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SN 2005kd: Another Very Luminous, Slowly Declining Type IIn Supernova

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Abstract

CCD $UBVRI$ photometry is presented for type IIn SN 2005kd. The maximum luminosity exceeded $M_V = -19.8$, and the SN remained brighter than $-18^{\rm m}$ for about 400 days. While its overall photometric evolution is quite similar to SN 1997cy, SN 2005kd shows a plateau at phases between 119 and 311 days past explosion, which is a unique feature for SNe IIn.

SN 2005kd was discovered by T.Puckett and A.Pelloni with an 0.35-m automated supernova patrol telescope on 2005 November 12.22 UT at magnitude 17.0, while on November 9 the object was not detected (fainter than $20^{\rm m}$). It is located at $\alpha = 4^{\rm h}03^{\rm m}16^{\rm s}.88, \delta = +71°43'18''.9$ (2000.0), which is $0''.1$ west and $5''$ north from the center of the Sc galaxy PGC 14370 (Puckett and Pelloni, 2005).

SN 2005kd was found by an Ohio State University group (Prieto, 2005) to be a young type IIn supernova from a 390–730 nm spectrogram taken on November 13.3 UT with the MDM 2.4-m telescope; the spectrum shows a blue continuum and strong hydrogen Balmer and He I lines in emission.

We started our photometric observations of SN 2005kd immediately after its discovery, on 2005 November 13, and continued till 2007 April 16. Observations were carried out with the following telescopes and CCD cameras: the 60-cm reflector of the Crimean Observatory of Sternberg Astronomical Institute (C60) equipped with an Apogee AP-47p camera; the 50/70-cm meniscus telescope of the Crimean Observatory (C50) with a Meade Pictor 416XT camera; the 70-cm reflector in Moscow (M70) with Apogee AP-47p (a) or AP-7p (b) cameras.

The color terms for C60 and M70 were reported by Tsvetkov et al. (2006). The observations with C50 were carried out only using a V filter close to the standard system, so no correction was applied.

All image reductions and photometry were made using IRAF.[†] The position of SN 2005kd is quite close to the center of the host galaxy, and the subtraction of galaxy background is necessary for reliable photometry. The template images were constructed from frames obtained on 2007 August 8 and 2007 September 25, when the SN was no longer visible. After template subtraction, the magnitudes of the SN were derived by PSF fitting relative to a sequence of local standard stars. The image of SN 2005kd with local standard stars is shown in Fig. 1, and the magnitudes of these stars are reported in Table 1.

The observations of SN 2005kd are presented in Table 2, and the light curves are shown in Fig. 2. Some unfiltered CCD magnitudes were reported in IAU Circulars and at

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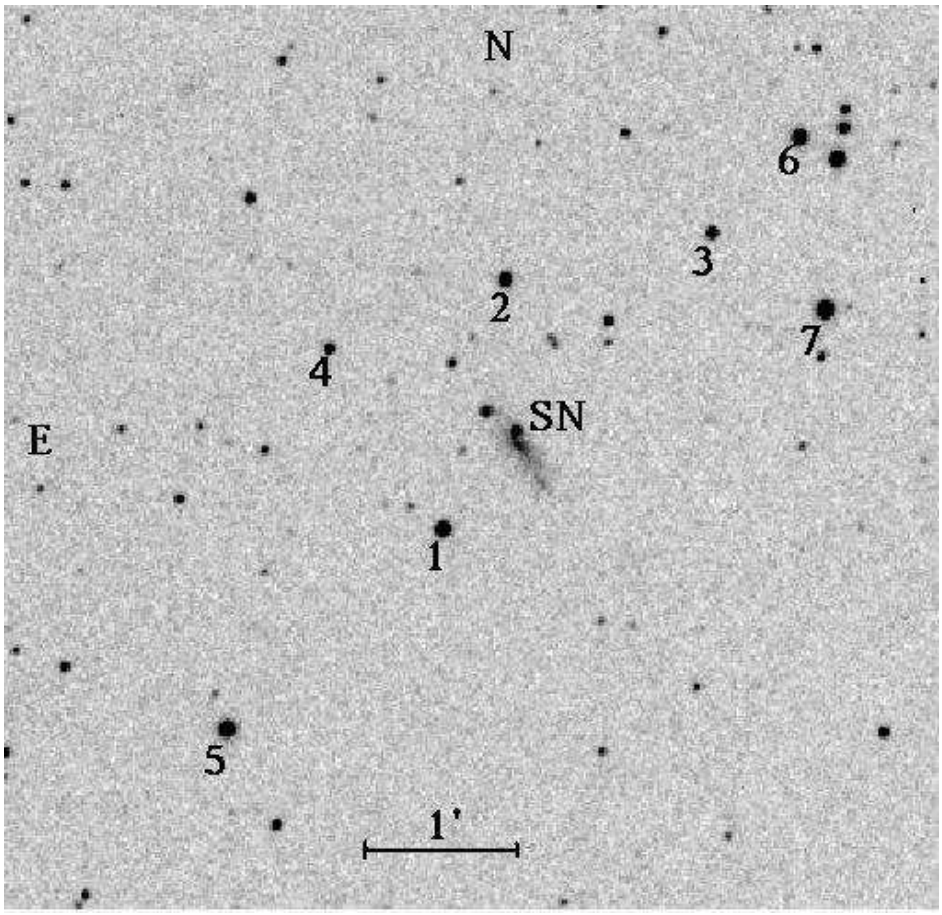

Figure 1. SN 2005kd in PGC 14370 with local standard stars

SNWeb,† they are also plotted in Fig. 2. The data show that SN 2005kd was discovered immediately after its explosion, and our first two observations were on the rising branch of the light curve. The rate of brightness increase was about $0\overset{m}{.}3$–$0\overset{m}{.}4$ per day in all bands. Most likely, the outburst occurred on 2005 November 10 or 11, and we accept JD 2453685 as the explosion date. Unfortunately, we missed the most interesting part of the light curve and cannot reliably establish the shape of the light curve peak and the maximum luminosity. Our next observation was only on 2006 January 3, and on this date, the SN was the brightest of all our data set. The magnitudes from SNWeb allow to suggest quite a flat maximum, but they also have a large gap. After a small drop from the maximum, the SN entered a plateau stage, which lasted for at least 192 days, from day 119 till day 311 past explosion. Another gap in observations does not allow to determine the length of the plateau more definitely. Since 2005 September 17 (day 341) and till the end of our observations on day 522, the SN was gradually fading, but at different rates. To day 405, the decline was slow, with rates of $0\overset{m}{.}0077$ per day in the R and I bands, $0\overset{m}{.}0087$ per day in V, and $0\overset{m}{.}013$ per day in B. The late decline was about twice faster: $0\overset{m}{.}017$ mag per day in the R and I bands, $0\overset{m}{.}025$ per day in B and V.

The color curves are presented in Figure 3. The $(V-R)$ color was gradually increasing, $(R-I)$ remained nearly constant after its initial increase, while $(B-V)$ reached its maximum on the plateau and then was slightly decreasing.

†http://www.astrosurf.com/snweb2/2005/05kd/05kdMeas.htm

Table 1: Magnitudes of local standard stars

Star	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I
1	15.50	0.08	15.21	0.02	14.51	0.03	14.09	0.02	13.68	0.02
2			16.15	0.03	15.09	0.02	14.45	0.02	13.92	0.02
3			16.50	0.05	15.90	0.04	15.41	0.03	15.01	0.02
4			16.80	0.04	16.13	0.04	15.62	0.03	15.24	0.02
5	15.76	0.10	15.10	0.03	14.13	0.02	13.62	0.01	13.10	0.02
6	15.36	0.14	15.18	0.05	14.42	0.04	13.98	0.02	13.56	0.02
7	15.33	0.16	14.80	0.05	13.82	0.04	13.32	0.05	12.81	0.03

Table 2: Observations of SN 2005kd

JD 2450000+	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
3688.47	15.38	0.12	16.06	0.03	16.06	0.03	15.77	0.03	15.77	0.06	C60
3689.52	15.15	0.09	15.72	0.03	15.68	0.02	15.48	0.02	15.41	0.03	C60
3739.47			15.67	0.03	15.10	0.03	14.59	0.02	14.17	0.03	M70b
3804.36			16.12	0.03	15.54	0.03	14.91	0.02	14.47	0.02	M70a
3822.30			16.06	0.03	15.60	0.04	14.94	0.02	14.51	0.03	M70a
3831.27			16.07	0.04	15.59	0.03	14.94	0.02	14.49	0.02	M70a
3852.28			16.02	0.03	15.66	0.03	14.88	0.02	14.50	0.02	M70a
3872.34			16.03	0.03	15.59	0.02	14.86	0.02	14.44	0.03	M70a
3996.42			16.42	0.07	16.61	0.04	15.53	0.02	15.20	0.03	M70b
4026.44	16.93	0.14	17.00	0.04	16.86	0.03	15.74	0.03	15.35	0.07	M70b
4044.61					16.93	0.07	16.08	0.04			C60
4056.49					17.07	0.08					C50
4059.38					17.26	0.04					C50
4059.53			17.57	0.03	17.38	0.04	15.97	0.06	15.70	0.08	C60
4062.38					17.26	0.03					C50
4090.48			17.69	0.04	17.21	0.06	16.07	0.04	15.81	0.03	M70b
4118.30			18.50	0.04	18.17	0.07	16.85	0.03	16.36	0.04	M70b
4127.25							17.04	0.08			M70b
4131.27			18.99	0.12			17.06	0.05	16.81	0.09	M70b
4143.23			18.94	0.10	19.07	0.20	17.35	0.06	16.83	0.08	M70b
4158.26							17.70	0.05	17.21	0.12	M70b
4180.30							17.99	0.06	17.40	0.06	M70b
4183.28			19.78	0.13	19.44	0.28	17.70	0.09	17.29	0.08	M70b
4187.27							17.80	0.04	17.30	0.04	M70b
4201.27							18.21	0.10	17.58	0.08	M70b
4207.27							18.11	0.04	17.80	0.10	M70b

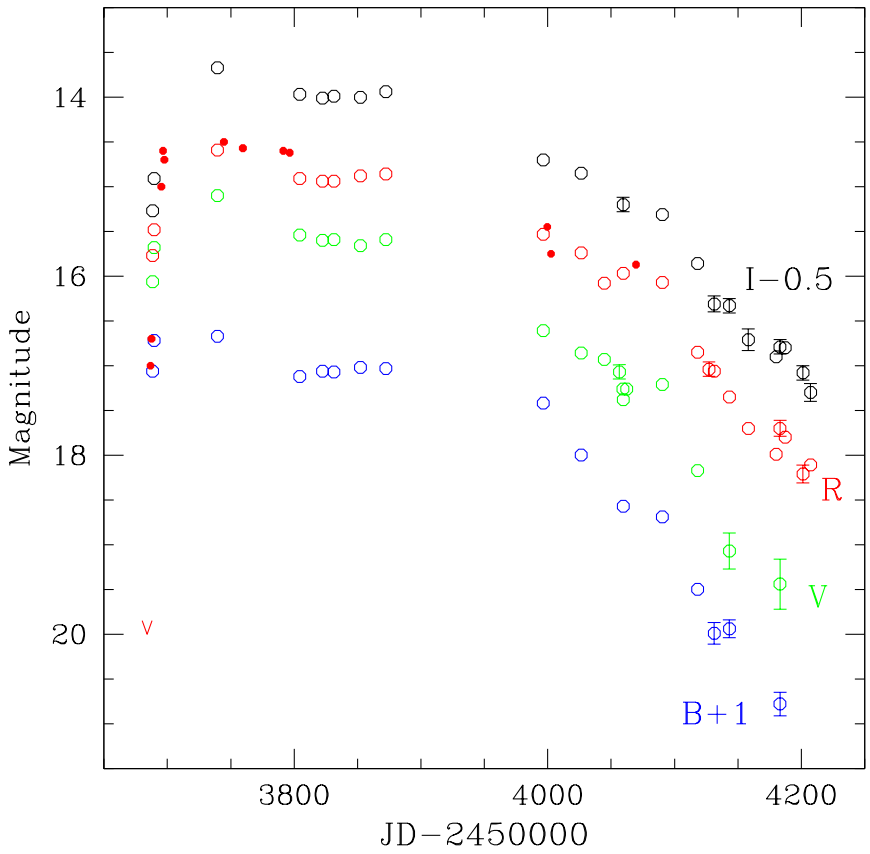

Figure 2. *BVRI* light curves of SN 2005kd, showing our photometry (circles) and the magnitudes reported at SNWeb (dots). Error bars for our magnitudes are plotted only when they exceed the size of a point

If we adopt the distance modulus $\mu = 34.07$ and Galactic extinction $A_V = 0.87$ from NED† for PGC 14370, then the absolute magnitude on 2006 January 3 (day 54) was $M_V = -19.84$. The real maximum luminosity can be significantly higher because we missed the peak of the light curve and do not know the extinction in the host galaxy.

The absolute V-band light curve of SN 2005kd is shown in Fig. 4 and compared to the light curves of well-studied slowly declining type IIn SNe: 1997cy (Germany et al., 2000), 1999E (Rigon et al., 2003), 1995G (Pastorello et al., 2002), 1988Z (Turatto et al., 1993). The similarity of overall photometric evolution of SNe 2005kd and 1997cy is evident, although the differences are also noticeable. We note that, for both SNe, the rate of brightness decline changed at about the same phase, close to day 400. SN 1999E was fainter, but the shape of its light curve is the same as for SN 1997cy; SNe 1988Z and 1995G were much fainter and have different light curves. The plateau of SN 2005kd is the unique feature for SNe IIn, nothing similar can be seen for any of the other light curves.

The $(B-V)_0$ color curves for these SNe are compared in Fig. 5. SNe 1997cy, 1999E and 1999G had similar color evolution: after an initial reddening, the $(B-V)$ color remained nearly constant, at about $0\overset{m}{.}5$–$0\overset{m}{.}6$. SNe 2005kd and 1988Z were certainly bluer, and at the phases after 300 days SN 2005kd was the bluest among these objects.

†http://nedwww.ipac.caltech.edu

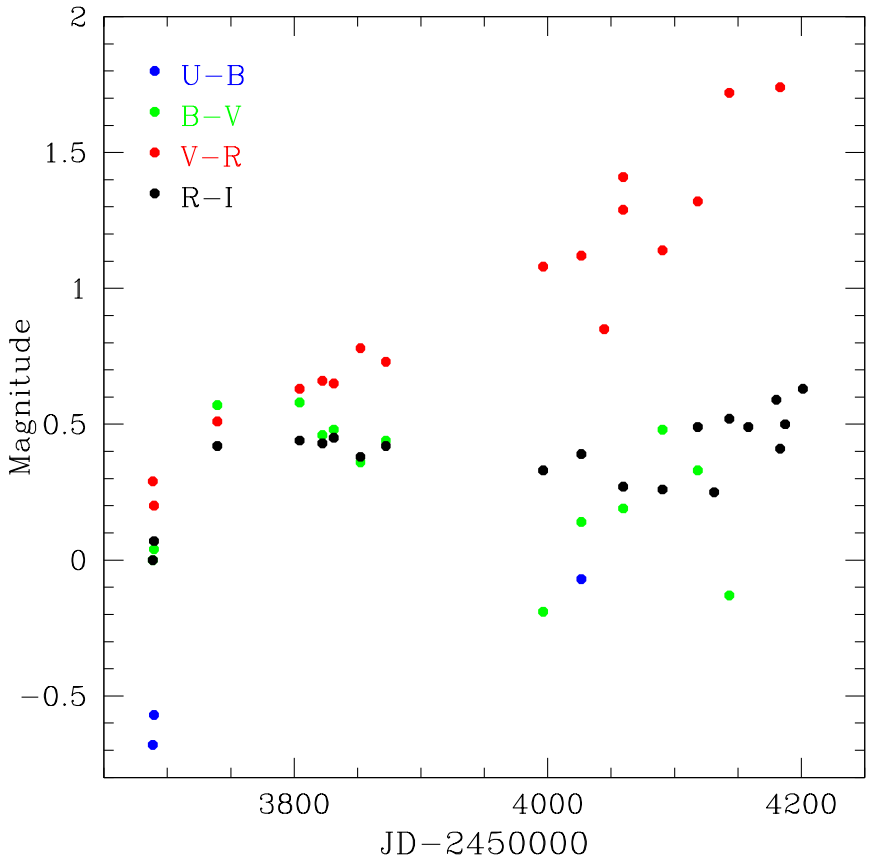

Figure 3. Color curves for SN 2005kd

We can roughly estimate the lower limit to the energy radiated by SN 2005kd in the $UBVRI$ bands during the first 500 days of evolution. Assuming the distance and extinction reported earlier and using simple linear interpolations in the gaps, we obtain $E_{rad} = 3.2 \cdot 10^{50}$ ergs.

SN 2005kd is among the most luminous SNe ever observed. As for other SNe IIn, its high energy release is likely due to the interaction of ejecta with a dense circumstellar medium. For all well-studied SNe IIn, the brightness decline was slow but gradual, without periods of constant luminosity. The plateau lasting at least 192 days observed for SN 2005kd is a unique feature for SNe IIn. Unfortunately, the gaps in our data do not allow to trace the peak of the light curve and the end of the plateau.

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

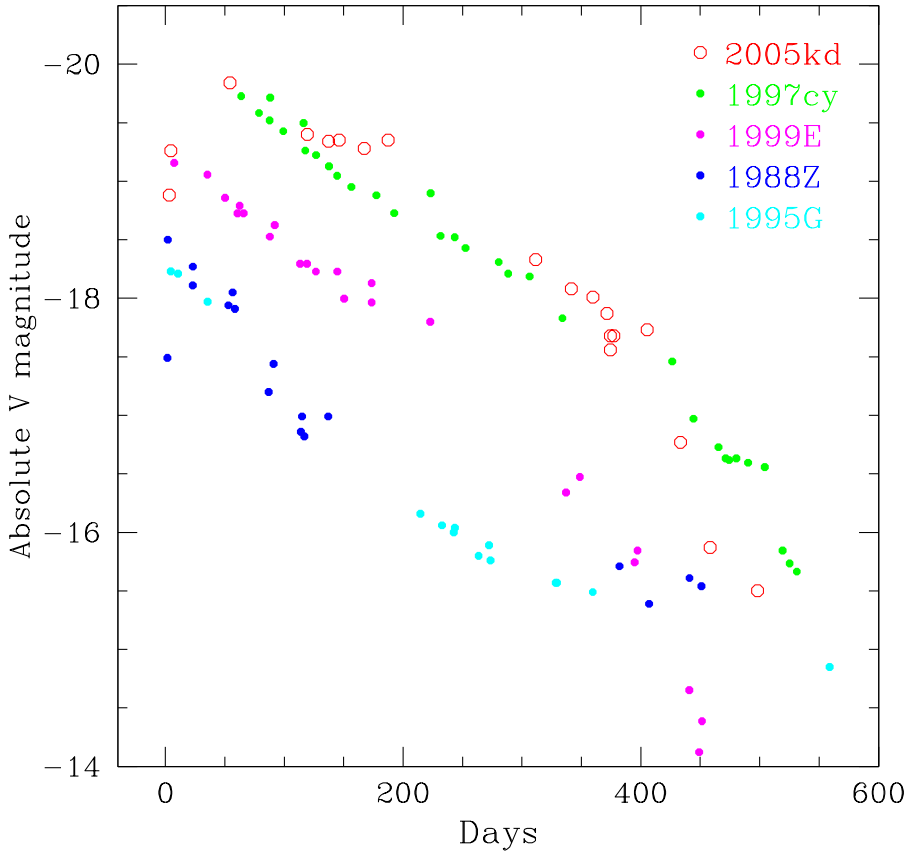

Figure 4. The absolute V-band light curve of SN 2005kd compared to those for SNe IIn 1997cy, 1999E, 1995G and 1988Z

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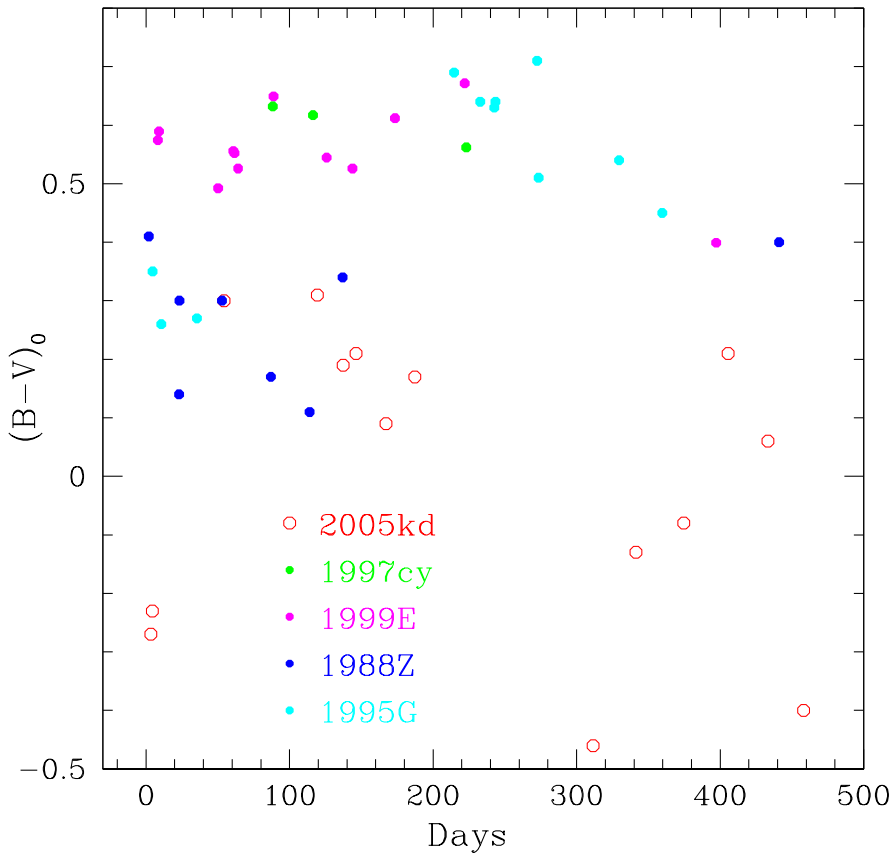

Figure 5. The $(B-V)_0$ color curve for SN 2005kd compared to those for SNe IIn 1997cy, 1999E, 1995G, and 1988Z