as telluric lines, with typical EWs between 2 and 5 mÅ. An upper limit to the EWs of the Na I D interstellar features is $EW \lesssim 1$ mÅ. Therefore, a very low amount of interstellar material is expected along the line of sight within the host galaxy. In fact, using the data for the second epoch, when the signal-to-noise is maximum (~160), we have estimated a 3σ upper limit for the Na I column density N(Na I) $\leq 2\times10^{10}$ cm^{-2} for a velocity parameter $b \leq 10$ km s^{-1}.

A very weak Ca II absorption is detected at v = +176.3 km s^{-1} on both −2 and −7 days (Fig. 3). The column density estimated from the K component on day −2 ($EW \sim$ 4 mÅ) is N(Ca II) = $(4.4\pm0.5)\times10^{10}$ cm^{-2} ($b = 2.1\pm1.0$ km s^{-1}). Since the upper limit for a Na I D component with the same velocity and velocity parameter on day −2 is N(Na I) $\leq 5\times10^9$ cm^{-2}, the Na I to Ca II ratio is N(Na I)/N(Ca II) $\leq$ 0.1. This is a rather low value, observed in a few cases along the line of sight to some Galactic stars and is usually interpreted as arising in low-density, non-molecular clouds, where calcium depletion onto dust grains is negligible (see Crawford 1992 and references therein).

Since the SN appears to be projected onto the approaching side of NGC 524 (see Sect. 3), the high positive velocity measured for the weak Ca II absorption cannot be explained in terms of galaxy rotation, leading us to conclude that this feature arises in a high-velocity cloud (Wakker & van Woerden 1997), possibly falling into NGC 524, and not related to the circumstellar environment of SN 2000cx.

The absence of narrow emission lines, which would signal interaction between the fast moving SN ejecta and the slow circumstellar wind, was discussed by Lundqvist et al. (2003) for the two early epochs. We confirm that there is no trace of Hα or He I 5876 Å in the two later epochs either.

5. Discussion

SN 2000cx exploded in the outskirts of NGC 524. While the non-detection of interstellar lines is compatible with the

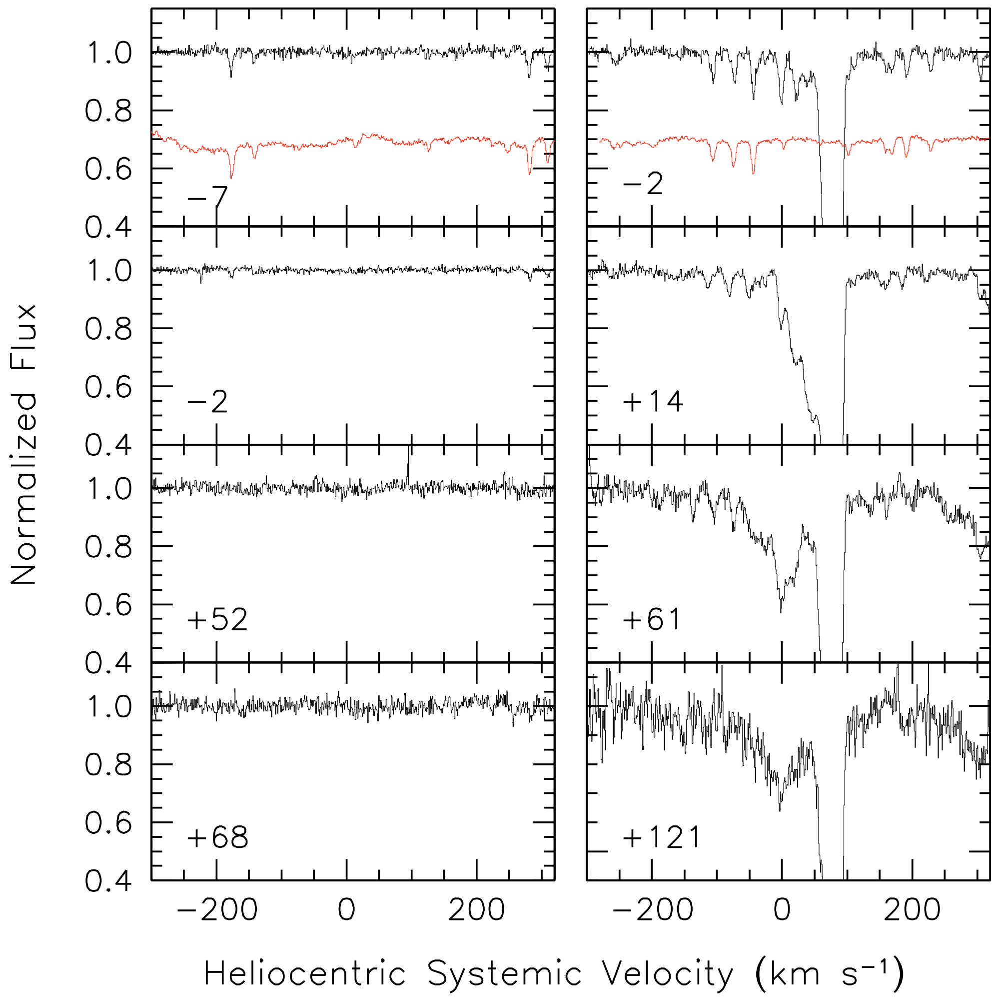

Fig. 2. The Na I D spectral region for SN 2000cx (left) and SN 2006X (right; P07) at four different epochs. The velocity scale is relative to the Na I D_2 component. The light-colored spectrum in the center of the right and left top panels traces the atmospheric absorption features in the relevant wavelength ranges.

peripheral position of the SN within its host galaxy, it also marks a difference with respect to the time-variable Na I D features detected in the normal type Ia SN 2006X (Fig. 2, right panels; P07). In SN 2006X, in fact, while the variable features were barely visible around maximum, they were well developed two weeks later and still clearly present two months later. Therefore, if circumstellar gas was located close to SN 2000cx as in SN 2006X, one might have expected no detectable absorption at the first two epochs (days −7 and −2), but significant absorption at the two later epochs.

The column density deduced from the most intense time-variable feature in SN 2006X (day +14) is $N(\mathrm{NaI}) \sim 10^{12}$ cm^{-2} (P07). If the absorbing material is confined within a thin spherical shell with a radius of $\sim 10^{16}$ cm, then for solar abundance ($\log N(\mathrm{Na})/N(\mathrm{H}) = -5.83$; Asplund et al. 2005) the implied hydrogen mass is $M(\mathrm{H}) \sim 10^{-6}\ M_\odot$. The upper limit set by our analysis for SN 2000cx on day +52 ($N(\mathrm{NaI}) \leq 5 \times 10^{10}$ cm^{-2}) imposes that in this SN, everything else being the same, $M(\mathrm{H}) \leq 4 \times 10^{-8}\ M_\odot$ ($N(\mathrm{H}) \leq 3 \times 10^{16}$ cm^{-2} for a solar Na/H abundance ratio).

The firm upper limit suggests that the circumstellar environment of SN 2000cx is indeed very different from that of the normal Ia SN 2006X. This can be due to a different *i)* progenitor system, *ii)* viewing angle, *iii)* metallicity or *iv)* UV radiation field.

5.1. Progenitor system

SN 2000cx has been classified as a peculiar, if not unique SN Ia (Li et al. 2001). Therefore, one might attribute the lack of Na I D absorption detection to a different progenitor system, where the circumstellar environment is significantly less dense than in the case of the normal SN 2006X as one would predict, for instance, for the case of a double degenerate scenario. Following the prescriptions given in Benetti et al. (2005), the main spectrophotometric parameters characterizing SN 2000cx are as follows[4]: $\Delta m_{15}(\mathrm{B})_{\mathrm{true}} = 0.94$ (Li et al. 2001 and assuming only Galactic reddening); $\dot{v} = 2$ km s^{-1} d^{-1}; $\mathcal{R}(\mathrm{SiII}) = 0.11$; $v_{10}(\mathrm{SiII}) = 11.85$ km s^{-1} 1000^{-1}. These parameters definitely place SN 2000cx in the low-velocity gradient (LVG) subgroup, which includes SN 1991T and all slowly evolving (both photometrically and kinematically) normal SNe Ia (Benetti et al. 2005).

A detailed analysis has shown that this SN is most likely at the edge of normal events, bearing some resemblance to SN 1991T (Mazzali et al. 2007). A double degenerate, super-Chandrasekhar scenario has been suggested for both SN 1991T (Fisher et al. 1999) and SN 2000cx (Li et al. 2001). In this

[4] The spectroscopic parameters have been derived using unpublished spectra of SN 2000cx from the Asiago-ESO-TNG supernova archive.

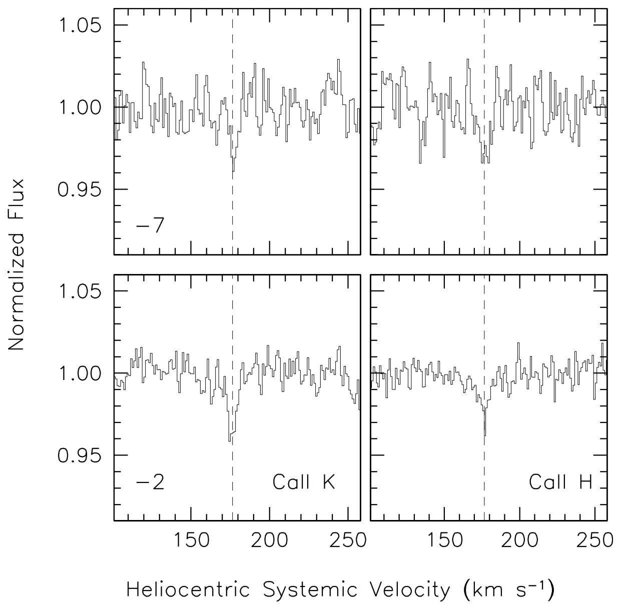

Fig. 3. The Ca II H (*right*) and K (*left*) spectral regions for SN 2000cx on days −7 (*top*) and −2 (*bottom*). The vertical dashed line is placed at +176.3 $km\,s^{-1}$.

respect, we emphasize that while SN 1991T, like other overluminous SNe Ia, was probably associated with a young stellar population (Hamuy et al. 1996; Howell 2001) this is not the case for SN 2000cx, which exploded in the outer halo of an S0 Galaxy (see Sect. 3 and the discussion below). Even though this is certainly not a stringent argument, it suggests a different evolutionary path in the two cases, which do display several dissimilarities (Mazzali et al. 1995; Li et al. 2001).

However, the non-detection of CSM in SN 2000cx does not rule out a more standard single-degenerate scenario. Theoretical models suggest that there are at least two single-degenerate channels that can produce SNe Ia, where the companion is either a main-sequence star/subgiant (the so-called "supersoft channel") or a giant (e.g. Hachisu et al. 1999). P07 suggested that the companion in SN 2006X was most likely linked to the giant channel. On the other hand, SN 2000cx may be representative of the supersoft channel (van den Heuvel et al. 1992; Rappaport et al. 1994; Han & Podsiadlowski 2004). In this case, one would expect a lower mass-loss rate from the system and a higher velocity of the wind material, producing a much lower-density circumstellar medium. Moreover, P07 speculated that the density enhancements seen in SN 2006X could be shells of wind material that were swept up by recurrent novae (e.g. Wood-Vasey & Sokolosky 2006). Without such density enhancements the Na I D recombination time would be very long and the absorption features would be hard to detect. Hence SN 2000cx and SN 2006X could easily both have been produced through different single-degenerate evolutionary channels (also see Parthasarathy et al. 2007; and Tutukov & Fedorova 2007, for recent reviews).

In this context, Wang et al. (2007), based on the photometric and spectroscopic analysis of SN2006X, propose that this object belongs to a subclass of type Ia events, characterized by distinct properties like very high expansion velocities and abnormal extinction laws.

5.2. CSM geometry

The analysis of P07 suggested that, if the progenitor of SN 2006X was a recurrent nova, the circumstellar structure around similar SNe Ia might only be observed for viewing angles close to the orbital plane. If the material was concentrated in an equatorial torus, it would be easier to decelerate the nova shells and to match the observed velocities. Such an aspherical geometry around recurrent novae is supported by observations of RS Ophiuchi (O'Brien et al. 2006; Bode et al. 2007). In SN 2006X we may have observed the supernova through this equatorial torus, which would help to explain the low observed velocities of the circumstellar shells (P07). However, in general it is more likely that our line of sight does not pass through such a torus. In the model of Bode et al. (2007), the narrow waist covers less than a sixth of the solid angle around the binary. Thus, if the Na I D lines in SN 2006X were only seen because of a favourable inclination, this would imply that it should only be detectable in a fraction of all SNe Ia (1 in 6 SNe in the Bode et al. model for RS Oph).

If the material observed in SN 2006X is simply the wind from a subgiant star, it is not clear whether that stellar wind could be aspherical enough for some of the possible lines-of-sight to avoid passing through it.

5.3. Metallicity

An alternative explanation for the lack of detectable Na I D lines in SN 2000cx is the effect of low metallicity in the accreted material. SN2000cx exploded in the outer regions of NGC 524, at a projected distance of about 18 kpc from the nucleus (Sect. 3). Given the abundance gradients observed in early-type galaxies (Carollo et al. 1993), this most likely implies that the SN was produced by the explosion of a low metallicity star, as proposed by Li et al. (2001) as a possible explanation for the observed peculiarities. In fact, a metallicity $[Na/H] = -1.2$ would be already sufficient to make SN 2006X-like features undetectable at the last two epochs (+52, +68). Such sub-solar values are not rare in the outer halos of S0 galaxies (see for instance Harris & Harris 2002) even though it is not clear that this is the case for NGC 524 (see Sect. 3).

Even though clear relations seem to exist between the SN properties and the parent population (Filippenko 1989; Branch & van den Bergh 1993; Hamuy et al. 1995; Branch et al. 1996; Howell 2001), the origin of this link seems to be age rather than metallicity (Hamuy et al. 2000; Ivanov et al. 2000). Therefore, a possible low metallicity in the outskirts of NGC 524 might be responsible for the absence of Na I D circumstellar absorption but, in the light of the currently available data, it is most unlikely that this is the cause of the peculiarities shown by SN 2000cx (Li et al. 2001). In this context, although the models of Kobayashi et al. (1998, 2000) predict that no SNe Ia should occur for $[Fe/H] \lesssim -1$ within single-degenerate systems, some over-luminous SNe are observed in low metallicity environments. For example, the 1991T-like SN 2007bk (Prieto et al. 2007b) went off in the outskirts of its dwarf host galaxy. Prieto et al. (2007b) have suggested that this might be an indication that they come from a distinct class of progenitors, such as double-degenerate systems.

5.4. UV deficiency

If what we have seen in SN 2006X is a common property of normal type Ia SNe, then the absence of time-variable absorption features in SN 2000cx may suggest that the UV spectrum was different. In fact, in order for the ionized Na I to recombine on timescales of the order of 10 days, the medium has to have a sufficiently high electron density ($n_e \geq 10^5$ cm^{-3}), which must be produced by the partial ionization of H (P07). Since SN 2000cx was a peculiar object, one possibility is that its UV flux was sufficient to ionize Na I (ionization potential 5.4 eV), but not to ionize H (13.6 eV). Under these circumstances, the sodium recombination time would become very large and no absorption features would appear. However, the ionization potential of Ca II is rather high (11.9 eV), and under these conditions one would reasonably expect that most calcium is in the form of Ca II. Therefore some H&K absorption components should be visible and their intensity should remain constant in time, as observed in SN 2006X (P07). Since this is not the case, it is hard to believe that a UV deficient SN radiation field is responsible for the lack of Na I lines in SN 2000cx.

6. Conclusions

Clearly, with only two objects studied it is impossible to decide why SN 2000cx did not show the time-variable features displayed by SN 2006X. As we have seen, the reason could be a different progenitor channel, either a different single-degenerate channel or more radically a double-degenerate system, an orientation effect of the CSM or low metallicity. Many more objects need to be observed in order to settle these open issues, requiring high-resolution spectroscopy covering the first weeks after the explosion, when the existence of circumstellar shells can be revealed before they are swept away by the fast moving SN ejecta. For this purpose we have started a dedicated campaign. The first results, obtained for SN 2007af, will be discussed in a forthcoming paper (Simon et al. 2007).

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