The light curves of type II-P SN 2017eaw: first 200 days

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Abstract

We present UBVRI photometry of the supernova 2017eaw in NGC 6946, obtained in the period from May 14 until December 7, 2017. We derive dates and magnitudes of maximum light in the UBVRI bands and the parameters of the light curves. We discuss colour evolution, extinction and maximum luminosity of SN 2017eaw. Preliminary modeling is carried out, and the results are in satisfactory agreement with the light curves in the UBVRI bands.

Keywords: supernovae: individual (SN 2017eaw)
Introduction

Supernova (SN) 2017eaw was discovered by Patrick Wiggins on UT 2017 May 14.238 at magnitude 12.8 (Dong, Stanek, 2017). The SN was located at $\alpha = 20^\mathrm{h}34^\mathrm{m}44^\mathrm{s}.238$, $\delta = +60^\circ11'36''.00$, 61''.0 west and 143''.0 north of the center of NGC 6946 (Sarneckzy et al., 2017).

The new object was classified as a young type II SN by Cheng et al. (2017) and Tomasella et al. (2017). The detection of the probable progenitor was reported by Khan (2017) and Van Dyk et al. (2017).

We present in this paper the results of extensive monitoring of SN 2017eaw in the optical bands undertaken at six observatories, and preliminary modeling of the light curves using the multi-group radiation-hydrodynamics numerical code STELLA.

Observations

Photometric observations of SN 2017eaw commenced on 2017 May 14, immediately after discovery. CCD frames in the $UBVRI$ passbands were obtained at six sites, with 10 telescopes. The telescopes used for monitoring are: the 2.5-m telescope of the Caucasus Mountain Observatory of Sternberg Astronomical Institute (SAI) (K250) (Potanin et al. 2017); the 1-m and 0.6-m telescopes of Simeiz Observatory (S100, S60); the 0.7-m reflector of Crimean Astrophysical Observatory (C70); the 0.6-m reflector of Crimean Observatory of SAI (C60); the 0.7-m and 0.2-m telescopes of SAI in Moscow (M70, M20); the 0.6-m and 0.18-m telescopes of the Stará Lesná Observatory of the Astronomical Institute of the Slovak Academy of Sciences (T60, T18); the 0.4-m telescope of the Astronomical Institute of St. Petersburg State University (P40).

All telescopes were equipped with CCD cameras and sets of Johnson-Cousins $UBVRI$ filters.

The standard image reductions and photometry were made using the IRAF. The magnitudes of the SN were derived by aperture photometry or PSF-fitting relatively to local standard stars. The CCD image of SN 2017eaw and local standard stars is presented in Fig. 1. The magnitudes of stars 4,5 were reported by Botticella et al. (2009), stars 6–9 were calibrated by Misra.

1IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation.
et al. (2007). Some of the instruments employed for photometry have small field of view of about 6\arcmin (M70, S60), and only stars 1–3 could be measured on the frames. We calibrated the stars 1–3 on images with larger field of view relative to the stars 4–9.

The surface brightness of the host galaxy at the location of the SN is low, and subtraction of galaxy background is not necessary.

The photometry was transformed to the standard Johnson-Cousins system by means of instrument colour-terms, determined from observations of standard star clusters.

Our photometry of the SN is presented in Table 1.

Table 1: \textit{UBVRI} magnitudes of SN 2017eaw

| JD−2450000 | \(U\) | \(\sigma_U\) | \(B\) | \(\sigma_B\) | \(V\) | \(\sigma_V\) | \(R\) | \(\sigma_R\) | \(I\) | \(\sigma_I\) | Tel. |
|-----------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|
| 7888.47   | 12.62 | 0.04  | 13.32 | 0.02  | 13.13 | 0.01  | 12.92 | 0.02  | 12.68 | 0.02  | T60  |
| 7890.41   | 13.30 | 0.04  | 12.93 | 0.02  | 12.64 | 0.02  | 12.37 | 0.03  | P40  |
| 7892.41   | 12.53 | 0.06  | 13.25 | 0.03  | 12.89 | 0.02  | 12.54 | 0.02  | 12.19 | 0.03  | M70  |
| 7892.52   | 13.20 | 0.02  | 12.86 | 0.01  | 12.54 | 0.02  | 12.18 | 0.02  | S100 |
| 7898.52   | 12.50 | 0.09  | 13.33 | 0.03  | 12.97 | 0.02  | 12.56 | 0.02  | 12.22 | 0.03  | C60  |
| 7901.45   | 12.94 | 0.10  | 12.99 | 0.01  | 12.58 | 0.01  | 12.26 | 0.01  | K250 |
| 7901.48   | 12.82 | 0.10  | 13.37 | 0.03  | 13.00 | 0.01  | 12.57 | 0.03  | 12.23 | 0.03  | C60  |
| 7904.35   | 13.10 | 0.06  | 13.48 | 0.03  | 13.05 | 0.01  | 12.55 | 0.02  | 12.16 | 0.03  | M70  |
| 7904.46   | 13.20 | 0.01  | 13.01 | 0.01  | 12.59 | 0.01  | 12.26 | 0.01  | K250 |
| 7905.49   | 13.22 | 0.06  | 13.52 | 0.02  | 13.02 | 0.02  | 12.58 | 0.02  | 12.24 | 0.03  | C60  |
| 7912.38   | 13.82 | 0.02  | 13.06 | 0.01  | 12.56 | 0.02  | 12.15 | 0.02  | M70  |
| 7912.39   | 13.79 | 0.03  | 13.00 | 0.02  | 12.53 | 0.02  | 12.16 | 0.03  | S100 |
| 7914.45   | 13.93 | 0.04  | 13.10 | 0.02  | 12.59 | 0.03  | 12.21 | 0.04  | T18  |
| 7916.39   | 14.32 | 0.04  | 14.01 | 0.02  | 13.11 | 0.01  | 12.64 | 0.02  | 12.26 | 0.02  | T60  |
| 7916.47   | 14.00 | 0.04  | 13.07 | 0.03  | 12.64 | 0.03  | 12.24 | 0.03  | C70  |
| 7921.53   | 14.18 | 0.03  | 13.18 | 0.01  | 12.67 | 0.02  | 12.24 | 0.02  | S100 |
| 7923.45   | 14.80 | 0.04  | 14.22 | 0.02  | 13.19 | 0.02  | 12.69 | 0.02  | 12.27 | 0.02  | T60  |
| 7926.31   | 14.31 | 0.02  | 13.21 | 0.01  | 12.69 | 0.02  | 12.26 | 0.02  | S100 |
| 7926.45   | 14.26 | 0.05  | 13.20 | 0.02  | 12.70 | 0.03  | 12.25 | 0.04  | C70  |
| 7927.54   | 14.34 | 0.02  | 13.22 | 0.02  | 12.70 | 0.02  | 12.27 | 0.02  | S100 |
| 7928.41   | 14.35 | 0.03  | 13.22 | 0.01  | 12.69 | 0.02  | 12.19 | 0.02  | M70  |
| 7929.34   | 15.04 | 0.05  | 14.35 | 0.03  | 13.22 | 0.01  | 12.71 | 0.02  | 12.26 | 0.03  | T60  |
| 7930.33   | 14.40 | 0.02  | 13.23 | 0.02  | 12.72 | 0.02  | 12.24 | 0.03  | S100 |
| 7931.32   | 14.41 | 0.02  | 13.24 | 0.01  | 12.71 | 0.02  | 12.25 | 0.02  | S100 |
Table 1: Continued.

| JD−2450000 | $U$ | $\sigma_U$ | $B$ | $\sigma_B$ | $V$ | $\sigma_V$ | $R$ | $\sigma_R$ | $I$ | $\sigma_I$ | Tel. |
|------------|-----|----------|-----|----------|-----|----------|-----|----------|-----|----------|------|
| 7932.30    | 14.39 | 0.04  | 13.24 | 0.01  | 12.71 | 0.02  | 12.24 | 0.02  | S100 |
| 7933.31    | 14.44 | 0.02  | 13.23 | 0.02  | 12.24 | 0.03  | S100  |
| 7934.30    | 14.46 | 0.03  | 13.22 | 0.02  | 12.24 | 0.04  | S100  |
| 7934.43    | 14.47 | 0.03  | 13.26 | 0.03  | 12.69 | 0.04  | 12.20 | 0.05  | C70  |
| 7944.55    | 14.59 | 0.03  | 13.28 | 0.02  | 12.71 | 0.02  | 12.21 | 0.02  | S100 |
| 7956.46    | 14.68 | 0.03  | 13.30 | 0.03  | 12.72 | 0.03  | 12.23 | 0.03  | C70  |
| 7960.50    | 14.75 | 0.02  | 13.33 | 0.02  | 12.71 | 0.02  | 12.21 | 0.02  | T60  |
| 7966.33    | 14.82 | 0.02  | 13.37 | 0.02  | 12.73 | 0.02  | 12.23 | 0.02  | T60  |
| 7972.28    | 14.90 | 0.05  | 13.43 | 0.02  | 12.79 | 0.03  | S100  |
| 7975.57    | 15.05 | 0.02  | 13.51 | 0.01  | 12.80 | 0.02  | 12.27 | 0.03  | S100 |
| 7978.50    | 15.11 | 0.03  | 13.55 | 0.01  | 12.83 | 0.02  | 12.30 | 0.02  | S100 |
| 7981.36    | 15.10 | 0.04  | 13.58 | 0.02  | 12.87 | 0.02  | 12.32 | 0.03  | M20  |
| 7982.53    | 15.16 | 0.02  | 13.59 | 0.01  | 12.88 | 0.02  | 12.34 | 0.02  | T60  |
| 7985.47    | 15.18 | 0.02  | 13.63 | 0.02  | 12.89 | 0.02  | 12.36 | 0.03  | S100 |
| 7986.29    | 15.23 | 0.08  | 13.67 | 0.02  | 12.92 | 0.04  | 12.38 | 0.03  | M20  |
| 7990.37    | 15.42 | 0.03  | 13.80 | 0.02  | 13.02 | 0.03  | S60   |
| 7990.48    | 15.54 | 0.04  | 13.86 | 0.01  | 13.09 | 0.02  | 12.52 | 0.03  | C60  |
| 7992.49    | 15.55 | 0.04  | 13.88 | 0.01  | 13.11 | 0.02  | 12.53 | 0.02  | C60  |
| 7994.46    | 15.60 | 0.03  | 13.99 | 0.01  | 13.18 | 0.02  | 12.60 | 0.02  | C60  |
| 7995.37    | 15.76 | 0.03  | 14.02 | 0.01  | 13.22 | 0.03  | 12.62 | 0.03  | T60  |
| 7997.30    | 15.74 | 0.04  | 14.07 | 0.02  | 13.26 | 0.03  | 12.68 | 0.03  | P40  |
| 7997.33    | 15.87 | 0.05  | 14.15 | 0.03  | 13.32 | 0.03  | 12.69 | 0.04  | M20  |
| 8004.29    | 15.81 | 0.03  | 14.14 | 0.02  | 13.34 | 0.02  | 12.81 | 0.03  | P40  |
| 8005.37    | 15.84 | 0.05  | 14.14 | 0.05  | 12.87 | 0.06  | C70   |
| 8015.55    | 15.97 | 0.05  | 14.14 | 0.05  | 12.97 | 0.03  | P40   |
| 8004.29    | 16.48 | 0.02  | 14.77 | 0.01  | 13.80 | 0.02  | 13.14 | 0.02  | C60  |
| 8005.37    | 16.61 | 0.02  | 14.90 | 0.01  | 13.93 | 0.02  | 13.25 | 0.02  | C60  |
Table 1: Continued.

| JD−2450000 | $U$  | $\sigma_U$ | $B$  | $\sigma_B$ | $V$  | $\sigma_V$ | $R$  | $\sigma_R$ | $I$  | $\sigma_I$ | Tel. |
|-----------|------|------------|------|------------|------|------------|------|------------|------|------------|------|
| 8006.32   | 16.75| 0.02       | 15.03| 0.01       | 14.03| 0.02       | 13.34| 0.02       | C60  |
| 8007.26   | 16.88| 0.03       | 15.15| 0.01       | 14.14| 0.02       | 13.45| 0.02       | C60  |
| 8008.30   | 17.06| 0.03       | 15.28| 0.01       | 14.26| 0.02       | 13.57| 0.03       | C60  |
| 8008.38   |      | 14.23      |      | 0.02       | 13.58| 0.04       |      |            | P40  |
| 8009.25   | 17.09| 0.02       | 15.38| 0.01       | 14.33| 0.02       | 13.64| 0.02       | C60  |
| 8009.32   | 17.03| 0.13       | 15.37| 0.05       | 14.39| 0.03       | 13.67| 0.04       | M20  |
| 8009.47   | 17.12| 0.08       | 15.27| 0.05       | 14.27| 0.04       |      |            | C70  |
| 8011.44   | 17.22| 0.04       | 15.43| 0.08       | 14.37| 0.03       | 13.79| 0.04       | C70  |
| 8013.43   |      | 15.45      |      | 0.05       | 14.45| 0.02       |      |            | C70  |
| 8014.31   |      | 15.49      |      | 0.02       | 14.52| 0.02       | 13.87| 0.03       | P40  |
| 8019.19   | 15.72| 0.04       | 14.66| 0.03       | 13.99| 0.06       |      |            | M20  |
| 8019.45   | 17.42| 0.07       | 15.62| 0.04       | 14.61| 0.02       | 13.91| 0.03       | P40  |
| 8020.44   |      |            |      |            |      |            |      |            | P40  |
| 8021.28   |      | 15.64      |      | 0.05       | 14.65| 0.03       | 13.97| 0.03       | P40  |
| 8022.30   | 17.59| 0.03       | 15.74| 0.01       | 14.66| 0.02       | 13.94| 0.02       | T60  |
| 8023.21   | 15.72| 0.06       | 14.65| 0.03       |      |            |      |            | M70  |
| 8025.38   | 17.44| 0.06       | 15.73| 0.05       | 14.64| 0.05       | 13.93| 0.03       | C70  |
| 8027.35   | 17.51| 0.10       | 15.72| 0.06       | 14.65| 0.05       | 13.94| 0.04       | C70  |
| 8028.43   | 17.63| 0.03       | 15.80| 0.02       | 14.72| 0.03       | 13.98| 0.03       | T60  |
| 8029.40   | 17.43| 0.09       | 15.71| 0.06       | 14.63| 0.03       | 13.96| 0.03       | C70  |
| 8040.36   |      |            |      |            |      |            |      |            | P40  |
| 8044.15   |      |            |      |            |      |            |      |            | P40  |
| 8049.40   |      |            |      |            |      |            |      |            | P40  |
| 8052.30   | 17.74| 0.05       | 16.00| 0.02       | 14.91| 0.02       | 14.23| 0.03       | T60  |
| 8059.47   |      |            |      |            |      |            |      |            | T60  |
| 8061.15   | 17.72| 0.05       | 16.16| 0.03       | 15.03| 0.04       | 14.37| 0.04       | C60  |
| 8063.14   | 17.81| 0.03       | 16.18| 0.01       | 15.04| 0.02       | 14.34| 0.02       | C60  |
| 8074.22   | 16.31| 0.02       | 15.12| 0.03       |      |            |      |            | C60  |
| 8075.27   | 17.81| 0.04       | 16.33| 0.02       | 15.15| 0.02       | 14.45| 0.02       | C60  |
| 8076.20   | 17.87| 0.03       | 16.34| 0.02       | 15.16| 0.02       | 14.47| 0.02       | C60  |
| 8095.22   | 18.03| 0.04       | 16.43| 0.02       | 15.32| 0.02       | 14.60| 0.02       | T60  |
Figure 1: The image of SN 2017eaw and local standard stars, obtained at the T60 telescope in the $V$-band
Light and colour curves

The light curves of SN 2017eaw are presented in Fig. 2. The results for all the telescopes are in a fairly good agreement. The light curves are typical for type II-P SNe, with a plateau lasting about 100 days. Our first observations were made before maximum light, and the date of maximum can be determined as JD 2457892.5. The magnitudes at maximum are $U = 12.5$, $B = 13.22$, $V = 12.87$, $R = 12.54$, $I = 12.18$. The fast decline after the plateau stage started at about JD 2457980, and the final linear tail started at JD 2457810, with $B = 17.3$, $V = 15.5$, $R = 14.5$, $I = 13.8$ mag. The rates of decline on the tail in the $B, V, R, I$ bands are, respectively, 0.0054, 0.0106, 0.0092, 0.0090 mag day$^{-1}$.

The light curves of SN 2004et (Maguire et al., 2010), which occurred in the same galaxy and also belonged to the type II-P, are plotted for comparison. We shifted the curves for SN 2004et only in time, assuming JD 2453270.5 as the date of explosion for SN 2004et (Maguire et al., 2010), and JD 2457884 as explosion date for SN 2017eaw (Tomasella et al., 2017). The shape of the light curves is practically identical, but SN 2004et is about 0.3 mag brighter at the plateau stage in the $B, V, R, I$ bands. But on the tail the difference between two SNe becomes negligible.

The colour curves for SNe 2004et and 2017eaw are compared in Fig. 3. The similarity of the curves is evident, some difference can be noticed only for the $R - I$ colour. We may suppose that the values of interstellar extinction for these SNe are very close. The reddening for SN 2004et was estimated as $E(B - V) = 0.41$ mag by Maguire et al. (2010) considering the strength of interstellar Na I lines. Using the same method, Tomasella et al. (2017) derived $E(B - V) = 0.22$ mag for SN 2017eaw. The Galactic extinction in the direction of NGC 6946 is $E(B - V) = 0.30$ mag according to Schlafly, Finkbeiner (2011) (via NED). We suppose, that the extinction for both SNe has nearly equal value and occurs only in the Galaxy. The difference of estimates based on the equivalent width of Na I lines may be due to the large dispersion of results obtained with this method. This supposition is supported by the fact that both SNe exploded at quite large distances from the center of the galaxy: 8 kpc for SN 2004et, 4.7 kpc for SN 2017eaw, in the regions with low surface brightness.

Assuming the distance of 6.0 Mpc for NGC 6946 (Efremov et al., 2011)
and reddening $E(B - V) = 0.30$ mag we derive absolute magnitudes of SN 2017eaw at maximum light: $M_U = -17.9, M_B = -16.9, M_V = -17.0, M_R = -17.1, M_I = -17.2$ mag. The value of $M_B$ is only slightly brighter than the mean absolute magnitude $M_B = -16.75$ mag for SNe II-P (Richardson et al., 2014). SN 2004et is about 0.3 mag brighter, but its luminosity is also quite close to the mean value for SNe II-P.

**Modeling**

The light curve shapes with a luminous plateau shows that SN 2017eaw is a normal type II-P SN and its presupernova star was a red supergiant (RSG). SNe II-P show large variety in their light-curve shapes. The main features of the light curves are determined by the initial radius $R$, total mass of presupernova $M$, mass of $^{56}$Ni and the energy of explosion $E$ (Litvinova, Nadyozhin, 1985; Kasen, Woosley, 2009). We computed the large grid of models on parameter space $(R, M, ^{56}$Ni, $E)$ to evaluate the best fit model.

For the model calculation, we use the multi-group radiation-hydrodynamics numerical code STELLA (Blinnikov et al., 1998; 2000; 2006). We constructed the presupernova RSG models in non-evolutionary hydrostatic equilibrium described previously (Baklanov et al., 2005). The shock propagation causes strong mixing of envelope matter due to Rayleigh-Taylor instability. The amount and distribution of $^{56}$Ni are manually adjusted to make its radial distribution closer to the actual distribution. The density and the elements distribution for the presupernova model $R600M23Ni005E20$ are shown in Fig. 4. The SN explosion was simulated by the release of $E_{\text{exp}} = 2 \times 10^{51}$ erg = 2 foe in the form of a “thermal bomb” in the innermost region of the ejecta. The parameters of the model $R600M23Ni005E20$ are $R = 600R_\odot, M = 23M_\odot, M_{\text{Ni}} = 0.05M_\odot$.

We found that the light curves of SN 2017eaw are better reproduced with the supernova model $R600M23Ni005E20$. (Fig. 5). The model $R1100M15Ni005E9$ has longer interval between explosion and maximum light, which does not agree with the observations (Fig. 6).

This is a preliminary result, which requires further investigation when more information is available, in particular on the rate of expansion of the supernova envelope. But it is remarkable that the our simulation results are in good agreement with the results of independent calculations of Utrobin and Chugai (2009) for SN 2004et, which earlier exploded in the same galaxy.
Figure 2: The light curves of SN 2017eaw in the $UBVRI$ bands. The error bars are plotted only when they exceed the size of a symbol. The dashed lines show the light curves of SN 2004et. The curves are shifted for clarity, the amount of shift is indicated on the plot.
Figure 3: The colour curves of SNe 2017eaw, the dashed lines show the colour curves for SN 2004et
Figure 4: The density and the elements distribution in the presupernova for the model R600M23Ni005E20
Figure 5: \textit{UBVRI} light curves of SN\,2017eaw for the model R600M23Ni005E20. Time from the explosion is along the horizontal axis.
Conclusions

We present the light and colour curves of SN 2017eaw. Our observations started immediately after discovery, and we detected the rising part of the light curves. The photometric evolution was followed through the plateau stage and to the linear tail. We determined the basic parameters of the light curves and estimated the maximum absolute magnitudes. The shape of the light curves and maximum luminosity of SN 2017eaw are typical for NGC 6946.

Figure 6: UBVRI light curves of SN 2017eaw for the model R1100M15Ni005E9
the class II-P. We compared the light curves of SN 2017eaw with those for SN 2004et which exploded in the same galaxy and also belonged to the type II-P. Two objects have very similar photometric evolution and we supposed that interstellar reddening for them is nearly equal.

We present preliminary results of model calculation using the multi-group radiation-hydrodynamics numerical code STELLA.

We continue the observations of SN 2017eaw, the results and more detailed analysis of the data will be presented in a subsequent paper.

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