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Optical and near-infrared photometry of supernovae in galaxies of the local Universe

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Abstract. In this paper I briefly present and discuss photometric results for three SNe exploded in nearby galaxies: SN 1999el, SN 2000E and SN 2002cv. All data were acquired at optical and infrared bands with dedicated telescopes that allowed us to obtain well sampled and accurate light curves spanning a wide wavelength range. The fundamental role of infrared wavelengths in studying SNe is emphasized.

Key words. supernovae – galaxies – infrared – stars

1. Introduction

In recent years a considerable effort has been devoted to pursuing supernovae (SNe) search, leading to an increase in the number both of dedicated telescopes and of planned high-redshift surveys. However, it remains fundamental the role of nearby SNe which, besides being essential to calibrate such objects as standard candles on cosmological distances, can be followed with swiftly accessible ground-based telescopes allowing total flexibility in scheduling observational time. This is the case, for instance, of the photometric results showed in this short contribution. Of particular note is our capability of simultaneous acquisition of images at both optical (UBVRI)[1] and near infrared (NIR: JHK)[2] bands.This allows us to obtain well-sampled light curves (LCs) with high quality photometry at a wide range of wavelengths. A detailed study of the observed evolution of single events is not only useful to enlarge the database available in literature (which, incidentally, in the NIR is still much inferior to that at optical wavelengths) but is also critical to test theoretical predictions and to understand more deeply the physics of SNe.

Investigations in the NIR bands have a pivotal role in these studies. High quality photometric data can yield useful information on the circumstellar matter (CSM) and on its distribution around the progenitor star and, possibly, give some hints on its nature. For Type Ia SNe the lower sensitivity to extinction uncertainties in the NIR could imply that observations in this wavelength region may provide more reliable estimates of cosmological distances (Meikle

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[1] with the TNT (0.72m) telescope at Teramo Observatory (Italy), and in collaboration with other telescopes

[2] with the AZT-24 telescope (1.1m) in Campo Imperatore (Italy)

2000). Furthermore, combined NIR and optical data allow one to accurately derive the host galaxy extinction (Av) suffered by these objects (Krisciunas et al. 2001). We also recall that NIR LCs of Type Ia SNe exhibit interesting peculiar morphological features, such as a secondary maximum, that could constrain the theoretical progenitor model properties and give a chance to learn more about the physics of the innermost regions of the exploding star (Pinto & Eastman 2000).

2. The type IIn SN 1999el

Type IIn SNe are characterized by early time spectra dominated by strong narrow $H\alpha$ emission lines superimposed on a blue continuum, indicating the presence of diffuse low velocity matter around the site of the explosion (Schlegel 1990). There is, however, a marked inhomogeneity among the events for what concerns the features of the LCs, a topic that is worth discussing.

Assuming spherical symmetry for the dust surrounding the SN, Roscherr & Schaefer (2000) analyzed theoretically the modifications of optical LCs produced by echo processes. They find that, changing critical parameters (related with the total mass of dust and its geometrical properties), causes the decline rate, the peak luminosity and the times of light maxima to change according to the wavelength. In particular they address a parameter representing the decline rate of the LC at B in the 100 days past maximum ($\beta_{100,B}$) which provides information about the amount of dust around the SN. We report a case of extensive observations in optical and NIR bands which seem to challenge their models.

Type IIn SN 1999el, occurred in the NGC 6951 galaxy, exhibits typical spectral characteristics of Type IIn SNe, although its LCs are similar to that of typical II L SNe. Figure 1 shows the LCs and time evolution of the color indices obtained for SN 1999el (see Di Carlo et al. 2002). We draw attention to some details.

First, we see that there are small delays in the time of the LCs maxima which increase with decreasing wavelength. This is also appreciable as a blueing effect in the early evolution of NIR colors and can be attributed to an infrared excess. The most likely origin for this early NIR excess is ascribable to an IR echo light from preexisting hot dust within the CSM of SN 1999el.

We note also that during the first 100 days the luminosity drop in the B band of SN 1999el LC is quite fast: $\beta_{100,B} \sim 4.8$ mag.

Finally, we note that after 100 days the NIR light curves exhibit a much slower decrease up to ~ 420 days from the shock outbreak, and, in particular in the K band, the LC appears to remain flat. The reddening effect at late times is also evident in the NIR color evolution and can be ascribed to an interaction of the ejecta with the preexisting dust not sublimated during the explosion.

A comparison between the observed $\beta_{100,B}$ index and the quoted theoretical results suggests that an extremely small amount of dust should be expected around SN 1999el. This is in contrast with the presence of an early IR excess caused by an echo light from nearby dust. We think that the failure of the $\beta_{100,B}$ index to diagnose the presence of CSM around the SN may be ascribed to the assumption of spherically distributed dust in the theoretical models. These data, in comparison also with those of SN 1998S (the other extensively observed SN IIn discussed by Fassia et al. 2000) suggest that the progenitor star of SN 1999el was still undergoing a probably asymmetric mass-loss episode at the time of the explosion. Emmering & Chevalier (1988) find theoretically that IR LCs can substantially change by varying the geometrical properties of a given nonspherical (but still axisymmetric) CSM distribution and/or its orientation relative to the line of sight.

Therefore, we propose that the mass-loss in the progenitor star is episodic and occurs with asymmetric distribution. Such a mass-loss phenomenon seems to be responsible for the observed scenario: if the explosion takes place during a quiescent phase of mass-loss, then we observe a normal Type II SN, whereas the SN appears as a Type IIn if a large mass-loss episode is in progress, with observable features of LCs reflecting the CSM properties.

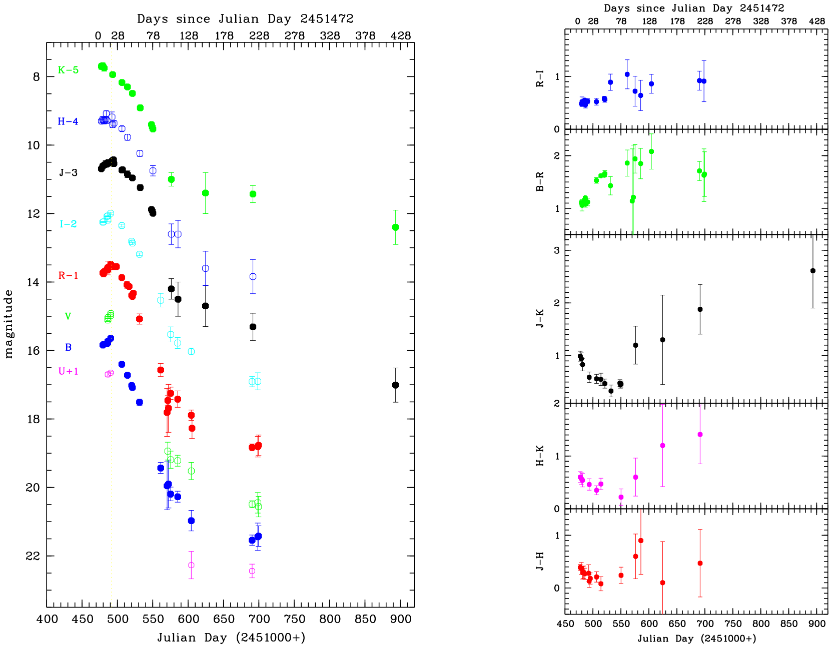

Fig. 1. Optical and near-infrared LCs (left) and colors (right) of the Type IIn SN 1999el.

3. SN 2000E

While monitoring SN 1999el we discovered SN 2000E in the same galaxy. SN 2000E turned out to be a slow-declining Type Ia SN with $\Delta m_{15}(B) = 0.94 \pm 0.05$ mag and showing the typical features of such a class of objects, as described in Valentini et al. (2003). However there is an issue that is worth noticing: Type Ia SNe in the NIR seem to behave differently than in the optical wavelengths. This is shown in Fig. 2, in which the LCs of SN 2000E are compared to those of five SNe having the same $\Delta m_{15}(B)$. These differences could suggest that a single parameter, e. g. $\Delta m_{15}(B)$, cannot properly describe the brightness evolution of SNe Ia at all wavelengths. More work is needed for a deeper analysis.

I also want to quote an additional point: under the hypothesis that the photosphere can be approximated by a blackbody, until one week before maximum B light, we find (see Valentini et al. 2003,for a complete description) that it starts receding well before maximum light. This result seems to support the suggestions of Pinto & Eastman (2000) to explain the double-peak structure in the NIR LCs. They, contrarily to Hoflich, Khokhlov & Wheeler (1995), propose that after (main) peak the photosphere recedes in the NIR through the innermost layers of the ejecta. This occurs when the photospheric temperature declines, therefore at lower ionization states when there is more emissivity at longer wavelengths. The combination of these effects leads to a sharp reduction in the mean opacity and, in turn, to a decrease of the diffusion time. The energy previously stored within the SN is then rapidly released in the infrared, thus yielding an increase in the IR luminosity (secondary maximum) which is sufficient to determine a shoulder in the bolometric LC.

We therefore stress the importance of NIR photometry in constructing bolometric LCs in the post maximum phase. This is a potentially significant diagnostic of the composition and of the physics at work in the innermost regions of a SN Ia progenitor.

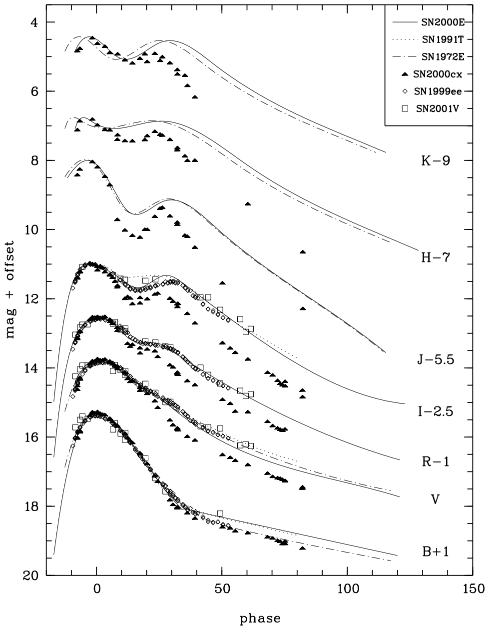

Fig. 2. The luminosity curve of SN 2000E compared with five Ia SNe with the same $\Delta m_{15}(B)$.

4. SN 2002cv

SN 2002cv is a Type Ia SN which exploded in NGC 3190. It is by far the most reddened supernova ever observed, with $Av = 7.9 \pm 0.9$ mag (see Di Paola et al. 2002,for details). SN 2002cv was discovered in the NIR with SWIRCAM at the AZT-24 telescope in Campo Imperatore and it has been undetected at optical B and V wavelengths In fact, from IR measurements there is evidence of a strong dust lane passing across the SN location. SN 2002cv was observed with a good temporal sampling starting long before the maximum light epoch, 11 days before the IR maximum. Indeed, the pre-maximum phase is one of the longest ever followed for such a kind of objects. Figure 2 from Di Paola et al. (2002) shows preliminary light curves obtained during the first 23 days of SN 2002cv monitoring. A further and more complete analysis will be published in a forthcoming paper.

Maiolino et al. (2002) first showed the existence of highly extincted supernovae discovering SN 2001db in the NIR (Av=5.5 mag). These prototypical objects clearly indicate that highly extincted SNe are a relevant issue to be accounted for when estimating SN rates on observational grounds. They also indicate that, because of reduced extinction suffered at these wavelengths, NIR observations are instrumental in the search and follow-up of reddened SNe.

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