Supernova 2014J at maximum light

D.Yu. Tsvetkov¹, V.G. Metlov¹, S.Yu. Shugarov¹,², T.N. Tarasova³ and N.N. Pavlyuk¹

¹ Sternberg Astronomical Institute, M.V. Lomonosov Moscow State University, Universitetskii pr. 13, 119992 Moscow, Russia
(E-mail: tsvetkov@sai.msu.su)

² Astronomical Institute of the Slovak Academy of Sciences 059 60 Tatranská Lomnica, The Slovak Republic

³ Crimean Astrophysical Observatory, Nauchnyi, Crimea

Received: March 28, 2014; Accepted: 2014

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. We derive dates and magnitudes of maximum light in the UBVRI bands, the light curve parameters $\Delta m_{15}$ 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 $\alpha = 9^h55^m42^s.14$, $\delta = +69^\circ40'26''0$ (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 also 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] | FoV [arcmin] |
|----------------|----------|-------------|------------|---------|---------------------|-------------|
| S60            | Stará, Lesná, Slovakia | 0.6          | FLI        | $UBVRC_{IC}$ | 0.85 | 14.0 |
| K50            | Nauchnyi, Crimea | 0.5          | Apogee Alta U8300 | $UBVRC_{IC}$ | 1.10 | 30.5x23.0 |
| M70            | Moscow, Russia | 0.7          | Apogee AP-7P | $UBVRI_{J}$ | 0.64 | 5.5 |
| M20            | Moscow, Russia | 0.2          | Apogee AP-7P | $UBVRI_{J}$ | 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 galaxy background is necessary for accurate photometry. We had no images of M82 obtained at our instruments before SN outburst, and 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 were calibrated on 7 nights relative to a standard in the field of the nearby galaxy M81 (Richmond \textit{et al.}, 1996), they 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 the star 2 the difference between our results and AAVSO data is significant.

Table 2. $UBVRI$ magnitudes of local standard stars

| Star | $U$ | $\sigma_U$ | $B$ | $\sigma_B$ | $V$ | $\sigma_V$ | $R$ | $\sigma_R$ | $I$ | $\sigma_I$ |
|------|-----|------------|-----|------------|-----|------------|-----|------------|-----|------------|
| 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
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 details 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 $R$, $I$-bands to Cousins system, so $R$ and $I$ are equivalent to $R_C$, $I_C$.

The photometry of the SN is presented in Table 3.

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

**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 $\Delta m_{15}$. These data are reported in Table 4. The values of $\Delta m_{15}$ confirm that
SN 2014J is a normal type Ia SN with rate of brightness decline close to the mean values. The explosion likely occurred on January 14.72 (Zheng et al., 2014, Goobar et al., 2014)(JD 2456672.22), and we can determine that the time interval between explosion and the $B$-band maximum equals 19.2 days.

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 $\Delta m_{15}$. 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), it 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 $E(B-V)_{host} = 1.16$. Assuming distance modulus for M82 $\mu = 27.73$ (distance 3.5 Mpc, Karachentsev and Kashibadze 2006) and mean absolute magnitude for SN Ia with $\Delta m_{15} = 1.01 M_B = -19.35$ (Prieto et al., 2006) we obtain for ratio of total to selective extinction $A_V/E(B-V) \approx 1.5$. 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).

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 un-blended 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 SiII$\lambda 6355$, $v=10330$ km s$^{-1}$ for the line SiII$\lambda 5640$. For the epoch 30 days we find $v=10780$ km s$^{-1}$ for the line SiII$\lambda 6355$. 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)$= 5.8\AA, in agreement with the data reported by Cox et al. (2014) and Kotak (2014).

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

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 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 mean value for SNe Ia. The comparison of colour excess and the luminosity, expected from Pskovskiy-Phillips relation, results in 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.
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: SiII λ5454; 6: SiII λ5640; 7: SiII λ5972; 8: SiII λ6355.

Acknowledgements. The work of DT and NP was partly supported by the RFBR grant 13-02-92119.

This paper makes use of data obtained from the Isaac Newton Group Archive which is maintained as part of the CASU Astronomical Data Centre at the Institute of Astronomy, Cambridge.

References
Cox, N.L.J., Davis, P., Patat, F., Van Winckel, H.: 2014, Astron. Tel. 5797, 1
Goobar, A., Johansson, J., Amanullah, R., Cao, Y., Perley, D. A., Kasliwal, M. M., Ferretti, R., Nugent, P. E., Harris, C., Gal-Yam, A., Ofek, E. O., Tendulkar, S. P., Dennefeld, M., Valenti, S., Arcavi, I., Banerjee, D. P. K., Venkataraman, V., Joshi,
V., Ashok, N. M., Cenko, S. B., Diaz, R. F., Fremling, C., Horesh, A., Howell, D. A., Kulkarni, S. R., Papadogiannakis, S., Petrushevskaya, T., Sand, D., Sollerman, J., Stanishev, V., Bloom, J. S., Surace, J., Dupuy, T. J., Liu, M. C.: 2014, Astrophys. J., Lett. 784, L12
Elmhamdi, A., Tsvetkov, D., Danziger, I.J., Kordi, A.: 2011, Astrophys. J. 731, 129
Karachentsev, I., Kashibadze, O.G.: 2006, Astrophysics 49, 3
Kotak, R.: 2014, Astron. Tel. 5816, 1
Prieto, J.L., Rest, A., Suntzeff, N.B.: 2006, Astrophys. J. 647, 501
Richmond, M.W., Treffers, R.R., Filippenko, A.V., Paik, Y.: 1996, Astron. J. 112, 732
Sclafly, E.F., Finkbeiner, D.P.: 2011, Astrophys. J. 737, 103
Srivastav, S., Ninan, J.P., Anupama, G.C., Sahu, D.K., Ojha, D.K.: 2014, Astron. Tel. 5876, 1
Stanishev, V., Goobar, A., Benetti, S., Kotak, R., Pignata, G., Navasardyan, H., Mazzali, P., Amanullah, R., Garavini, G., Nobili, S., Qiu, Y., Elias-Rosa, N., Ruiz-Lapuente, P., Mendez, J., Meikle, P., Patat, F., Pastorello, A., Altavilla, G., Gustafsson, M., Harutyunyan, A., Iijima, T., Jakobsson, P., Kichizhieva, M.V., Lundqvist, P., Mattila, S., Melinder, J., Pavlenko, E.P., Pavlyuk, N.N., Sollerman, J., Tsvetkov, D.Yu., Turatto, M., Hillebrandt, W.: 2007, Astron. Astrophys. 469, 645
Tsvetkov, D.Yu., Goranskij, V.P., Pavlyuk, N.N.: 2008, Perem. Zvezdy 28, 8
Tsvetkov, D.Yu., Shugarov, S.Yu, Volkov, I.M., Goranskij, V.P., Pavlyuk, N.N., Katsycheva, N.A., Barsukova, E.A., Valeev, A.F.: 2013, Contrib. Astron. Obs. Skalnaté Pleso 43, 94
Wang, X., Li, W., Filippenko, A.V., Krisciunas, K., Suntzeff, N.B., Li, J., Zhang, T., Ganeshalingam, M., Foley, R.J., Li, T., Lou, Y., Shang, R., Zhang, S., Zhang, Y.: 2008, Astrophys. J. 675, 626
Zheng, W., Shiivers, I., Filippenko, A.V., Itagaki, K., Clubb, K.I., Fox, O.D., Graham, M.L., Kelly, P.L., Mauerhan, J.C.: 2014, Astrophys. J., Lett. 783, L24
Table 3. \textit{UBVRI} magnitudes of SN2014J

| JD−2456000 | $U$   | $\sigma_U$ | $B$   | $\sigma_B$ | $V$   | $\sigma_V$ | $R$   | $\sigma_R$ | $I$   | $\sigma_I$ | 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       | M20  |
| 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       |      |            |      |            |      |
| 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  |
Table 4. Dates and magnitudes of maximum light and the decline rate parameters in different passbands.

| Band | JD−2456000 | mag   | $\Delta m_{15}$ |
|------|-------------|-------|-----------------|
| 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     |