The Late UVOIR Light Curve of SN 2000cx

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Summary. We present preliminary data and modeling of the late time light curve of the Type Ia supernova SN 2000cx. Optical and near-infrared data obtained with the VLT at 360 to 480 days past maximum light show the increasing importance of the near-infrared regime. Detailed multi-band modeling based on W7 also show this effect. Conclusions on positron escape in this phase may therefore require more detailed observations and modeling than hitherto appreciated.

1 Introduction

Type Ia supernovae (SNe Ia) are believed to be the destructive thermonuclear explosions of white dwarfs. Their light curves are during the first couple of years powered by the radioactive decay of freshly synthesized ^{56}Ni, releasing γ-rays and positrons in the ejecta. At phases later than about 200 days, virtually all γ-rays escape freely from the ejecta, and the luminosity is then provided by the kinetic energy deposited by the positrons.

Whether or not the positrons are able to slip out of the ejecta depends on the strength and geometry of the magnetic field (e.g., [5, 6, 8]). While a weak and radially combed magnetic field might allow positron escape, thus providing a steep light curve, a strong, tangled magnetic field would efficiently trap all the positrons, and drive the light curve to the radioactive decay rate.

As a first step to investigate whether or not observations of the positron phase can establish conclusions about positron escape, we have conducted a photometric study at late phases of the SN Ia 2000cx, and modeled its light curve in detail. Here we present some preliminary results from that study. The final analysis will be reported elsewhere.

2 Observations of SN 2000cx

SN 2000cx was discovered on 17.5 July 2000 [10] far from the nucleus of the S0 galaxy NGC 524, and became the brightest supernova observed that year.

This made it a very good target for late time photometry. The early evolution has been extremely well covered [1, 4].

We have observed the field of SN 2000cx in the optical, (U)BVRI, regime during four epochs between 360 and 480 days past maximum light. These observations were obtained with the FORS instruments at the ESO VLT. The data were reduced in a standard way using `IRAF`.

Near-infrared observations were obtained using the ISAAC instrument at the VLT. Data were obtained in the J and H (and K) bands at three epochs close to the optical observations. The data were reduced within `Eclipse` and `IRAF`.

Magnitudes were measured using aperture photometry and zero points in the standard system were obtained by observations of standard stars.

A detailed description of the observations and the data reductions will be given elsewhere. Very late observations using the HST will be included in a future study.

3 Modeling

We have performed detailed modeling of the emission from SNe Ia in the nebular phase, $100 - 1000$ days after explosion, in order to interpret our observations of SN 2000cx. The code is an updated version of the code described by Kozma & Fransson [3].

The decay of ^{56}Co dominates the energy input at the epochs we are modeling. The γ-rays emitted in the decays give rise to fast electrons which deposit their energy by heating, ionizing, or exciting the ejecta. In our calculations we assume full and immediate positron deposition within the regions containing the newly synthesized iron.

As input to our calculations we use the density structure, abundances and velocity structure from model W7 [7, 9]. UV-scattering is not included and as it may be important for the ionization structure we have made model calculations with and without including photoionization.

4 Results

In Fig. 1 the light curves for the B- to H-bands are shown for both observations and models. We find a general good agreement between observations and models, with a steeper slope in the BVR- (V band declines 1.4 mag. per 100 days) and virtually constant light curves in the JH-bands.

The curves for the model without photoionization (dotted) drops quickly after 400-600 days. This is due to a lower temperature in the ejecta for this model. For the $BVRI$-bands the model including photoionization (dashed-dotted) appears to give a better fit to the observations. However, since the differences in the light curves are mainly a temperature effect, other processes might give the same result. For example, clumping of the ejecta would allow low density regions to be hotter, keeping the light curves from dropping.

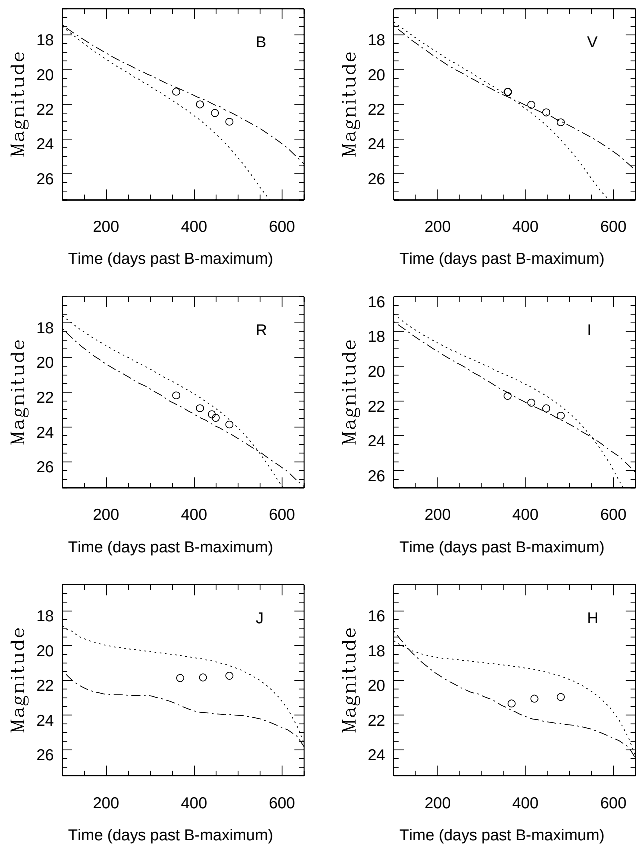

Fig. 1. Late light curves of SN 2000cx. The error bars fall within the circles.

4.1 Bolometric luminosity

The wide coverage of broad band magnitudes allows an attempt to construct a uvoir "bolometric" lightcurve. We estimated the bolometric lightcurve by simply integrating the flux from (U)B to H(K) at all epochs. The result is shown in Fig. 2.

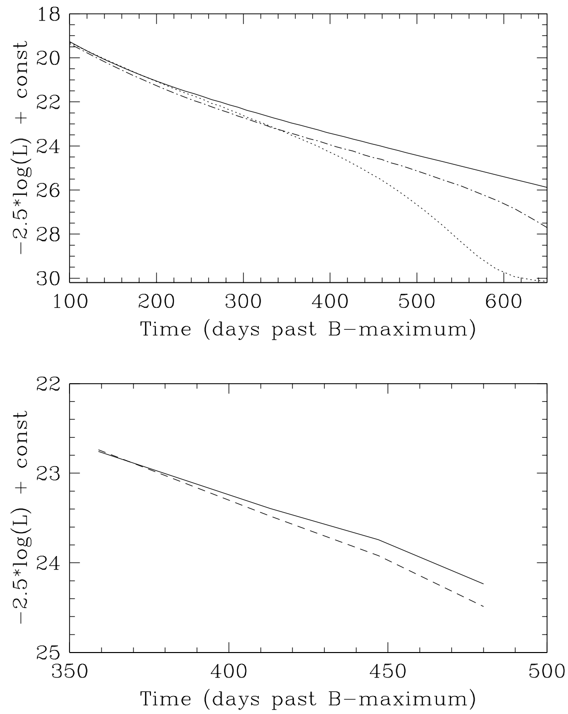

Fig. 2. Upper panel: The full curve shows the modeled bolometric luminosity and the others show the V-band for the two models (see Fig. 1). The curves are matched to the same value at 100 days. Lower panel: The full curve shows the observed integrated luminosity in the (U)BVRIJH(K) bands, while the dashed curve is the observed luminosity in the V-band. For both models and observations the slope of the "bolometric" light curve diverges from the V-band light curve at later epochs.

5 Discussion

As the trapping of the γ-rays decreases, the kinetic energy of the positrons will start to dominate the energy input to the ejecta. Our model assumes full trapping of the positrons. In this case the bolometric light curve should flatten out and approach the decay rate of ^{56}Co in the positron dominated phase. However, late observations of SNe Ia in different pass bands indicate that the light curve continues to fall more rapidly also at epochs later than 250 days. This has been interpreted as due to positron escape [2, 5, 6, 8].

However, since the observations of late light curves are sparse, in particular in the near-IR, it is generally not possible to construct true bolometric light curves. For example, Cappellaro et al. [2] had to assume that the late bolometric light curve follows the V-band. This assumption is not necessarily valid. As the input heating decreases and the ejecta expands the temperatures will decrease, and color evolution could mimic the effect of positron escape.

In Fig. 2 we compare the bolometric light curve to the V-band light curve for our two model calculations. Even with full positron trapping we find an increasing deviation between the bolometric and V-band light curve with time. Especially for the model without photoionization the drop in the V-band is rapid around 400-500 days.

The emission in the various bands behave quite differently, due to the evolution of temperature and ionization structure within the ejecta. This makes it a hazard to assume that any particular band reflects the true bolometric luminosity. Also in the observations do we find that the slope of the bolometric and V-band light curves differs (Fig. 2 lower panel). A comparison to a true bolometric light curve would increase this effect.

We therefore find it difficult to draw any conclusions about the degree of positron escape in SNe Ia without having a detailed and consistent knowledge of the temperature and ionization evolution of the ejecta. Time dependent bolometric corrections can instead be a likely explanation for these observations.

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