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Photometric study of type Ia supernova SN 2002hu

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ABSTRACT

Optical *UBVRI* photometry of the type Ia supernova (SN Ia) SN 2002hu covering the period from −2 to +73 d since *B* maximum is presented. The supernova reached at maximum brightness in *B* on JD 245 2591.78 ± 0.5 with an apparent magnitude of 16.83 ± 0.02 mag and a relatively blue colour $(B - V) = -0.08 \pm 0.04$ mag. The luminosity decline rate of $\Delta m_{15}(B) = 1.00 \pm 0.05$ indicates an absolute *B* magnitude at maximum of $M_B^{\rm max} = -19.38 \pm 0.3$. The estimated absolute *B* magnitude, together with the photometric evolution, indicate SN 2002hu was slightly overluminous compared to the average SNe Ia. The distance modulus to the parent galaxy is estimated to be $\mu = 36.04 \pm 0.20$.

Key words: supernovae: general – supernovae: individual: SN 2002hu – galaxies: individual: MCG+6−6−12.

1 INTRODUCTION

Very high intrinsic luminosities, an impressive homogeneity in the light curves and peak luminosities make type Ia supernovae (SNe Ia) potential candidates to be used as standard candles for determining the extragalactic distance scale. Normal SNe Ia are known to have a fairly uniform absolute *B* magnitude at maximum light, with an intrinsic dispersion of < 0.2 mag (Hamuy et al. 1996a; Phillips et al. 1999). The multicolour light-curve method (Riess, Press & Krishner 1996; Riess et al. 1998) linking the light-curve shapes in *UBVRI* to the absolute magnitude provides a way of determining the absolute magnitudes of SNe Ia along with the extinction suffered by the supernovae, which reduces the observed intrinsic dispersion in the absolute magnitudes of SNe Ia.

The observed homogeneity in SNe Ia puts a strong constraint on the progenitor models of these events. There are two competing progenitor models: (i) the single degenerate model (Whelan & Iben 1973) which involves a single white dwarf accreting material from a non-degenerate star and (ii) the double degenerate model, which involves the merger of C–O white dwarf pairs (Iben & Tutukov 1984; Livio 2001). Recent developments favour model (i) as it explains the observed photometric and spectroscopic properties of SNe Ia better (Nomoto et al. 2000; Livio 2001).

Though a majority of the observed SNe Ia belong to the so-called normal or Branch normal variety (Branch, Fisher & Nugent 1993), a number of studies have pointed out significant photometric as well as spectroscopic differences. For example, Li et al. (2001) report a high rate (∼36 per cent) of peculiarity among SNe Ia and point towards the existence of more than one kind of progenitor. On the other hand, other studies show that the observed diversity can be explained, within the framework of the single degenerate model, primarily by differences in the ejected mass of ^{56}Ni (which controls the temperature and peak luminosity) (Branch 2001) and secondarily by the difference in the amount of mass that is ejected at high velocity (controlled by mode of burning propagation) (Hatano et al. 2000; Lentz et al. 2001), and to a lesser extent by the differences in progenitor metallicity (Lentz et al. 2000). However, there are some emerging observational evidences (Hamuy et al. 2003; Ruiz-Lapuente et al. 2004) which support different progenitor channels proposed by Branch et al. (1995). The emerging evidences of diversity among SNe Ia make it important to study individual events.

We present in this paper the optical *UBVRI* photometry of the type Ia supernova SN 2002hu. SN 2002hu was discovered by Boles (2002) in 2002 November 7 in the outskirts of the spiral galaxy MCG+6−6−12, at a redshift of 0.03. The supernova was located 20.6 arcsec east and 6.6 arcsec south of the nucleus of the host galaxy. Based on a spectrum obtained in 2002 November 8 (Matheson et al. 2002), the supernova was classified as type Ia, around 5 ± 2 d before maximum.

2 OBSERVATIONS AND REDUCTION

SN 2002hu was monitored in the *UBVRI* bands using the 2-m Himalayan Chandra Telescope at the Indian Astronomical Observatory, Hanle, India. The monitoring began, shortly after the discovery, on 2002 November 10 (JD 245 2589.2), and continued until 2003 January 25 (JD 245 2665.2). The Himalaya Faint Object Spectrograph Camera, equipped with a SITe 2048 × 4096 pixel CCD was used. The central 2048 × 2048 pixel region of the CCD used for imaging covers a field of view of 10 × 10 arcmin^2, with a scale of 0.296 arcsec pixel^{-1}.

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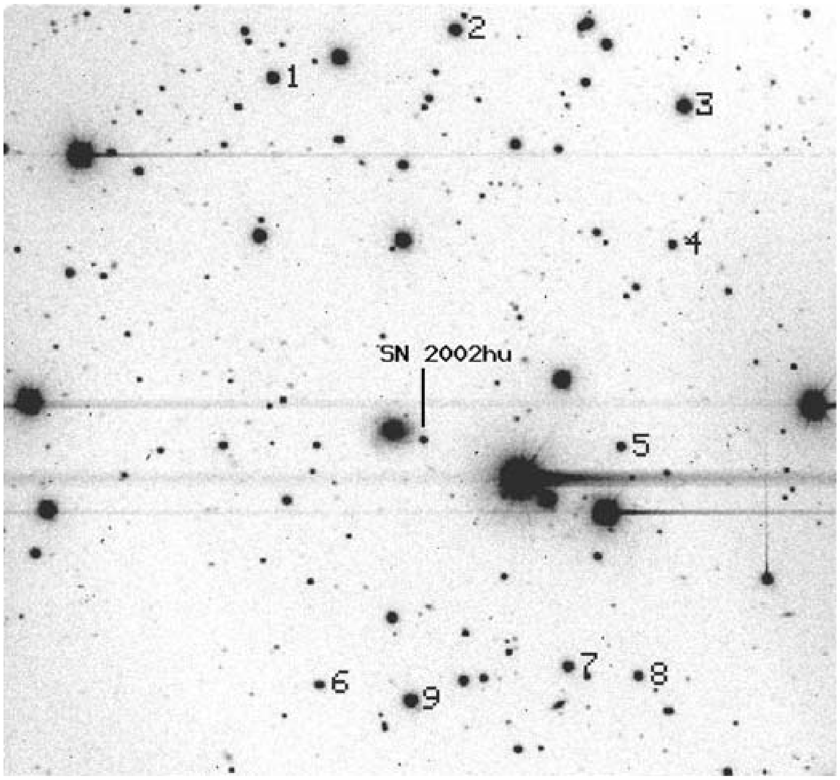

Figure 1. Identification chart for SN 2002hu. The stars used as local standards are marked as numbers 1–9. South is up and east to the right-hand side. The field of view is $10 \times 10\,\text{arcmin}^2$.

The data were bias subtracted and flat-field corrected, and the cosmic rays were removed adopting the standard manner, using the various tasks available under the IRAF software. Landolt (1992) standard fields were observed in 2002 November 15 and December 29 and in 2003 January 8 under photometric conditions for calibrating a sequence of local standards in the supernova field. SN 2002hu and the secondary calibrators in the field are shown marked in Fig. 1. Table 1 gives the *BVRI* magnitudes of the secondary standards, averaged over the three nights and the *U* magnitudes estimated on December 29, the only occasion when the standard fields were observed in the *U* band. These magnitudes were then used to calibrate the data obtained on other nights.

Aperture photometry was performed on the local standards using an aperture of radius three to four times that of the full width at half-maximum (FWHM) of the stellar profile that was determined based on an aperture growth curve. The magnitudes of the supernova and also the local standards were estimated using the profile-fitting method, using a fitting radius corresponding to the FWHM of the stellar profile. The difference between aperture and profile-fitting magnitudes was obtained using the standards and this correction was applied to the supernova magnitude. The supernova magnitudes were calibrated differentially with respect to the local standards listed in Table 1. The estimated supernova magnitudes are listed in Table 2.

3 LIGHT AND COLOUR CURVES

3.1 *UBVRI* light curves

The *UBVRI* light curves of SN2002hu are plotted in Fig. 2. Our observations include the maximum phase in *BVR* bands. We estimated the time of maximum and peak magnitude using cubic spline fits to the observed points in these bands (see Table 3). The maximum in *B* band occurred at 16.83 ± 0.02 mag on JD 245 2591.8 $\pm$ 0.5. The

Table 1. Magnitudes for the sequence of secondary standard stars in the field of SN 2002hu. The stars are identified in Fig. 1.

ID	*U*	*B*	*V*	*R*	*I*
1	17.80 ± 0.04	16.52 ± 0.01	15.31 ± 0.01	14.57 ± 0.01	13.90 ± 0.01
2	15.67 ± 0.03	15.30 ± 0.01	14.64 ± 0.01	14.25 ± 0.01	13.87 ± 0.01
3	15.08 ± 0.03	14.63 ± 0.01	13.96 ± 0.01	13.57 ± 0.01	13.21 ± 0.01
4	16.61 ± 0.04	16.39 ± 0.01	15.91 ± 0.01	15.59 ± 0.02	15.31 ± 0.01
5	17.27 ± 0.05	16.75 ± 0.02	16.02 ± 0.02	15.60 ± 0.02	15.21 ± 0.02
6	17.27 ± 0.05	16.91 ± 0.01	16.24 ± 0.02	15.84 ± 0.02	15.45 ± 0.02
7	17.47 ± 0.06	16.46 ± 0.02	15.38 ± 0.01	14.80 ± 0.01	14.25 ± 0.01
8	17.04 ± 0.06	16.60 ± 0.01	15.91 ± 0.01	15.50 ± 0.01	15.12 ± 0.02
9	14.91 ± 0.04	14.68 ± 0.01	14.19 ± 0.01	13.88 ± 0.01	13.57 ± 0.01

Table 2. Photometric observations of SN 2002hu.

Date	JD 245 2000+	Phase[a] (d)	U	B	V	R	I
10/11/2002	589.211	−2.6	16.69 ± 0.06	16.88 ± 0.01	16.93 ± 0.01	16.86 ± 0.01	17.01 ± 0.01
11/11/2002	590.359	−1.4	16.68 ± 0.07	16.84 ± 0.01	16.88 ± 0.01	16.82 ± 0.01	17.02 ± 0.02
13/11/2002	592.108	−0.3	16.67 ± 0.06	16.83 ± 0.02	16.86 ± 0.02	16.81 ± 0.01	17.09 ± 0.01
14/11/2002	593.337	+1.6	16.74 ± 0.06	16.84 ± 0.01	16.86 ± 0.02	16.75 ± 0.01	17.12 ± 0.02
15/11/2002	594.284	+2.5	16.82 ± 0.06	16.88 ± 0.02	16.84 ± 0.01	16.75 ± 0.02	17.11 ± 0.03
16/11/2002	595.308	+3.5	16.80 ± 0.06	16.91 ± 0.02	16.86 ± 0.02	16.76 ± 0.01	17.11 ± 0.03
18/11/2002	597.231	+5.5		17.01 ± 0.03	16.90 ± 0.02	16.85 ± 0.02	17.20 ± 0.04
19/11/2002	598.113	+6.3	17.03 ± 0.06	16.99 ± 0.03	16.93 ± 0.03	16.84 ± 0.02	17.21 ± 0.05
21/11/2002	600.187	+8.4	17.42 ± 0.06	17.19 ± 0.02	17.02 ± 0.01	16.94 ± 0.02	17.29 ± 0.04
29/11/2002	608.262	+16.5	18.29 ± 0.06	17.95 ± 0.01	17.41 ± 0.01	17.39 ± 0.02	17.70 ± 0.04
01/12/2002	610.124	+18.3	18.57 ± 0.07	18.21 ± 0.02	17.55 ± 0.02	17.50 ± 0.02	17.70 ± 0.01
09/12/2002	618.194	+26.4		19.09 ± 0.01	17.96 ± 0.01	17.60 ± 0.01	17.54 ± 0.04
27/12/2002	636.195	+44.4		19.95 ± 0.02	18.85 ± 0.01	18.39 ± 0.02	18.21 ± 0.03
29/12/2002	638.148	+46.4	20.55 ± 0.07	20.01 ± 0.02	18.94 ± 0.01	18.49 ± 0.02	18.38 ± 0.02
03/01/2003	643.191	+51.4		20.07 ± 0.02	19.08 ± 0.02	18.65 ± 0.01	18.57 ± 0.03
08/01/2003	648.088	+56.3			19.17 ± 0.01	18.81 ± 0.01	18.78 ± 0.01
15/01/2003	655.072	+63.3			19.35 ± 0.02	19.08 ± 0.02	
25/01/2003	665.179	+73.4			19.55 ± 0.01	19.35 ± 0.02	19.31 ± 0.03

[a]Relative to the epoch of B maximum JD = 2452591.78).

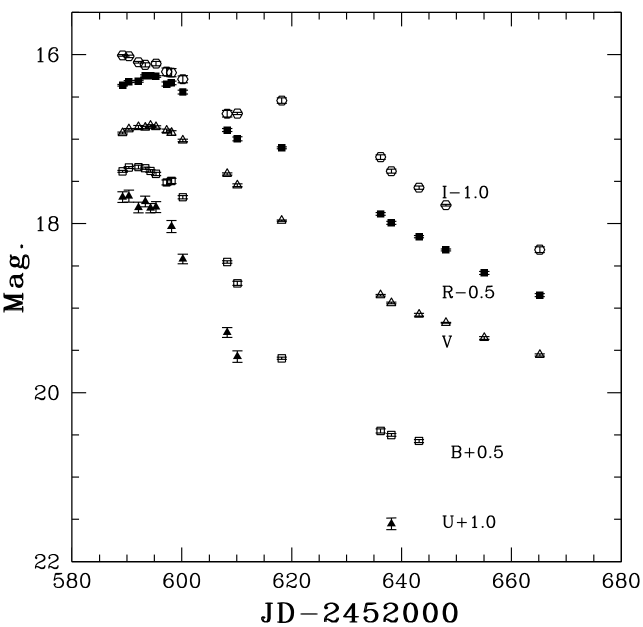

Figure 2. *UBVRI* light curves of SN 2002hu; ordinate scale refers to the V band, other bands are shifted by the amount indicated in the legend.

maxima in the V and R bands occurred a little later, as observed also in other SNe Ia. Similarly, the maximum in U may have occurred a bit earlier, very close to our first observation.

We have also compared the light curves of SN 2002hu with the SNe Ia light-curve templates of Hamuy et al. (1996b). The time-dilation correction as well as K-corrections were applied for the redshift of SN 2002hu ($z = 0.03$). The K_b and K_v values derived by Hamuy et al. (1993) from SN 1992A were used for K-correction in the B and V bands, and no correction was applied to the I band. Levenberg–Marquardt algorithm (Press et al. 1992), was used to obtain the best fits, treating the time of maximum and peak magnitude as free parameters for each of the six templates. The fit with SN 1992bc provided the lowest χ^2 in B and V bands, whereas the best fit was with SN 1992al in the I band. These fits are shown in Fig. 3. The decline rates of these two templates are $\Delta m_{15}(B) = 1.11$ mag (SN 1992al) and 0.87 mag (SN 1992bc). Valentini et al. (2003) have already pointed out that a single decline rate may not describe the light curve of a supernova in all the photometric bands. They found that the light curve of SN 2000E matched the template curve of SN 1992bc in B and V bands, whereas the best fit for the I band was with SN 1991T [$\Delta m_{15}(B) = 0.94$]. The peak magnitude and time of maximum, obtained by template fitting agree with the values determined from spline fitting. We provide in Table 3 the values derived from the template fit for the I band.

Table 3. Photometric parameters of SN 2002hu.

Data	B	V	R	I^c
Epoch of max[a]	591.78 ± 0.5	592.7 ± 0.5	593.8 ± 0.5	592.7 ± 0.5
Magnitude at max	16.83 ± 0.02	16.84 ± 0.02	16.73 ± 0.02	17.04 ± 0.04
$\Delta m_{15}(B)$	1.00 ± 0.05			
Colours at B max[b]		$B - V$	$V - R$	$R - I$
		−0.08 ± 0.04	−0.01 ± 0.03	−0.30 ± 0.03

[a]JD 245 2000+; [b]colours are corrected for reddening $E(B - V)_{\rm total} = 0.044$; [c]obtained with template fit.

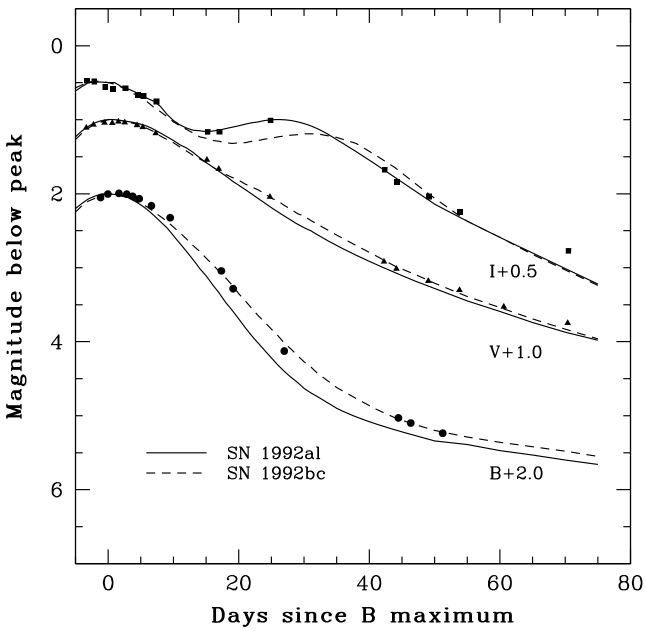

Figure 3. *BVI* light curves of SN 2002hu with the best-fitting templates of SN 1992al [$\Delta m_{15}(B) = 1.11$] and SN 1992bc [$\Delta m_{15}(B) = 0.87$] overlaid. The templates have been modified for time dilation and *K*-correction for the redshift of SN 2002hu

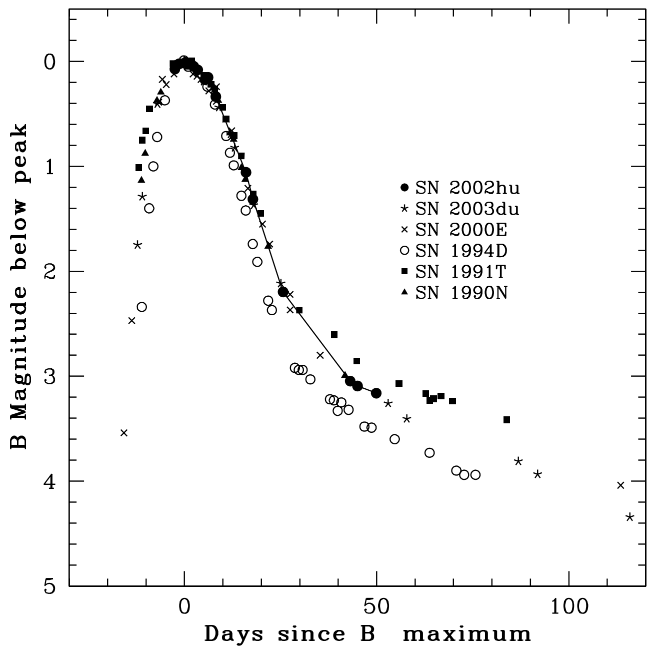

Figure 4. *B*-band light curve of SN 2002hu together with those of SN 2003du, SN 2000E, SN 1994D, SN 1991T and SN 1990N. All the light curves are shifted to match the time of *B* maximum and peak magnitude in *B* band.

The *R*- and *I*-band light curves show a secondary peak, characteristic of the light curves of all normal and overluminous SNe Ia. In the *I* band, the secondary peak occurs ∼30 d after the maximum in *B*, and is ∼0.5 mag fainter than the primary maximum, as estimated by the fitted template (Fig. 3).

Following Phillips (1993), $\Delta m_{15}(B)$ is estimated to be 1.00 ± 0.05, accounting for the *K*-corrections. The $\Delta m_{15}(B)$ values for SNe Ia range from 0.75 (SN 1999aa; Krisciunas et al. 2000) to 1.95 mag (SN 1999de; Modjaz et al. 2001), with a typical value of 1.1 (Phillips et al. 1999). SN 2002hu thus appears to be a mid-decliner in between the slow-declining overluminous and 'Branch normal' SNe Ia.

3.2 Comparison of the light curves

In Figs 4–7, the light curves of SN 2002hu are compared with those of the normal SNe Ia, namely: SN 1994D [$\Delta m_{15}(B) = 1.26$; Richmond et al. 1995], SN 1990N [$\Delta m_{15}(B) = 1.03$; Lira et al. 1998], SN 2003du [$\Delta m_{15}(B) = 1.04$; Anupama, Sahu & Jose 2005]; and the overluminous SNe Ia, namely: SN 1991T [$\Delta m_{15}(B) = 0.95$; Lira et al. 1998] and SN 2000E [$\Delta m_{15}(B) = 0.94$; Valentini et al. 2003]. All the light curves have been normalized to the time of *B* maximum for each supernova and to the respective peak magnitude in the plotted band. A comparison of the light curves of SN 2002hu with those of others reveals that the *B*, *V*, *R* and *I* light curves of SN 2002hu are similar to SNe Ia SN 1990N, SN 2000E and SN 2003du, while it is significantly different from those of SN 1994D. In particular, the light curve of SN 2002hu in all bands is remarkably similar to that of the slightly overluminous SN 2000E. Supernovae SN 1991T, SN 2000E, SN 1990N and SN 2003du occurred in spirals whereas SN 1994D occurred in a lenticular galaxy. Thus, the light curves of SN 2002hu in different bands are similar to those of other SNe Ia that occurred in spiral galaxies.

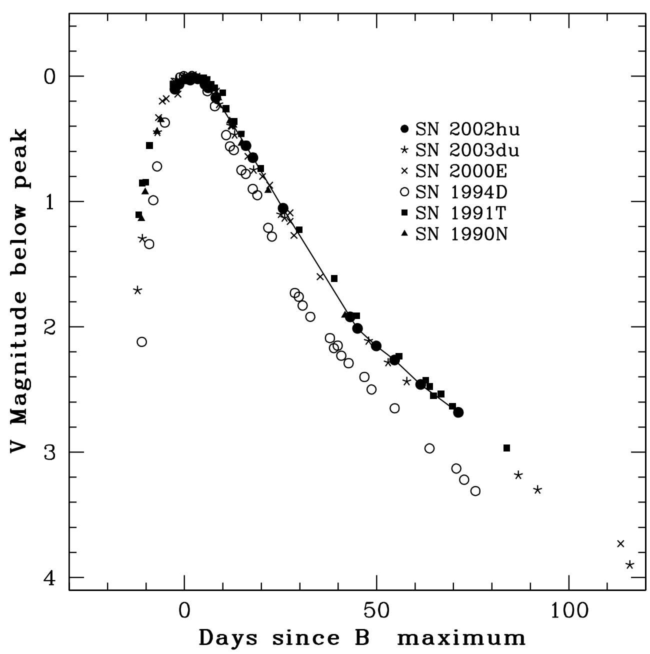

Figure 5. Same as Fig. 4 but for *V*-band light curves of SN 2002hu. All the light curves are shifted to match the time of *B* maximum and peak magnitude in *V* band.

3.3 Colour curves

The $(B - V)$, $(V - R)$ and $(R - I)$ colour curves of SN 2002hu are plotted in Figs 8–10. Also plotted in the same figures are the colour curves of the other SNe Ia used for comparison of the light curves. The colour curves have been dereddened using the Cardelli extinction law (Cardelli, Clayton & Mathis 1989) and the extinction

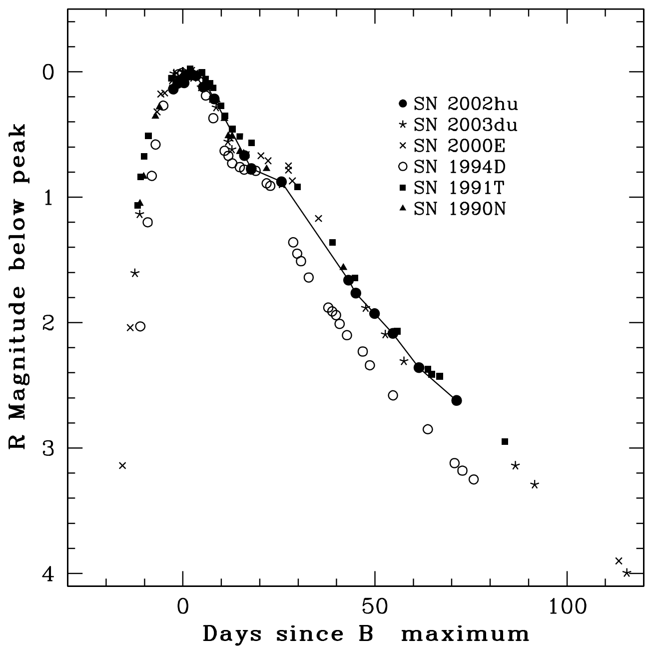

Figure 6. Same as Fig. 4 but for *R*-band light curves of SN 2002hu. All the light curves are shifted to match the time of *B* maximum and peak magnitude in *R* band.

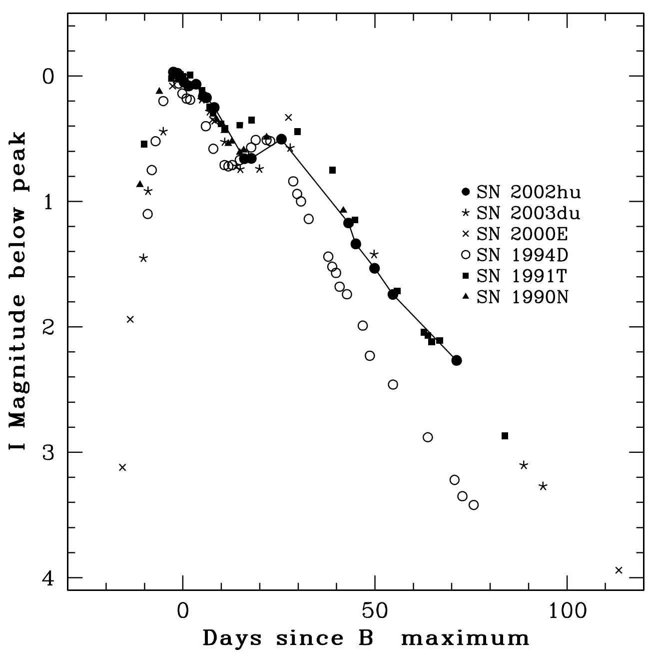

Figure 7. Same as Fig. 4 but for *I*-band light curves of SN 2002hu. All the light curves are shifted to match the time of *B* maximum and peak magnitude in *I* band.

values of $E(B-V)=0.13$ for SN 1991T (Phillips et al. 1992), $E(B-V)=0.04$ for SN 1994D (Richmond et al. 1995), $E(B-V)=0.026$ for SN 1990N (Schlegel, Linkbeiner & Davis 1998), $E(B-V)=0.5$ for SN 2000E (Valentini et al. 2003) and $E(B-V)=0.02$ for SN 2003du (Anupama et al. 2005). An $E(B-V)_{\text{total}}=0.044$, as estimated in section 4 has been applied for SN 2002hu. *K*-correction has been applied to the *B* and *V* magnitudes before applying the reddening correction for $B-V$. Since

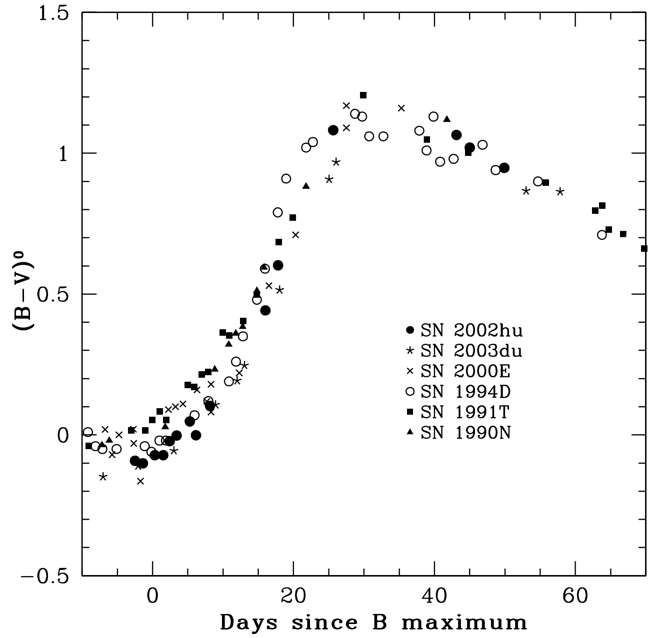

Figure 8. The intrinsic $B-V$ colour evolution of SN 2002hu, compared to those of other SNe Ia. The adopted reddening for each supernova is mentioned in the text.

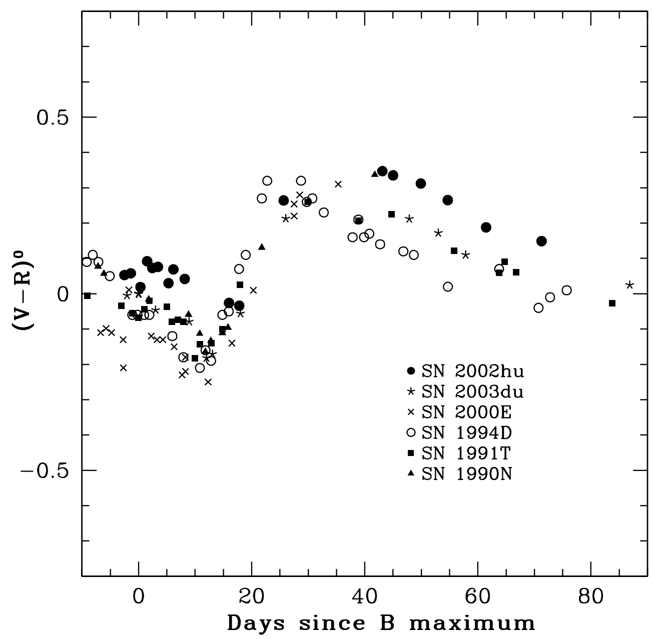

Figure 9. The intrinsic $V-R$ colour evolution of SN 2002hu, compared to those of other SNe Ia.

no *K*-correction has been applied to the *R* and *I* magnitudes, the $(V-R)$ and $(R-I)$ colours are only reddening corrected.

The $(B-V)$ colour of SN 2002hu is very similar to other SNe Ia at all epochs. The $(V-R)$ colour of SN 2002hu is redder as compared to other supernovae, at all epochs, while the $(R-I)$ colour is similar to the SNe Ia in spirals.

4 REDDENING ESTIMATE

The Galactic reddening towards the supernova estimated using the extinction maps of Schlegel et al. (1998) indicates

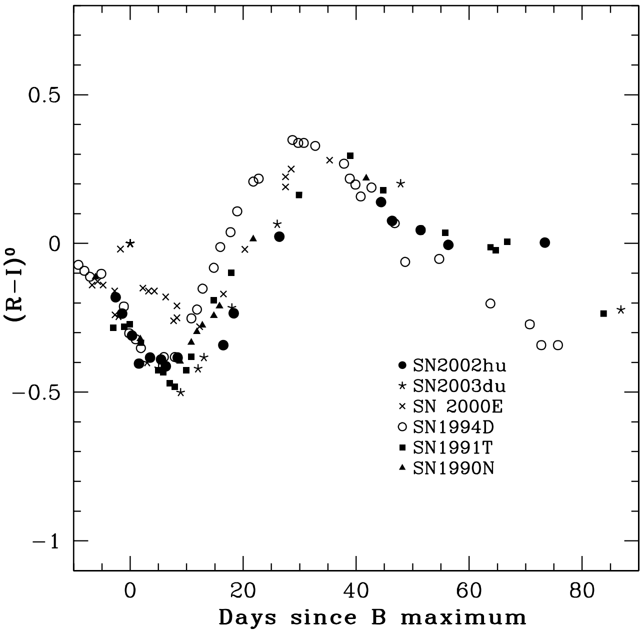

Figure 10. The intrinsic $R - I$ colour evolution of SN 2002hu, compared to those of other SNe Ia.

$E(B - V)_{\rm Gal} = 0.044$. As the supernova occurred at the edge of an almost face-on spiral galaxy, not much interstellar reddening is expected within the host galaxy of the supernova. Also, no significant Na I absorption is detected in the spectrum obtained ∼3 d before maximum (Matheson et al. 2002). Nonetheless, we estimate the host galaxy extinction following the photometric methods of Phillips et al. (1999) and Altavilla et al. (2004).

Based on Phillips et al. (1999), we estimate $E(B - V)^{\rm max}_{\rm host} = 0.02 \pm 0.04$ and $E(V - I)^{\rm max}_{\rm host} = 0.07 \pm 0.06$, which implies an $E(B - V)$ value of 0.04 ± 0.06 for $R_V = 3.1$. Based on Altavilla et al. (2004), we obtain $E(B - V)^{\rm max}_{\rm host} = 0.02 \pm 0.09$. The $B - V$ colour at maximum, for SNe Ia that suffer low reddening within the parent galaxy is known to vary between −0.1 and +0.1 (Hamuy et al. 1996a). The observed $(B - V)$ colour of SN 2002hu after correcting for the Galactic reddening is −0.08, indicating that SN 2002hu has not suffered any significant reddening within its host galaxy. The total $E(B - V)$ is hence assumed to be 0.044.

5 ABSOLUTE MAGNITUDE AND DISTANCE MODULUS

The absolute magnitude of SN 2002hu estimated using the relation between M_B versus Δm_{15} gives $M_B = -19.34 \pm 0.18$ (Hamuy et al. 1996a) and $M_B = -19.33 \pm 0.20$ (Phillips et al. 1999), which corresponds to a distance modulus of $\mu = 35.98 \pm 0.2$. Using the improved estimate to the intercept in the Hamuy et al. (1996a) relation given by Della Valle et al. (1998), we obtain $M_B = -19.47 \pm 0.30$ and $\mu = 36.11 \pm 0.30$. Using the relation between M_B and $B - V$ colour ∼12 d after the B maximum i.e. ΔC_{12} (Wang et al. 2005), we obtain $M_B = -19.39 \pm 0.12$ and $\mu = 36.04 \pm 0.2$. The distance modulii obtained by all methods agree well within errors, and in the following we use the distance modulus of $\mu = 36.04 \pm 0.2$, which is consistent with the recession velocity of 11 000 km s^{-1} for the host galaxy (Matheson et al. 2002) . Further, this value is not too different from the distance modulus estimated using the heliocentric radial velocity of 8994 km s^{-1} for the host galaxy MCG+6−6−12 (NASA/IPAC Extragalactic Database; NED), which indicates a distance modulus of $\mu = 35.70$ for $H_0 = 65$ km s^{-1} Mpc^{-1}.

6 BOLOMETRIC LIGHT CURVE

The bolometric light curve of SN 2002hu is estimated using the *UBVRI* observations presented here. The observed, extinction-corrected magnitudes were converted into monochromatic fluxes according to Bessell, Castelli & Plez (1998). The bolometric flux was obtained by integrating the monochromatic fluxes between 3300 and 9000 Å. Suntzeff (1996) found that almost 80 per cent of the *uvoir* bolometric flux is emitted in *UBVRI* bands, with the contribution of *UV* flux to the total bolometric luminosity being less than 10 per cent at all epochs. Similarly, the near-infrared contribution is also found to be less than 10–15 per cent for over ∼80 d. Therefore, although the maximum contribution to the *uvoir* bolometric luminosity comes from the optical data, a correction, to account for the missing bands, has to be applied to the bolometric luminosity estimated using the optical data alone. To account for the missing *UV* and *IR* fluxes, we assume a constant total contribution of 20 per cent from these bands at all epochs. The *uvoir* bolometric light curve thus obtained is plotted in Fig. 11. From this we get the peak *uvoir* bolometric luminosity $\log L = 43.25 \pm 0.07$, very similar to SN 1992bc (Contardo, Leibundgut & Vacca 2000).

7 DISCUSSION AND CONCLUSION

Optical *UBVRI* photometry of SN 2002hu starting 2 d before maximum to 73 d after maximum is presented. The light curve of SN 2002hu in the B and V bands are approximated well with SN 1992bc [$\Delta m_{15}(B) = 0.87$] template, whereas the I-band light curve matches that of SN 1992al [$\Delta m_{15}(B) = 1.11$] template. SN 2002hu is a mid-decliner, with a B-band decline rate of $\Delta m_{15}(B) = 1.00$. The $(B - V)$ colour near $B_{\rm max}$ and $(B - V)$ and $(R - I)$ colour evolution of SN 2002hu is similar to other SNe Ia in spirals, while the $(V - R)$ colour is redder at all epochs. It is not possible to fit the colour curves with a single reddening correction as seen in the case

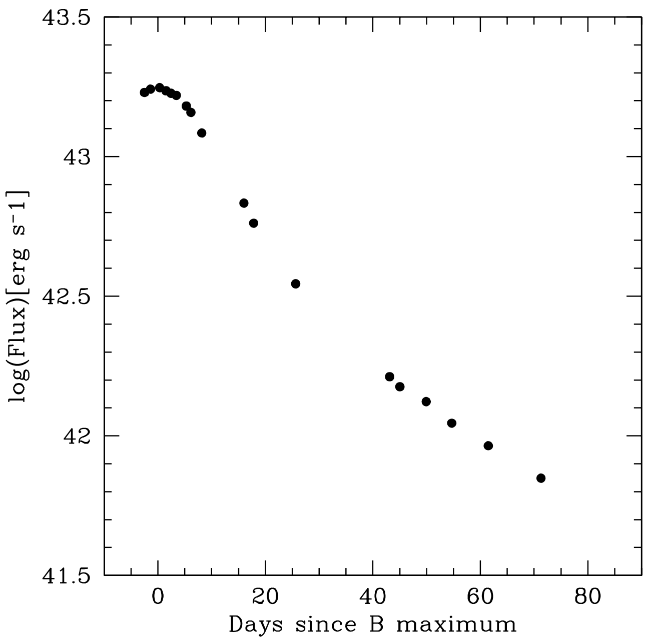

Figure 11. Bolometric light curve of SN 2002hu.

of SN 1999ee (Stritzinger et al. 2002). A comparison of the absolute magnitude $M_B = -19.38$ with that of other normal SNe Ia in spirals indicates SN 2002hu to be more luminous. The peak bolometric luminosity and thus the ^{56}Ni mass ejected during the explosion is also on the higher side compared to the SNe Ia discussed by Contardo et al. (2000). The $\Delta m_{15}(B)$ and bolometric luminosity of SN 2002hu compares well with that of SN 1991T, SN 2000E and SN 1995D. From this, it appears that SN 2002hu was a somewhat overluminous event like SN 2000E (Valentini et al. 2003), in the sense that it lies at the high-luminosity end of the observational range.

We do not have spectroscopic data for this supernova, however, we could find one spectrum, in the CfA website[1] obtained on 2002 November 8, which is approximately 5 d before maximum in *B*, as estimated in Section 3. The spectrum shows a blue continuum with broad and shallow Si II 6150 Å absorption line which is similar to other peculiar, overluminous, SNe Ia such as SN 1999dq (Jha et al. 1999), SN 1999gp (Jha & Berlind 2000), SN 1998es (Jha et al. 1998) and SN 1999aa (Garavini et al. 2004). In particular, the spectrum of SN 2002hu matches well with that of SN 1999aa 3 d before maximum.

The photometric data presented here together with the available spectrum indicate SN 2002hu to be a somewhat overluminous SN Ia.

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