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Photometric observations of Supernovae 2011df, 2011ek and 2012ea

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CCD *BVRI* photometry is presented for two type Ia supernovae, SN 2011df and 2011ek, and for a supernova of type Ia-1991bg, SN 2012ea. The light curve parameters and absolute magnitudes at maximum light are estimated. It is shown that SNe 2011df and 2012ea are typical for their classes considering the shape of their light curves and maximum luminosity. SN 2011ek shows some properties of 1991bg-like supernovae: red color at maximum and low luminosity, but the shape of the light curves is typical of normal SNe Ia.

1 Introduction

Continuing the long-term program of supernova (SN) observations in Sternberg Astronomical Institute, we carried out photometry of the bright SNe 2011df, 2011ek and 2012ea.

SN 2011df was discovered by J. Newton and T. Puckett at magnitude 17.6 on an unfiltered CCD image taken with an 0.40-m reflector at Portal, AZ, USA, on May 21.459 UT in the course of the Puckett Observatory Supernova Search. The new object was located at $\alpha = 19^{\rm h}27^{\rm m}33\overset{\rm s}{.}64$, $\delta = +54^\circ23'11\overset{''}{.}3$ (equinox 2000.0), which is $19\overset{''}{.}8$ west and $49\overset{''}{.}9$ north of the center of NGC 6801 (Newton and Puckett 2011).

Spectroscopic observations were reported by Liu et al. (2011), Balam et al. (2011), and Marion (2011). The spectra showed that SN 2011df was a type Ia SN near maximum light on May 28.

The near-IR observations of SN 2011df were published by Friedman et al. (2015).

SN 2011ek was discovered by K. Itagaki at 16.4 mag on unfiltered CCD frames taken on August 4.77 UT using an 0.60-m reflector. The new object was located at $\alpha = 2^{\rm h}25^{\rm m}48\overset{\rm s}{.}89$, $\delta = +18^\circ32'00\overset{''}{.}0$ (equinox 2000.0), which is $27''$ west and $133''$ north of the center of NGC 918 (Nakano and Itagaki 2011). Spectroscopic observations by Kawabata et al. (2011), Marion et al. (2011), and Balam et al. (2011) indicated the SN to belong to type Ia, although Kawabata et al. (2011) and Marion et al. (2011) suggested it might belong to the 1991bg-like subclass of SNe Ia.

Marion et al. (2011) also noted that the spectrum showed a narrow, unresolved Na D feature (EW about 0.11 nm), suggesting significant reddening.

Photometric observations were reported by Kanata Observatory[1] and at Swift's Optical/Ultraviolet Supernova Archive[2].

[1] http://kanatatmp.g.hatena.ne.jp/kanataobslog/20111011/p1

[2] http://people.physics.tamu.edu/pbrown/SwiftSN/ swift_sn.html

Table 1: Magnitudes of local standard stars

Star	B	σ_B	V	σ_V	R	σ_R	I	σ_I
2011df-1	13.92	0.03	13.25	0.01	12.87	0.01	12.52	0.01
2011df-2	14.34	0.01	13.72	0.01	13.35	0.01	13.02	0.01
2011df-3	16.10	0.04	14.86	0.03	14.21	0.01	13.56	0.01
2011df-4	15.49	0.04	14.41	0.02	13.83	0.01	13.32	0.01
2011ek-1	16.02	0.04	14.96	0.02	14.31	0.01	13.67	0.02
2011ek-2	16.82	0.03	15.59	0.01	14.76	0.03	13.99	0.05
2012ea-1	16.58	0.03	15.70	0.04	15.24	0.03	14.81	0.02
2012ea-2	14.91	0.04	14.26	0.04	13.88	0.03	13.77	0.03
2012ea-3	15.90	0.05	15.19	0.05	14.79	0.03	14.41	0.06

SN 2012ea was discovered by LOSS on August 8.29 UT at magnitude 16.8. SN was located at $\alpha = 17^{\rm h}45^{\rm m}10\overset{\rm s}{.}40$, $\delta = +18°08'26\overset{''}{.}8$, which is $55\overset{''}{.}3$ W, $7\overset{''}{.}0$ N from the center of NGC 6430 (Cenko et al. 2012).

Tomasella et al. (2012) reported that a spectrogram of SN 2012ea, obtained on Aug. 8.92 UT with the Asiago 1.82-m Copernico Telescope, suggested it to be a 1991bg-like type Ia supernova, the classification confirmed by Graham et al. (2012).

2 Observations and reductions

The observations were carried out with the 60-cm reflector (C60) using AP-47p CCD camera and with the 50-cm Maksutov telescope (C50) using Apogee Alta U8300, both telescopes located at the Crimean Observatory of the Sternberg Astronomical Institute, as well as with the 70-cm reflector in Moscow (M70) with AP-7p CCD, all telescopes equipped with a set of Johnson–Cousins $UBVRI$ filters.

CCD frames were also obtained with the telescopes of MASTER net located near Kislovodsk, Ekaterinburg, Blagoveshensk, and Irkutsk (MK, ME, MB, MT) (Lipunov et al. 2010). MASTER telescopes carried out observations in unfiltered mode, and also with V, R filters.

All reductions and photometry were made using IRAF[3].

Photometric measurements of SNe were made relative to local standard stars using PSF fitting with the IRAF DAOPHOT package. The background of host galaxies around the SNe was negligible for all studied SNe, which exploded far from the centers of their host galaxies.

The images of SNe and comparison stars are shown in Figs. 1–3; the magnitudes of local standards are presented in Table 1.

The results of our photometry of the SNe are presented in Tables 2–5. To mark the magnitudes estimated on images obtained without filters, a letter "u" is added to the telescope code.

[3]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation

Table 2: Observations of SN 2011df

JD 2455000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
714.46	15.36	0.04	15.27	0.03	15.20	0.01	15.20	0.04	M70
715.27					15.00	0.03			MBu
718.07					15.04	0.11			MBu
719.43	15.38	0.03	15.19	0.02	15.12	0.02	15.28	0.04	M70
720.12					14.89	0.05			MTu
724.23					15.15	0.02			MBu
725.14					15.24	0.03			MBu
726.06					15.35	0.03			MBu
733.16					15.76	0.03			MBu
741.12					15.91	0.03			MBu
742.44					15.93	0.08			MK
743.49					15.82	0.04			MK
749.41					16.37	0.11			MKu
752.13					16.48	0.05			MTu
783.47			17.83	0.03	17.57	0.01			C60
784.39	18.68	0.06	17.84	0.03	17.60	0.03			C60
786.44	18.62	0.08	17.90	0.04	17.66	0.03	17.39	0.14	C60
788.46	18.54	0.10	17.91	0.05	17.72	0.03			C60
789.40	18.88	0.10	18.00	0.04	17.79	0.04			C60
806.51			18.36	0.04	18.26	0.05			C60
810.45			18.43	0.03	18.35	0.02	17.95	0.12	C60
829.06					18.78	0.26			MTu
874.22					20.43	0.24			C60
879.22					20.76	0.29			C60
883.23			19.95	0.22	20.35	0.11			C60

Table 3: Observations of SN 2011ek

JD 2455000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
783.55	15.84	0.08	15.14	0.03	14.61	0.04	14.11	0.05	C60
784.51					14.43	0.02			MKu
784.55	15.72	0.05	14.98	0.03	14.42	0.03	13.98	0.05	C60
785.24					14.37	0.04			MBu
785.51					14.38	0.04			MKu
786.56	15.48	0.04	14.76	0.03	14.28	0.02	13.93	0.03	C60
787.26					14.27	0.05			MBu
788.53	15.41	0.05	14.69	0.02	14.24	0.03	13.87	0.06	C60
790.27					14.28	0.04			MBu
798.32			14.96	0.08					MB
798.33					14.82	0.04			MTu
798.43					14.79	0.05			MKu
800.19			15.07	0.02	14.74	0.02			MB
800.43					14.85	0.03			MKu
802.42					14.86	0.02			MKu
803.47					14.93	0.02			MKu
804.45					14.94	0.02			MKu
804.50			15.28	0.03	14.83	0.03			ME
805.36					15.00	0.05			MKu
805.42			15.37	0.01	14.90	0.01			ME
806.47			15.50	0.02	14.96	0.03			ME
807.22			15.45	0.02					MB
807.42			15.48	0.02	14.92	0.02			ME
808.40			15.57	0.01	14.97	0.02			ME
809.39			15.63	0.07	14.99	0.03			ME
809.57					15.02	0.07			MKu
810.36			15.77	0.19					ME
810.54					15.07	0.01			MKu
811.24			15.78	0.02	15.01	0.03			MB
811.47					15.10	0.01			MKu
812.43					15.13	0.02			MKu
813.23			15.95	0.03					MB
813.30					15.17	0.03			MTu
814.21					15.08	0.06			MBu
814.44					15.27	0.02			MKu
815.16			15.99	0.06					MB
816.22			16.31	0.11					MB
816.38					15.44	0.03			MKu
817.53					15.50	0.02			MKu
825.36					15.96	0.07			MKu
826.40			16.87	0.06	16.03	0.03			ME
826.49					16.08	0.03			MKu
827.36					16.09	0.04			MKu
828.40					16.18	0.05			MKu
852.34					17.10	0.09			MTu
874.29	19.09	0.20	18.07	0.07	17.67	0.06			C60
883.45			18.36	0.05	17.94	0.05			C60
885.28	19.36	0.06	18.39	0.04	18.12	0.04	17.46	0.09	C60

Table 4: Observations of SN 2012ea with C60 and C50 telescopes

JD 2456000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
153.35	16.61	0.05	16.20	0.05	16.01	0.04	16.03	0.10	C60
154.43	16.52	0.08	16.10	0.05	15.86	0.04	15.79	0.10	C60
155.41	16.39	0.06	15.89	0.05	15.67	0.04	15.80	0.14	C60
156.35			15.65	0.06	15.59	0.05			C50
166.36	17.08	0.06	15.92	0.05	15.66	0.03	15.60	0.09	C60
167.39	17.25	0.08	16.05	0.05	15.79	0.04	15.75	0.11	C60
169.34	17.47	0.10	16.23	0.05	15.89	0.04	15.65	0.11	C60
170.30	17.81	0.06	16.38	0.04	15.99	0.03	15.70	0.09	C60
171.36	18.06	0.17	16.45	0.05	16.05	0.03	15.70	0.10	C60
172.34	17.87	0.08	16.59	0.05	16.10	0.04	15.80	0.09	C60
173.38	17.96	0.14	16.67	0.05	16.18	0.03	15.87	0.12	C60
174.36	18.06	0.11	16.75	0.05	16.25	0.04	15.92	0.10	C60
175.40			16.82	0.05	16.30	0.04	15.85	0.11	C60
176.36	18.60	0.19	16.85	0.05	16.38	0.04	15.98	0.12	C60
177.39			16.93	0.05	16.45	0.04	16.01	0.11	C60
236.15			19.07	0.17	19.13	0.46			C60
237.20			19.25	0.10	19.10	0.11			C60
241.16			19.29	0.07	19.25	0.13			C60
244.18	19.93	0.20	19.51	0.07	19.58	0.09			C60
247.17			19.80	0.09	19.57	0.12			C60
249.16	19.86	0.17	19.54	0.09	19.77	0.14			C60
250.16	19.99	0.19	19.58	0.10	19.77	0.11			C60
254.15			19.85	0.15	19.74	0.20			C60

Table 5: Observations of SN 2012ea with MASTER telescopes

JD 2456000+	R	σ_R	Tel.	JD 2456000+	R	σ_R	Tel.
148.11	17.33	0.08	MBu	175.07	16.38	0.10	MBu
152.12	16.07	0.03	MTu	175.96	16.37	0.14	MBu
157.10	15.42	0.02	MTu	176.30	16.31	0.05	ME
157.10	15.57	0.05	MBu	176.96	16.42	0.07	MBu
157.99	15.35	0.04	MBu	177.16	16.36	0.06	ME
158.32	15.35	0.04	MKu	178.00	16.61	0.08	MBu
158.99	15.31	0.05	MBu	178.16	16.54	0.05	ME
160.04	15.32	0.03	MBu	178.96	16.57	0.05	MBu
160.99	15.37	0.04	MBu	180.16	16.62	0.05	ME
161.21	15.34	0.04	ME	182.19	16.98	0.04	MKu
162.01	15.39	0.04	MBu	184.96	16.93	0.14	MBu
162.20	15.37	0.03	ME	187.96	17.15	0.10	MBu
165.07	15.44	0.13	MBu	190.16	17.26	0.07	ME
165.99	15.62	0.03	MBu	191.16	17.34	0.06	ME
166.98	15.76	0.13	MBu	192.01	17.37	0.04	MTu
167.20	15.67	0.05	ME	196.14	17.46	0.21	ME
169.19	15.99	0.13	ME	196.17	17.57	0.13	MKu
169.98	15.99	0.04	MBu	196.93	17.69	0.22	MBu
174.05	16.28	0.03	MTu				

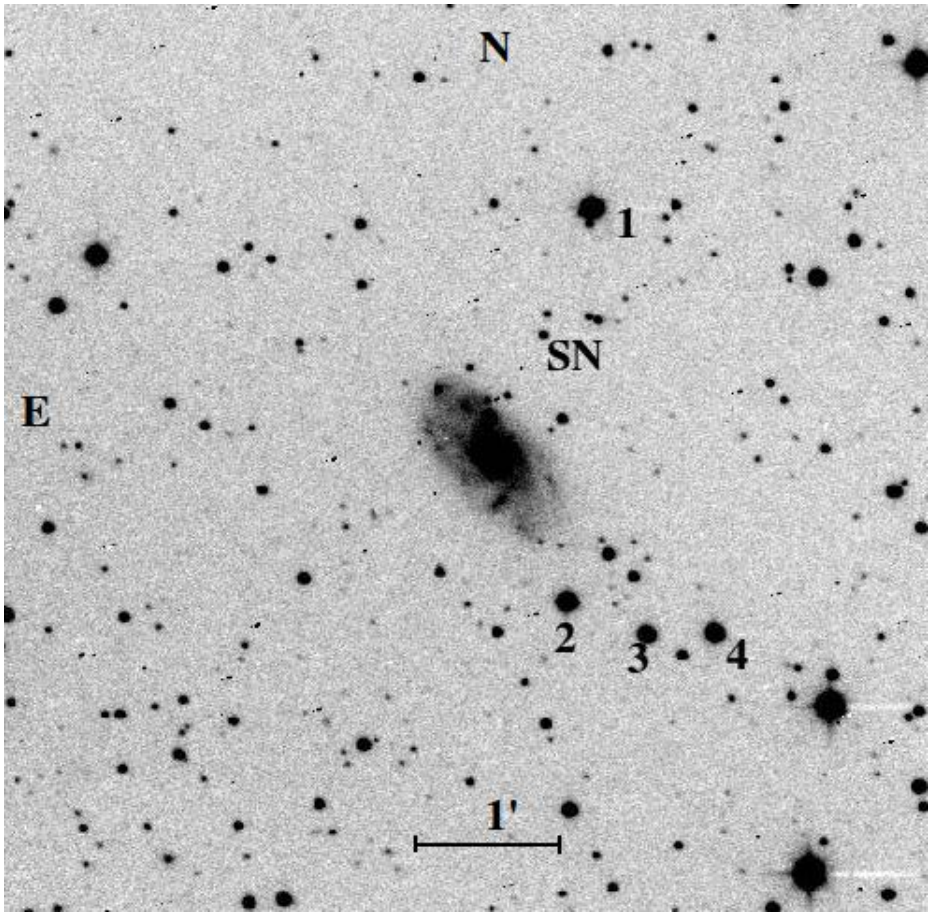

Figure 1.
SN 2011df in NGC 6801.

3 Results and conclusions

SN 2011df. The light curve is shown in Fig. 4. Most of the data were obtained in the R band, and only the R-band light curve can be clearly outlined. The data gathered by amateur astronomers[4] were used to better define the rising part of the light curve. The resulting light curve appears typical of SNe Ia, the data are in a good agreement with the template light curve of SN Ia 2011fe (Tsvetkov et al. 2013).

The time and magnitude of maximum light can be estimated: $R_{max} = 14.72$ on JD 2455718.

We assume the distance modulus for NGC 6801, $\mu = 34.02$, and Galactic extinction, $A_R = 0.28$, from the NED database[5] and derive the absolute magnitude for SN 2011df at maximum: $M_R = -19.2$. The SN is located far from the center of the parent galaxy, and we cannot expect significant extinction in NGC 6801. This is confirmed by the blue color of SN near maximum: the $B - V$ color index is about 0.1 mag, the small color excess is due to the Galactic extinction.

The maximum luminosity of SN 2011df is close to the mean one for type Ia SNe with photometric parameters resembling the template SN Ia 2011fe.

SN 2011ek. The light curves are shown in Fig. 5, where we also plotted the data

[4]http://www.rochesterastronomy.org/sn2011/sn2011df.html
[5]http://ned.ipac.caltech.edu/

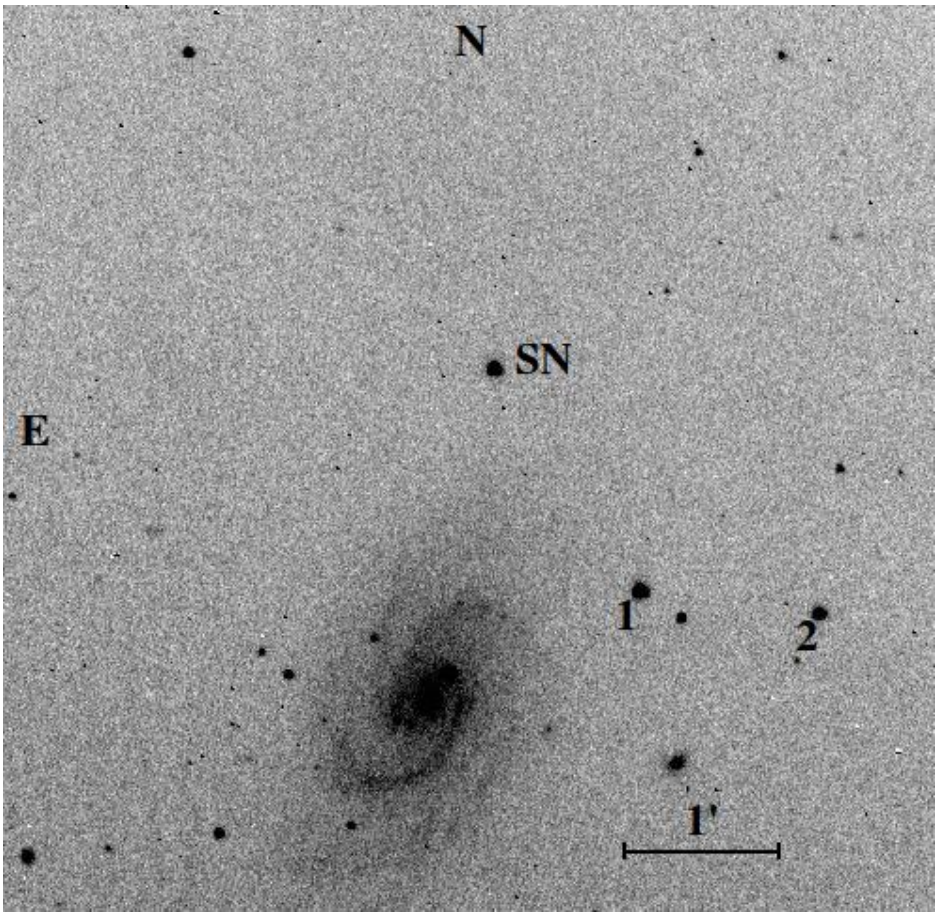

Figure 2.
SN 2011ek in NGC 918.

from Kanata Observatory and SOUSA. There are some systematic differences between the sets of data: the B magnitudes from Kanata Observatory are ∼0.1 mag brighter than our data near maximum, while the opposite trend of the same amount is observed for the I-band magnitudes.

The light curves of SN Ia 1994D (Richmond et al. 1995) are plotted for comparison, they are a good match for the light curves of SN 2011ek. We may assume that the rate of brightness decline for SN 2011ek is similar to that for SN 1994D: $\Delta m_{15} \approx 1.35$. The magnitudes at maximum light for SN 2011ek are: $B_{\max} = 15.38; V_{\max} = 14.62; R_{\max} = 14.22; I_{\max} = 13.96$. The dates of the B and V maximum are close to JD 2455791, the peaks in the R and I bands occurred approximately 1 and 2 days earlier.

The distance modulus for the galaxy NGC 918 is $\mu = 31.67$, the Galactic extinction being $A_B = 1.28$; $A_V = 0.97$; $A_R = 0.77$; $A_I = 0.53$ mag (from NED). Hence, the absolute magnitudes at maximum are $M_B = -17.57$; $M_V = -18.02$; $M_R = -18.22$; $M_I = -18.24$. These magnitudes are much fainter than the mean values for SNe Ia with $\Delta m_{15} \approx 1.35$, as calibrated by Prieto et al. (2006). The differences of absolute magnitudes in the B, V, R, I bands are, respectively, 1.6, 1.1, 0.9, 0.6 mag. The color of the SN at maximum was very red: $B-V \approx 0.7$ mag, which yields $B-V \approx 0.4$ mag after correction for the Galactic reddening. We also obtained one estimate of the U-band magnitude: $U = 16.10 \pm 0.15$ mag on JD 2455784.55; it shows that the $U-B$ color six days before maximum was ≈ 0.4 mag. The reddening and low brightness of the SN may be due to

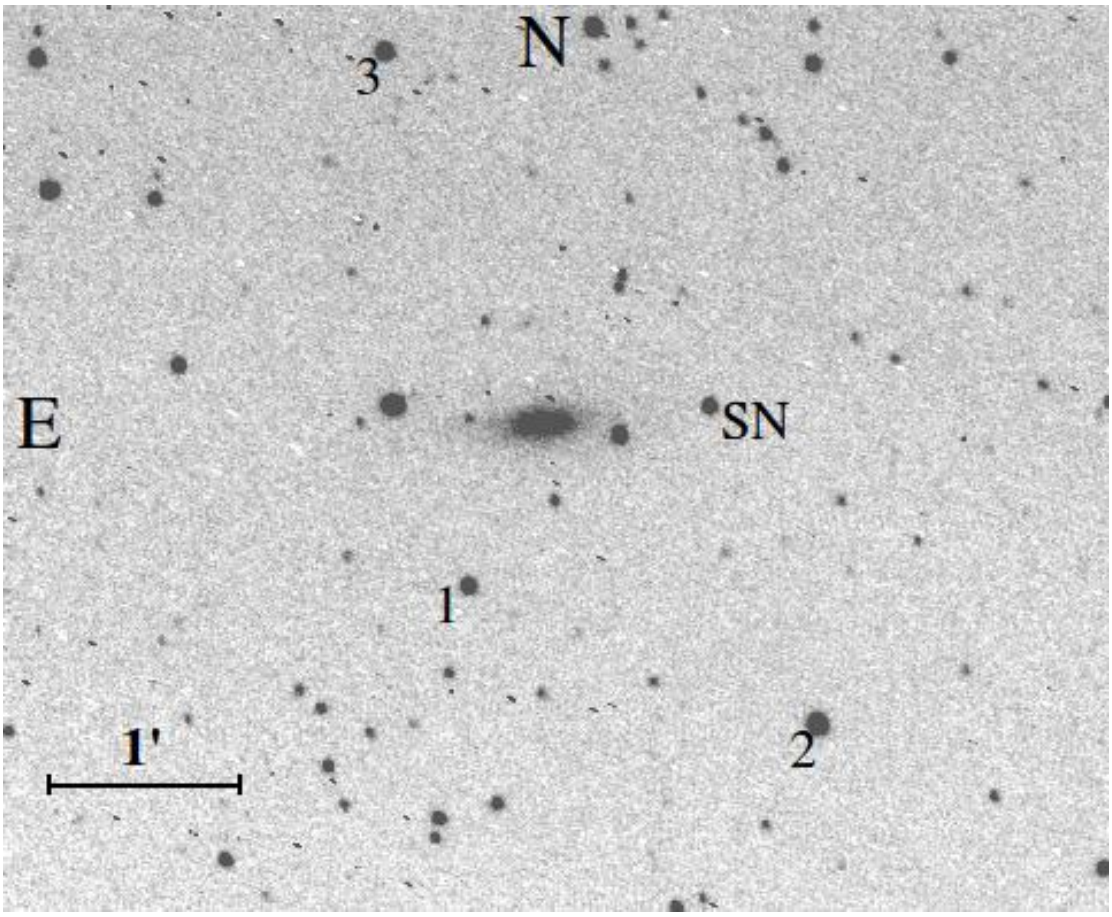

Figure 3.
SN 2012ea in NGC 6430.

the extinction in the parent galaxy, but we consider this highly improbable. The SN was located at projected distance of 13.8 kpc from the center of the galaxy and at the relative projected distance 1.3 (the angular distance divided by the photometric radius of the galaxy). Besides, the equivalent width of Na I absorption reported by Marion et al. (2011), 0.11 nm, corresponds to the color excess $E(B-V) = 0.27$ mag according to the relation from Poznanski et al. (2012). This is very close to the color excess due to Galactic extinction, which is 0.31 mag. We suppose that the extinction of SN in the parent galaxy was negligible, and so the red color and low luminosity are the properties of SN 2011ek. The possibility that this SN belongs to the class SN Ia-1991bg is excluded by the shape of the light curves. Thew show typical features of normal SNe Ia: a second maximum in the I band and a shoulder on the R-band light curve.

SN 2012ea. The light curves are presented at Fig. 6. The light curves of SN 1991bg (Leibundgut et al. 1993) are a good match to the observations, confirming the spectral classification of the object.

The magnitudes at maximum can be estimated: $B_{\max} = 16.21$; $V_{\max} = 15.46$; $R_{\max} = 15.33$; $I_{\max} = 15.43$. The dates of maximum in the V, R, I bands are nearly the same, at JD 2456160, while the B-band maximum occurred 2 days earlier.

Adopting, for the galaxy NGC 6430, the distance modulus $\mu = 33.31$ and Galactic extinction $A_B = 0.23$; $A_V = 0.18$; $A_R = 0.14$; $A_I = 0.10$ mag (from NED), we can estimate the absolute magnitudes of the SN at maximum: $M_B = -17.33$; $M_V = -18.03$; $M_R =$

-18.12; $M_I = -17.98$.

The luminosity of SN 2012ea at maximum is significantly lower than for normal SNe Ia, but typical of SNe of the 1991bg-like class.

The results of our study show that SNe 2011df and 2012ea are typical for their classes considering the shape of their light curves and absolute magnitudes at maximum. The nature of SN 2011ek is controversial, it shows some properties of 1991bg-like SNe: red color at maximum, low luminosity, some spectral details, but the shape of the light curves is typical of normal SNe Ia. This SN may be a transitional object between normal and 1991bg-like type Ia SNe.

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This research has made use of the NASA/IPAC Extragalactic Database (NED).

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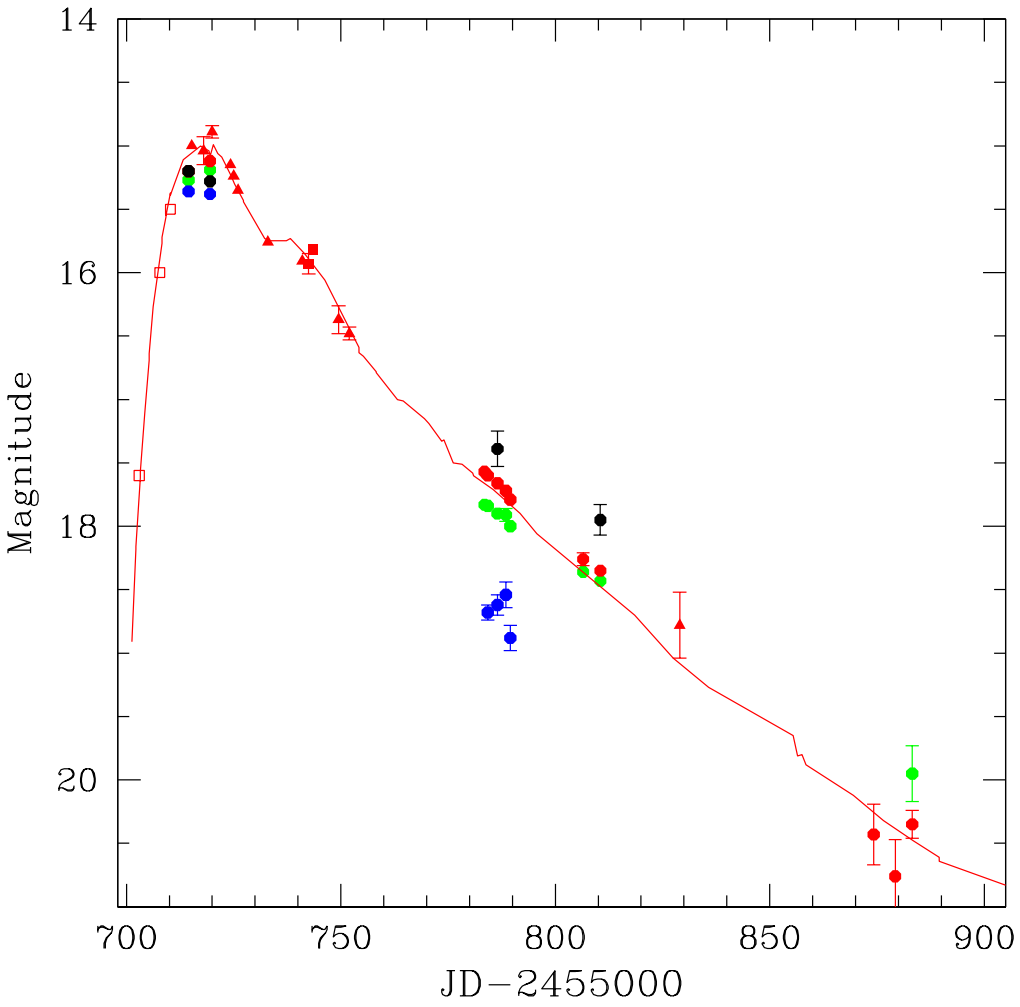

Figure 4.
The light curve of SN 2011df. In this figure and in the following ones the magnitudes in the B, V, R, I bands are plotted in blue, green, red, and black color. The data from C60, C50, and M70 telescopes are plotted as filled circles; MASTER data with filters are plotted as filled squares; and unfiltered MASTER magnitudes, as filled triangles. Open squares show the data acquired by amateur astronomers. The red line is the R-band light curve of SN 2011fe.

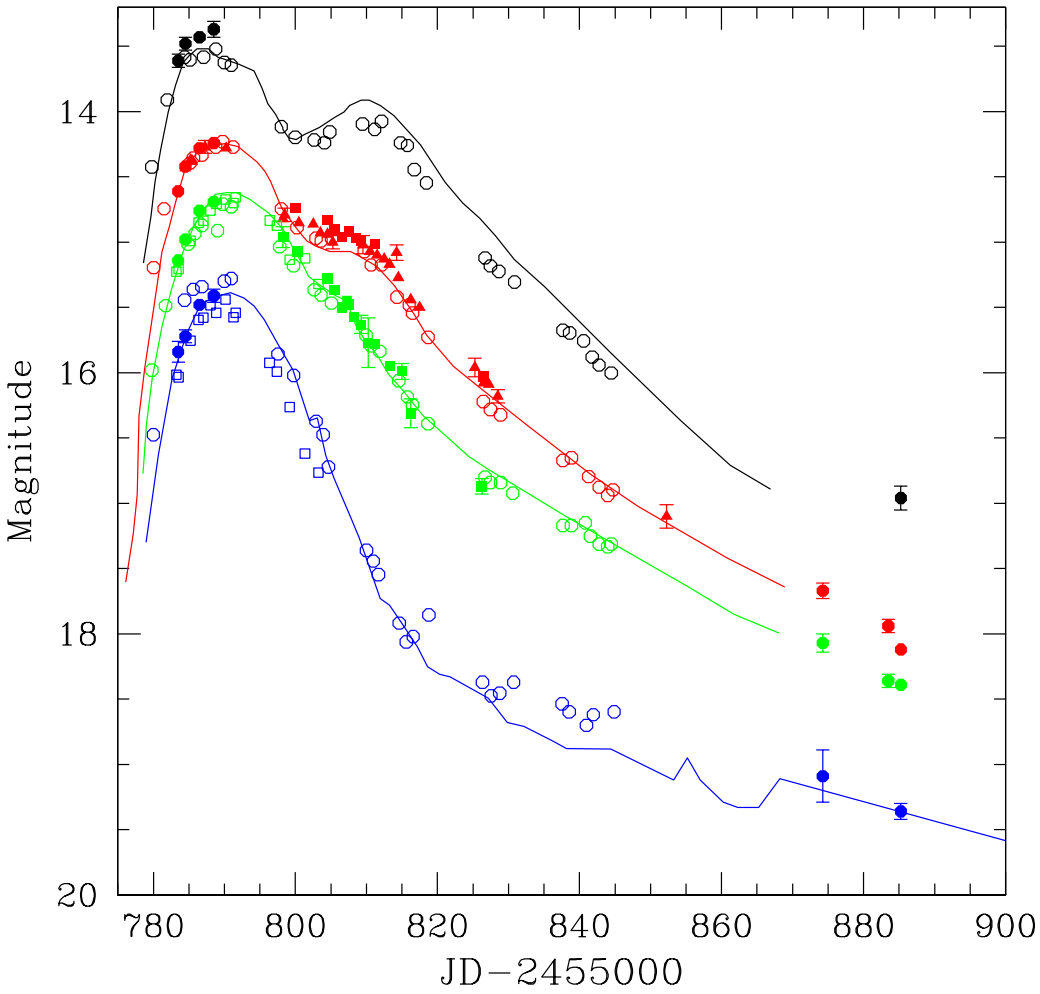

Figure 5.
The light curves of SN 2011ek. The light curve in the I band is shifted by –0.5 mag for clarity. Open circles show the magnitudes from Kanata Observatory; open squares are for the data from SOUSA. The solid curves are the light curves of SN 1994D.

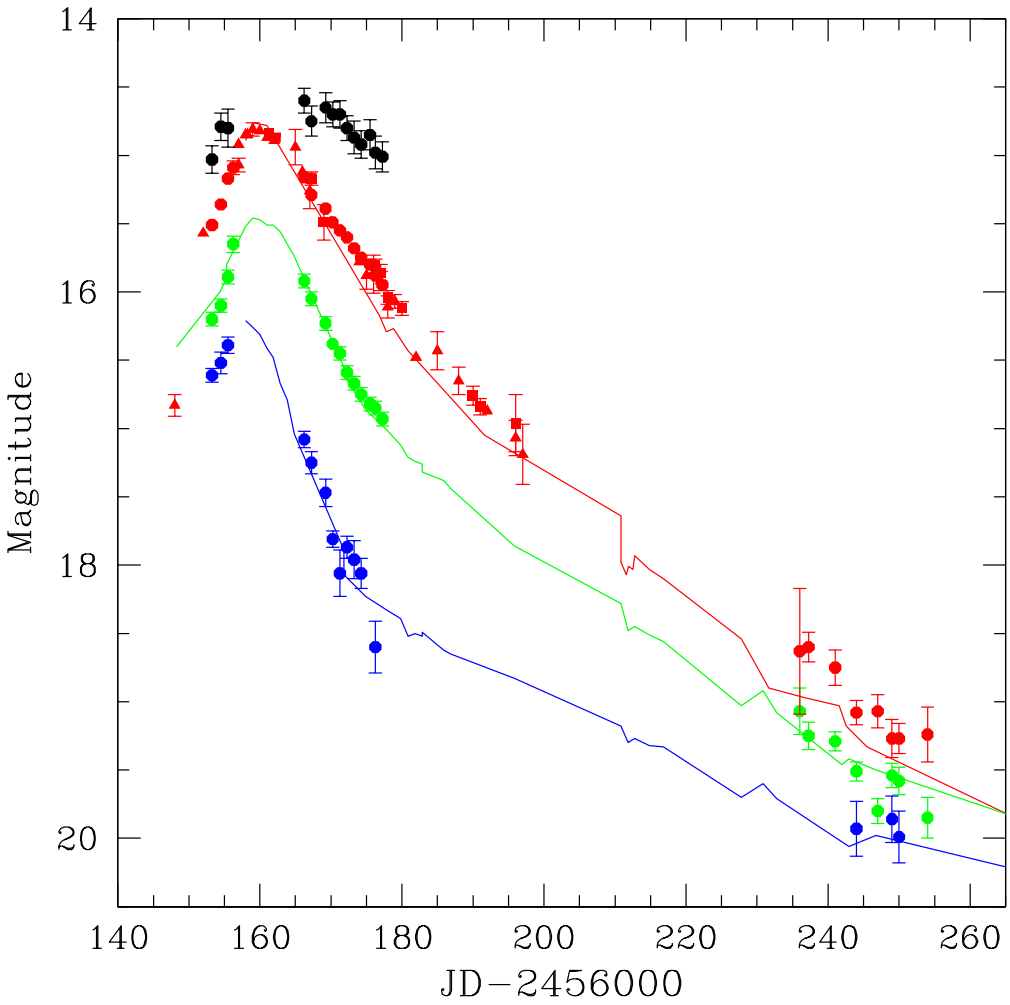

Figure 6.
The light curves of SN 2012ea. The light curve in the R band is shifted by –0.5 mag and in the I band, by –1.0 mag for clarity. The solid curves are the light curves of SN 1991bg.