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Supernova 2014J at maximum light

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Abstract. We present *UBVRI* photometry of the supernova 2014J in M82, obtained in the period from January 24 until March 3, 2014, as well as two spectra, taken on February 4 and March 5, 2014. We derive dates and magnitudes of maximum light in the *UBVRI* bands, the light curve parameters Δm_{15} and expansion velocities of the prominent absorption lines. We discuss colour evolution, extinction and maximum luminosity of SN 2014J.

Key words: supernovae: individual (SN 2014J)

1. Introduction

Supernova (SN) 2014J, located at $\alpha = 9^{\rm h}55^{\rm m}42^{\rm s}.14, \delta = +69^\circ 40' 26''.0$ (2000.0) in the galaxy M82, was discovered by Steve J. Fossey on UT 2014 January 21.8. The description of discovery and early observations were presented by Goobar *et al.* (2014). The prediscovery observations and early spectra were reported by Zheng *et al.* (2014). These sets of data show that SN 2014J is a spectroscopically normal Type Ia SN, although it exhibited high-velocity features in the spectrum and was heavily reddened by the dust in the host galaxy.

At a distance of 3.5 Mpc (Karachentsev and Kashibadze, 2006) SN 2014J is the nearest SNIa since SN 1972E, and it offers the unique possibility to study a thermonuclear SN over a wide range of the electromagnetic spectrum.

2. Observations

We present here CCD photometry of SN 2014J in the *UBVRI* passbands obtained at three sites. Nearly daily coverage was achieved in the period from January 24 until March 3, 2014. Observations were carried out at the Crimean Observatory of the Sternberg Astronomical Institute (SAI)(Nauchnyi, Crimea); at the Moscow Observatory of SAI (Moscow, Russia) and at the Stará Lesná Observatory of the Astronomical Institute of the Slovak Academy of Sciences.

Table 1. Telescopes and detectors employed for the observations.

Telescope code	Location	Aperture [m]	CCD camera	Filters	Scale [arcsec pixel^{-1}]	FoV [arcmin]
S60	Stará Lesná, Slovakia	0.6	FLI ML 341	$UBVR_CI_C$	0.85	14.0
K50	Nauchnyi, Crimea	0.5	Apogee Alta U8300	$UBVR_CI_C$	1.10	30.5x23.0
M70	Moscow, Russia	0.7	Apogee AP-7p	$UBVR_CI_J$	0.64	5.5
M20	Moscow, Russia	0.2	Apogee AP-7p	$UBVR_CI_J$	1.22	10.4

A list of the observing facilities is given in Table 1.

The standard image reductions and photometry were made using the IRAF[1]. The magnitudes of the SN were derived by a PSF-fitting relatively to two bright local standard stars. The surface brightness of the host galaxy at the location of the SN is quite high, and subtraction of the galaxy background is necessary for accurate photometry. We had no images of M82 obtained at our instruments before the SN outburst, so we used the images downloaded from the CASU archive[2]. They were transformed to match our images using appropriate IRAF tasks.

The CCD image of SN 2014J and local standard stars is presented in Fig. 1.

The magnitudes of the local standards, calibrated on 7 nights relative to a standard in the field of the nearby galaxy M81 (Richmond *et al.*, 1996), are reported in Table 2. The B, V-band magnitudes of star 1 are in a good agreement with the data reported by AAVSO[3], but for star 2 the difference between our results and the AAVSO data is significant.

Table 2. $UBVRI$ magnitudes of local standard stars.

Star	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I
1	10.86	0.02	10.62	0.01	10.04	0.01	9.70	0.01	9.41	0.01
2	12.17	0.02	11.53	0.01	10.70	0.01	10.23	0.01	9.85	0.02

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

[2]http://casu.ast.cam.ac.uk

[3]http://www.aavso.org/download-apass-data

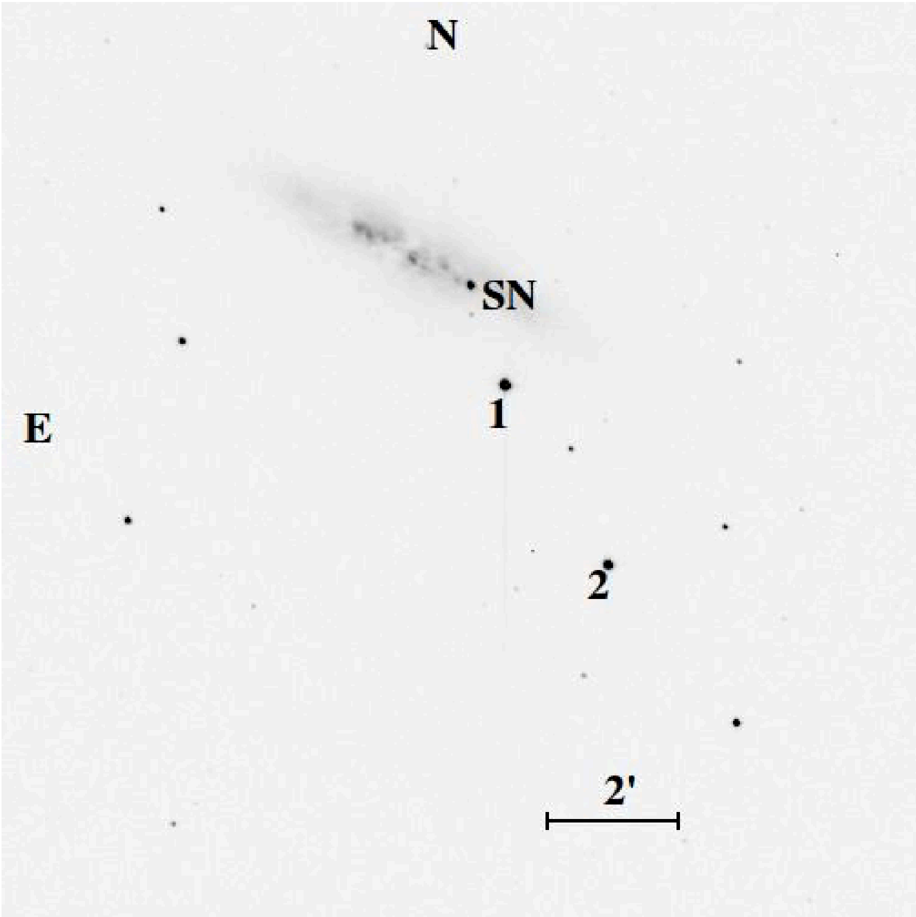

Figure 1. The image of SN 2014J and local standard stars, obtained at the S60 telescope in the V-band on February 23.

The photometry was transformed to the standard Johnson-Cousins system by means of instrument colour-terms, determined from observations of standard star clusters. The procedure was described in detail by Elmhamdi *et al.* (2011) and Tsvetkov *et al.* (2008). The type of R and I-filters is indicated in Table 1. We transformed the photometry in the I-band to the Cousins system, so R and I are equivalent to R_C, I_C.

Our photometry of the SN is presented in Table 3.

Our spectroscopic observations were carried out at the 2.6-m Shajn telescope of CrAO on 2014 February 4 and March 5. The spectrograph SPEM provided the wavelength range of 3300–7550 Å with a dispersion of 2Å pixel^{-1}. The

Table 3. $UBVRI$ magnitudes of SN2014J.

JD– 2456000	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
682.13			12.49	0.03	11.20	0.03	10.52	0.03	10.03	0.03	M20
686.20	13.00	0.12	12.08	0.02	10.77	0.03	10.24	0.03	9.77	0.03	M20
687.13	12.90	0.16	11.99	0.03	10.70	0.02	10.16	0.02	9.72	0.02	M20
688.17	13.02	0.25	11.98	0.03	10.67	0.02	10.14	0.02	9.72	0.02	M20
689.13	12.93	0.18	11.95	0.03	10.61	0.02	10.11	0.03	9.71	0.03	M20
691.18	12.72	0.04	11.85	0.03	10.56	0.01	10.05	0.01	9.86	0.02	K50
692.20	12.79	0.04	11.88	0.03	10.57	0.02	10.06	0.02	9.90	0.02	K50
693.17	12.79	0.03	11.91	0.03	10.58	0.01	10.08	0.01	9.93	0.02	K50
694.17	12.73	0.05	11.94	0.04	10.59	0.02	10.08	0.02	9.95	0.02	K50
694.49	12.88	0.05	12.01	0.04	10.65	0.02	10.11	0.02	9.99	0.03	S60
695.18			11.99	0.03	10.61	0.02	10.12	0.02	9.99	0.02	K50
696.16			12.03	0.03	10.63	0.02	10.17	0.02	10.02	0.02	K50
700.17	13.06	0.08	12.29	0.02	10.82	0.02	10.42	0.02	10.27	0.02	K50
701.20			12.39	0.02	10.89	0.02	10.52	0.02	10.32	0.02	K50
702.30	13.46	0.04	12.48	0.03	10.95	0.02	10.60	0.01	10.37	0.03	K50
702.45	13.53	0.04	12.55	0.03	10.94	0.01	10.57	0.02	10.38	0.02	S60
707.17	14.09	0.05	13.00	0.03	11.25	0.02	10.81	0.01	10.39	0.02	K50
708.22			13.19	0.05	11.28	0.03	10.77	0.04			M20
708.23	14.29	0.07	13.08	0.02	11.29	0.02	10.81	0.02	10.37	0.02	K50
711.35	14.60	0.06	13.40	0.04	11.41	0.02	10.81	0.02	10.29	0.03	K50
712.18			13.49	0.06	11.45	0.01	10.81	0.02	10.27	0.03	K50
712.25	14.85	0.06	13.56	0.04	11.43	0.02	10.76	0.02	10.21	0.02	S60
714.22			13.80	0.04	11.51	0.02	10.84	0.02	10.13	0.03	M20
714.40	14.99	0.05	13.71	0.03	11.47	0.02	10.80	0.02	10.12	0.02	S60
715.18			13.84	0.04	11.54	0.02	10.85	0.02	10.11	0.02	M20
715.42	15.12	0.05	13.79	0.02	11.53	0.02	10.81	0.01	10.13	0.02	S60
716.31	15.49	0.04	14.04	0.02	11.63	0.01	10.90	0.01	10.14	0.01	M70
716.41	15.26	0.07	13.90	0.04	11.58	0.03	10.85	0.03	10.12	0.02	S60
717.23	15.48	0.04	14.13	0.03	11.67	0.01	10.94	0.02	10.16	0.02	M70
718.42	15.34	0.04	14.08	0.03	11.65	0.01	10.86	0.02	10.08	0.02	S60
720.18	15.42	0.05	14.11	0.03	11.81	0.02	10.94	0.01	10.18	0.02	K50

spectra were bias and flat-field corrected, extracted and wavelength calibrated with the SPERED code developed by S.I. Sergeev at the Crimean Astrophysical Observatory. The spectrophotometric standard HR3894 was used for flux calibrated spectra.

3. Light and colour curves

The light curves of SN 2014J are presented in Fig. 2. The results for all the telescopes are in a fairly good agreement, some systematic differences can be noted only for the magnitudes in the U and I-bands. The shape of the light curves is typical for SNe Ia.

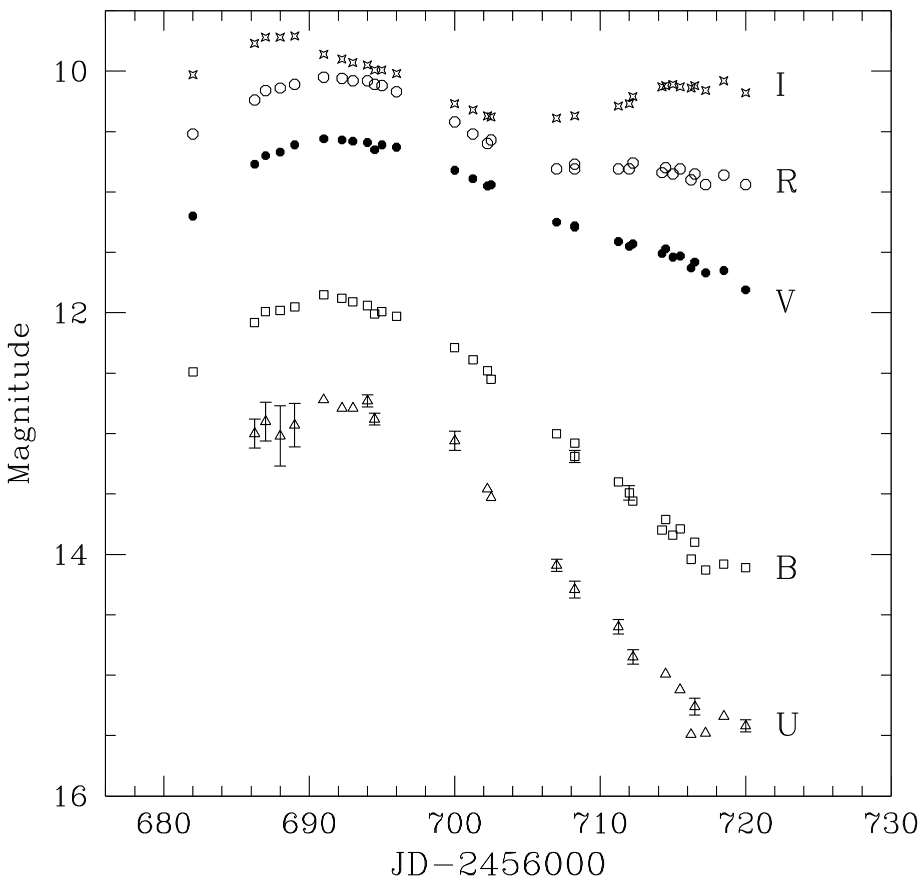

Figure 2. The light curves of SN 2014J in the *UBVRI* bands. The error bars are plotted only when they exceed the size of a symbol.

We fitted the light curves with cubic splines and determined the dates and magnitudes of maximum light in different bands and the decline rate parameters Δm_{15}. These data are reported in Table 4. The values of Δm_{15} confirm that SN 2014J is a normal type Ia, the light curve parameter $\Delta m_{15}(B) = 1.01 \pm 0.05$

is close to the fiducial decline rate of $\Delta m_{15}(B) = 1.1$ (Tammann and Reindl, 2013). The explosion likely occurred on January 14.72 (JD 2456672.22) (Zheng *et al.*, 2014, Goobar *et al.*, 2014). We can determine the time interval between the explosion and the B-band maximum as 19.2 days.

Table 4. Dates and magnitudes of maximum light and the decline rate parameters in different passbands.

Band	JD−2456000	mag	Δm_{15}
U	691.5± 2.0	12.76± 0.14	1.27± 0.15
B	691.4± 0.4	11.88± 0.05	1.01± 0.05
V	691.9± 0.3	10.57± 0.04	0.63± 0.04
R	691.5± 0.5	10.04± 0.04	0.72± 0.05
I	687.7± 1.5	9.71± 0.12	0.68± 0.10

The colour curves for SN 2014J are presented in Fig. 3. The colour evolution is typical for SN Ia, this is confirmed by comparison with the colour curves for SN 2011fe (Tsvetkov *et al.*, 2013), which is a "normal", unreddened SN Ia with nearly the same Δm_{15}. The evolution of all colours, except $(U - B)$, is similar for the two objects. The behaviour of the $(U - B)$ colour is different for SNe 2014J and 2011fe. We plotted also the $(U - B)$ color curve for SN Ia 2003du (Stanishev *et al.*, 2007), which is a better match for the curve of SN 2014J, but the differences are still evident. The amount of shift applied to match the curves can be considered as an estimate of the colour excess of SN 2014J. We obtained the following estimates: $E(U-B) = 1.1 \pm 0.15$; $E(B-V) = 1.3 \pm 0.05$; $E(V - R) = 0.47 \pm 0.05$; $E(R - I) = 0.6 \pm 0.05$. The colour excess due to the galactic extinction is $E(B - V)_{gal} = 0.14$ according to Schlafly and Finkbeiner (2011), so the colour excess in the host galaxy is $E(B - V)_{host} = 1.16$. If we assume the distance modulus for M82 $\mu = 27.73$ (distance 3.5 Mpc, Karachentsev and Kashibadze 2006), then the absolute V-band magnitude, corrected for the galactic extinction, is $M_V = -17.59$. According to the calibration of the Pskovskiy-Phillips relation by Prieto *et al.* (2006), the mean absolute magnitude for SN Ia with $\Delta m_{15}(B) = 1.01$ is $M_B = -19.35$. For "normal" unreddened SNe Ia $B_{max} \approx V_{max}$ (Tammann and Reindl, 2013), so we assume $M_{V0} = -19.35$ and calculate the most probable value of extinction in the host galaxy $A_V = 1.76$. Using our estimate $E(B-V)_{host} = 1.16$, we obtain the ratio of total-to-selective extinction $A_V/E(B-V) = 1.52$. This number is much smaller than the typical galactic value of 3.1, but close to the values found for another heavily reddened type Ia SNe (see e.g. Wang *et al.*, 2008).

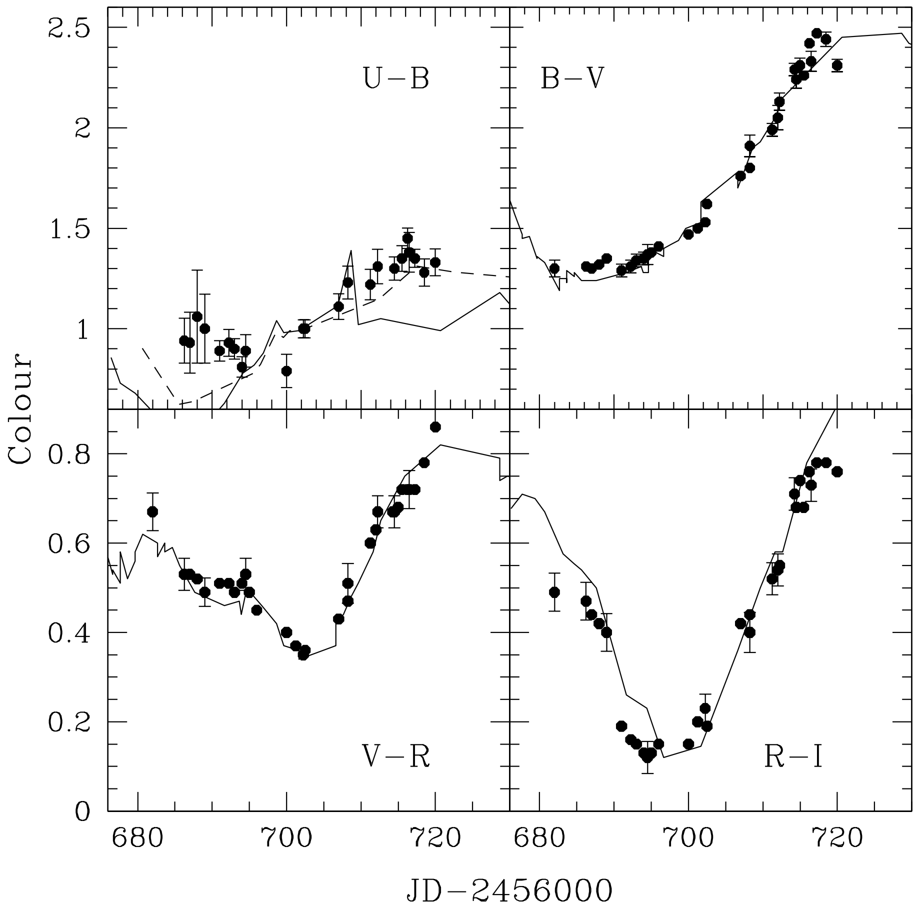

Figure 3. The colour curves of SN 2014J. The solid lines present colour curves for SN 2011fe and the dashed line the $(U - B)$ curve for SN 2003du.

4. Spectra

The spectra of SN 2014J obtained at the 2.6-meter telescope on February 4 (phase 2 days after the B-band maximum) and March 5 (phase 30 days) are shown in Fig. 4. The spectra are typical for SNe Ia at corresponding phases.

We estimated the expansion velocities from the wavelengths of prominent unblended absorption features and corrected them for the radial velocity of M82. For the phase 2 days we obtain v=11620 km s^{-1} for the line SiIIλ6355, and v=10330 km s^{-1} for the line SIIλ5640. For the phase 30 days we find v=10780 km s^{-1} for the line SiIIλ6355. The velocities are in good agreement with the results of Srivastav *et al.* (2014), they are higher than average for SNe of this type. The interstellar Na D line is very strong, we derive its equivalent width EW(Na D)= 5.8Å, in agreement with the data reported by Cox *et al.* (2014) and Kotak (2014).

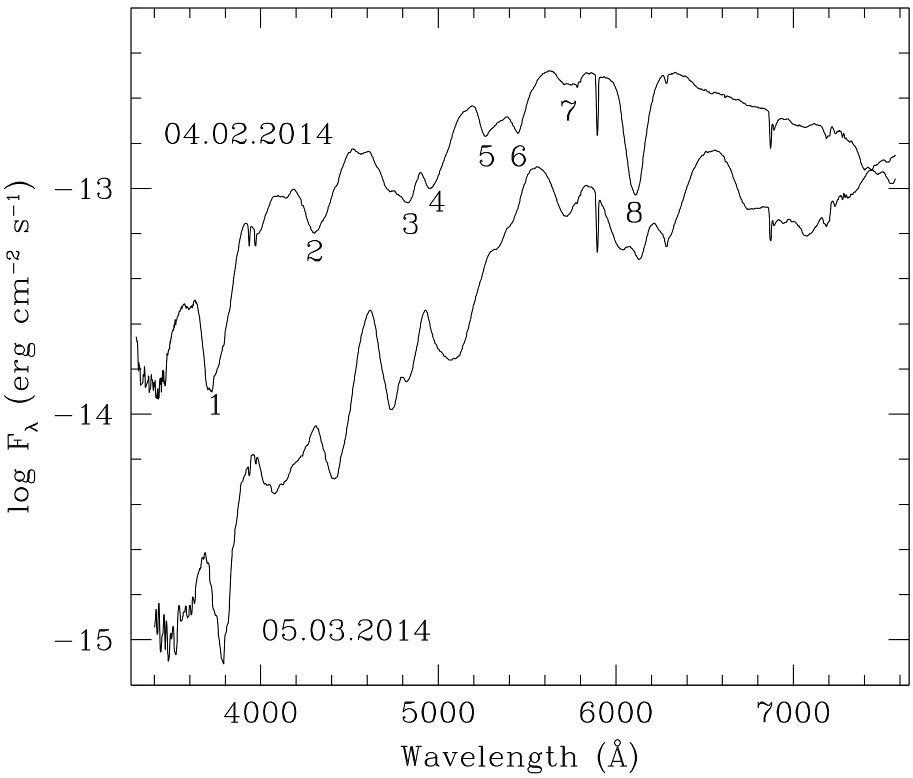

Figure 4. Spectra of SN 2014J. The identification of strongest absorption features: 1: CaII H&K, SiII λ3858; 2: MgII λ4481, FeII λ4404; 3,4: blends of several lines of FeII, FeIII, SiII; 5: SII λ5454; 6: SII λ5640; 7: SiII λ5972; 8: SiII λ6355.

5. Conclusions

We present the light and colour curves of SN 2014J starting 9 days before the B-band maximum and continuing until day 29 past the maximum. The spectra were obtained at phases 2 days and 30 days after the B-band maximum.

The light and colour curves for SN 2014J show that it belongs to the "normal" subset of type Ia SNe, but it is heavily reddened by the dust in the host galaxy. We estimate the decline rate parameter $\Delta m_{15}(B) = 1.01$ which is close to the fiducial value for SNe Ia. The comparison of colour excess and the luminosity, expected from the Pskovskiy-Phillips relation, results in a low value of the ratio of selective-to-total extinction, similar to the values found for other highly reddened type Ia SNe.

The spectral evolution is typical for this class of SNe, with expansion velocities higher than the mean values.

We continue the observations of SN 2014J, the results and more detailed analysis of the data will be presented in a subsequent paper.

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