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Light Curves of the Type II-P Supernova SN 2017eaw: The First 200 Days

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Abstract—We present the results of our *UBVRI* photometry for the type II-P supernova SN 2017eaw in NGC 6946 obtained from May 14 to December 7, 2017, at several telescopes, including the 2.5-m telescope at the Caucasus High-Altitude Observatory of the SAI MSU. The dates and magnitudes at maximum light and the light-curve parameters have been determined. The color evolution, extinction, and peak luminosity of SN 2017eaw are discussed. The results of our preliminary radiation—gasdynamic simulations of its light curves with the STELLA code describe satisfactorily the *UBVRI* observational data.

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INTRODUCTION

Type II-P supernovae (SNe II-P) are characterized by the presence of strong hydrogen lines in the spectrum and the shape of their light curves: the luminosity remains almost constant over 80–120 days. Observations of presupernovae show that red supergiants with initial masses from 8 to $\sim$17 $M_\odot$ flare up as SNe II-P (Smartt et al. 2009). SNe II-P can be used as "standard candles" for cosmological studies (see, e.g., Poznanski et al. 2009). Therefore, a detailed study of the presupernova parameters and explosion physics is of great interest.

SN 2017eaw was discovered by Patrick Wiggins on May 14, 2017, its brightness was $12\overset{m}{.}8$ (Dong and Stanek 2017). The SN coordinates are: $\alpha = 20^{\mathrm{h}}34^{\mathrm{m}}44\overset{\mathrm{s}}{.}238$ and $\delta = +60°11'36\overset{''}{.}00$; the distance from the center of NGC 6946 is $61\overset{''}{.}0$ to the west and $143\overset{''}{.}0$ to the north (Sarneczky et al. 2017).

The new object was classified by Cheng et al. (2017) and Tomasella et al. (2017) as a young SN II.

In this paper we present the results of our optical monitoring of SN 2017eaw at six observatories. The observations were begun on the ascending branch of the light curves; we managed to construct a detailed light curve, including the brightness rise, the plateau, and the final linear segment. We performed preliminary simulations of its light curves using the STELLA multigroup radiation—gasdynamic numerical code.

OBSERVATIONS

Our photometric observations of SN 2017eaw were begun on May 14, 2017, immediately after its discovery. Its CCD images in the *UBVRI* bands were obtained at six observatories with ten telescopes. The following telescopes were used for our observations: the 2.5-m telescope at the Caucasus High-Altitude Observatory of the SAI (C250; see Potanin

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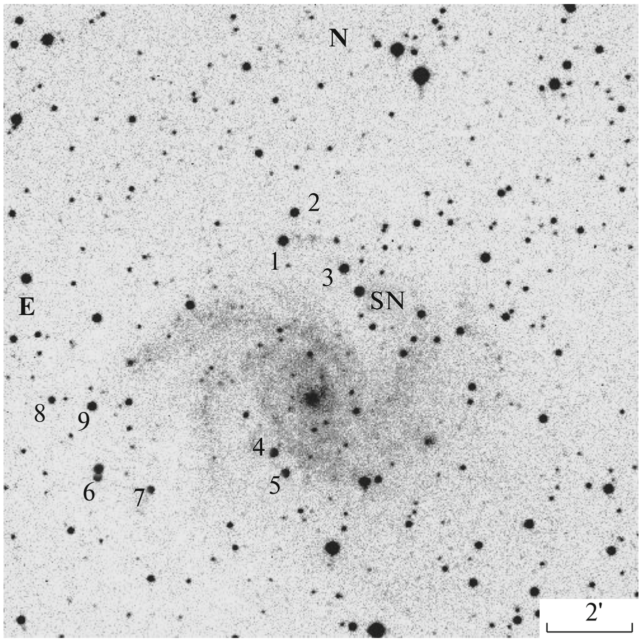

Fig. 1. Image of SN 2017eaw and comparison stars.

et al. 2017; Kornilov et al. 2014); the 1- and 0.6-m telescopes at the Simeiz station of the Crimean Astrophysical Observatory (S100, S60); the 0.7-m reflector at the Crimean Astrophysical Observatory (Cr70); the 0.6-m telescope at the Crimean astronomical station of the SAI (Cr60); the 0.7- and 0.2-m telescopes of the SAI in Moscow (M70, M20); the 0.6- and 0.18-m telescopes at the Stará Lesná Observatory of the Astronomical Institute of the Academy of Sciences of Slovakia (T60, T18); and the 0.4-m telescope of the Astronomical Institute of the St. Petersburg State University (P40).

All telescopes were equipped with CCD cameras and sets of Johnson–Cousins *UBVRI* filters.

The standard reduction and photometry were performed with the IRAF[1] software package. The SN magnitudes were obtained from aperture or PSF photometry relative to local standards. Figure 1 shows a CCD image of SN 2017eaw and local comparison stars. The magnitudes of stars 4 and 5 were taken from Botticella et al. (2009); stars 6–9 were measured by Misra et al. (2007). Some telescopes (M70, S60) had a small field of view, about 6′, and it was possible to measure only stars 1–3 with them. They were calibrated relative to stars 4–9 on frames with a large field of view. The surface brightness of the galaxy at the SN location is low; the subtraction of galaxy's background is not required.

[1] IRAF is distributed by NOAO operated by AURA under agreement with the NSF.

We reduced our photometry to the standard Johnson–Cousins system using the instrumental color equations derived from observations of photometric standards. The photometry is presented in Table 1.

LIGHT AND COLOR CURVES

The light curves of SN 2017eaw are shown in Fig. 2. The results for all telescopes agree satisfactorily. The light curves are typical for SNe II-P; the plateau lasts for about 100 days. Our first observations were made on the ascending branch, and we can reliably determine the date of maximum light, JD 2457892.5, and the peak brightness: $U = 12.5$, $B = 13.22$, $V = 12.87$, $R = 12.54$, $I = 12.18$.

The rapid brightness decline after the plateau began near JD 2457980; the linear segment of the light curve began on JD 2458810, at $B = 17.3$, $V = 15.5$, $R = 14.5$, and $I = 13.8$. The brightness decline rate on the linear segment was 0.0054, 0.0106, 0.0092, and 0.0090 mag day^{-1} in the B, V, R, and I bands, respectively.

The light curves of SN 2004et, which flared up in the same galaxy and also belonged to SNe II-P, are plotted in Fig. 1 for comparison. We shifted the light curves for SN 2004et only in time, taking JD 2453270.5 as the explosion date for SN 2004et (Maguire et al. 2010) and JD 2457884 as the explosion date for SN 2017eaw (Tomasella et al. 2017). The light-curve shapes are virtually identical, SN 2004et is brighter on the plateau approximately by $0^m.3$ in the B, V, R, and I bands. However, the difference between the two SNe is insignificant on the linear segment.

The color curves of SNe 2004et and 2017eaw are compared in Fig. 3. The similarity of the light curves is obvious; slight differences can be noticed only for the $R - I$ color. We can assume that the interstellar extinction for these SNe is also almost the same.

Maguire et al. (2010) estimated the reddening of SN 2004et from the intensity of interstellar Na I lines to be $E(B - V) = 0.41$. Using the same method, Tomasella et al. (2017) estimated $E(B - V) = 0.22$ for SN 2017eaw. The Galactic extinction toward NGC 6946 is $E(B - V) = 0.30$ (Schlafly and Finkbeiner 2011). We assume that the extinction for both SNe is approximately the same and occurs only in the Galaxy. The difference in the estimates based on the equivalent widths of Na I lines may stem from the fact that the accuracy of this method is not very high. Both SNe flared up quite far from the center of the galaxy NGC 6946, in a region of low surface brightness; therefore, a strong extinction in NGC 6946 is unlikely.

Table 1. *UBVRI* photometry for SN 2017eaw

JD 2450000	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Telescope
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	Cr60
7901.45	12.94	0.01			12.99	0.01	12.58	0.01	12.26	0.01	C250
7901.48	12.82	0.10	13.37	0.03	13.00	0.01	12.57	0.03	12.23	0.03	Cr60
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	C250
7905.49	13.22	0.06	13.52	0.02	13.02	0.02	12.58	0.02	12.24	0.03	Cr60
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	Cr70
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	Cr70
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
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	15.25	0.05	14.42	0.03	13.23	0.02	12.71	0.02	12.24	0.02	T60
7940.32			14.52	0.02	13.27	0.02	12.71	0.02	12.22	0.02	S100
7942.40			14.56	0.02	13.28	0.01	12.72	0.02	12.23	0.02	S100
7942.42			14.47	0.04	13.26	0.03	12.69	0.04	12.20	0.05	Cr70
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	Cr70
7960.50	16.14	0.05	14.75	0.02	13.33	0.02	12.71	0.02	12.21	0.02	T60
7966.33					13.38	0.02	12.73	0.02	12.21	0.03	M20
7967.56	16.31	0.04	14.82	0.02	13.37	0.02	12.73	0.02	12.23	0.02	T60
7972.28			14.92	0.02	13.41	0.02	12.79	0.03	12.22	0.06	S100
7975.57			14.90	0.05	13.43	0.02	12.79	0.03			S60
7978.50			15.05	0.02	13.51	0.01	12.80	0.02	12.27	0.03	S100
7980.47			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	16.91	0.05	15.16	0.02	13.59	0.01	12.88	0.02	12.34	0.02	T60
7985.54			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	17.24	0.07	15.45	0.04	13.81	0.01	13.05	0.02	12.49	0.02	T60

Table 1. (Contd.)

JD 2450000	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Telescope
7991.38			15.44	0.02	13.86	0.01	13.09	0.02	12.52	0.03	Cr60
7992.49			15.48	0.02	13.88	0.01	13.11	0.02	12.53	0.02	Cr60
7992.58			15.54	0.04	13.88	0.01	13.11	0.01	12.51	0.03	S60
7993.53			15.53	0.02	13.94	0.02	13.13	0.02	12.55	0.02	Cr60
7994.46			15.60	0.03	13.99	0.01	13.18	0.02	12.60	0.02	Cr60
7995.37					13.99	0.02	13.22	0.03	12.61	0.03	P40
7995.45	17.69	0.06	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
7998.36			15.81	0.03	14.14	0.02	13.34	0.02	12.81	0.03	P40
7999.44			15.84	0.05	14.14	0.05			12.87	0.06	Cr70
8001.55							13.53	0.02	12.97	0.03	P40
8004.29			16.48	0.02	14.77	0.01	13.80	0.02	13.14	0.02	Cr60
8005.37			16.61	0.02	14.90	0.01	13.93	0.02	13.25	0.02	Cr60
8006.32			16.75	0.02	15.03	0.01	14.03	0.02	13.34	0.02	Cr60
8007.26			16.88	0.03	15.15	0.01	14.14	0.02	13.45	0.02	Cr60
8008.30			17.06	0.03	15.28	0.01	14.26	0.02	13.57	0.03	Cr60
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	Cr60
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			Cr70
8011.44			17.22	0.04	15.43	0.08	14.37	0.03	13.79	0.04	Cr70
8013.43					15.45	0.05	14.45	0.02			Cr70
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							14.61	0.02	13.97	0.03	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	Cr70
8027.35			17.51	0.10	15.72	0.06	14.65	0.05	13.94	0.04	Cr70
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	Cr70
8040.36							14.80	0.02	14.20	0.03	P40
8044.15					15.82	0.09	14.78	0.04	14.16	0.04	M70
8049.40							14.85	0.02	14.23	0.03	P40
8052.30			17.74	0.05	16.00	0.02	14.91	0.02	14.23	0.03	T60
8059.47							14.94	0.02	14.34	0.03	P40
8061.15			17.72	0.05	16.16	0.03	15.03	0.04	14.37	0.04	Cr60
8063.14			17.81	0.03	16.18	0.01	15.04	0.02	14.34	0.02	Cr60
8074.22					16.31	0.02	15.12	0.03			Cr60
8075.27			17.81	0.04	16.33	0.02	15.15	0.02	14.45	0.02	Cr60
8076.20			17.87	0.03	16.34	0.02	15.16	0.02	14.47	0.02	Cr60
8095.22			18.03	0.04	16.43	0.02	15.32	0.02	14.60	0.02	T60

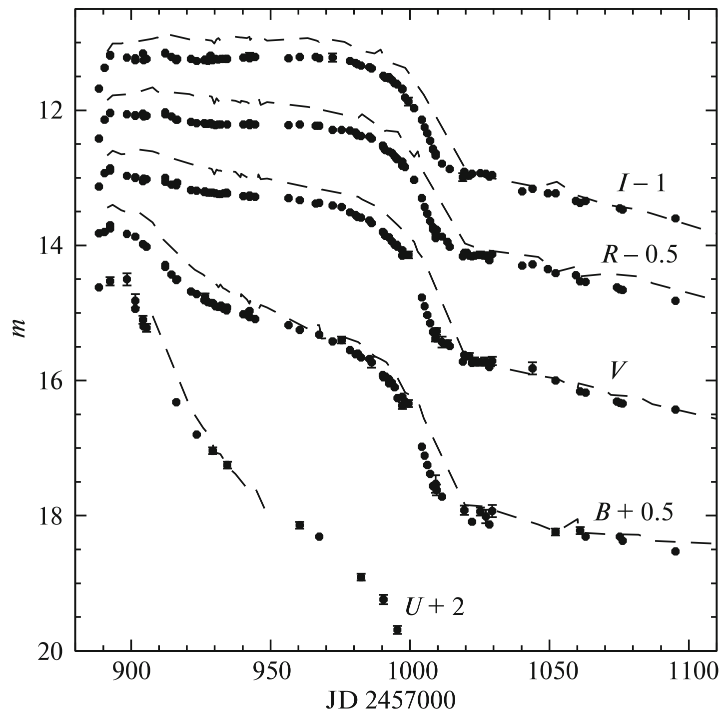

Fig. 2. *UBVRI* light curves of SN 2017eaw. The dashed lines are the light curves of SN 2004et.

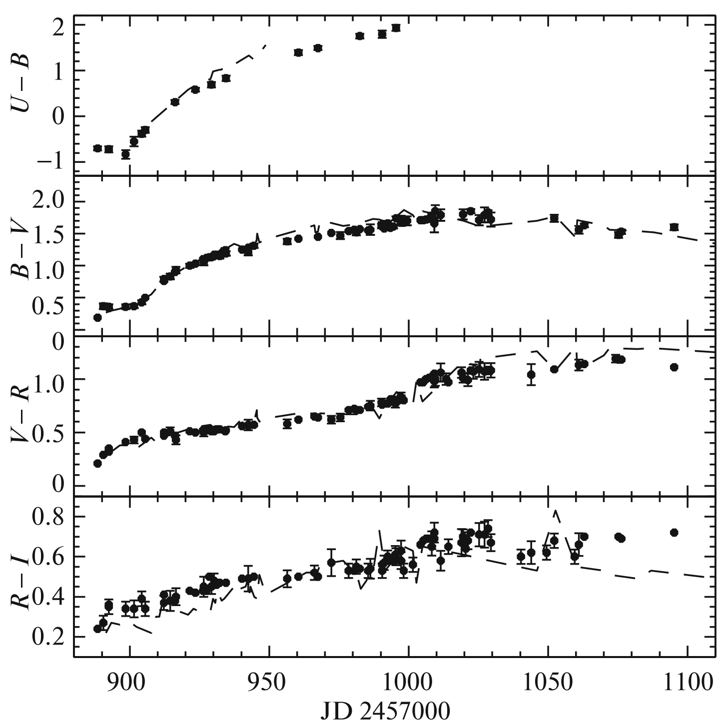

Fig. 3. Color curves of SN 2017eaw. The dashed lines are the color curves of SN 2004et.

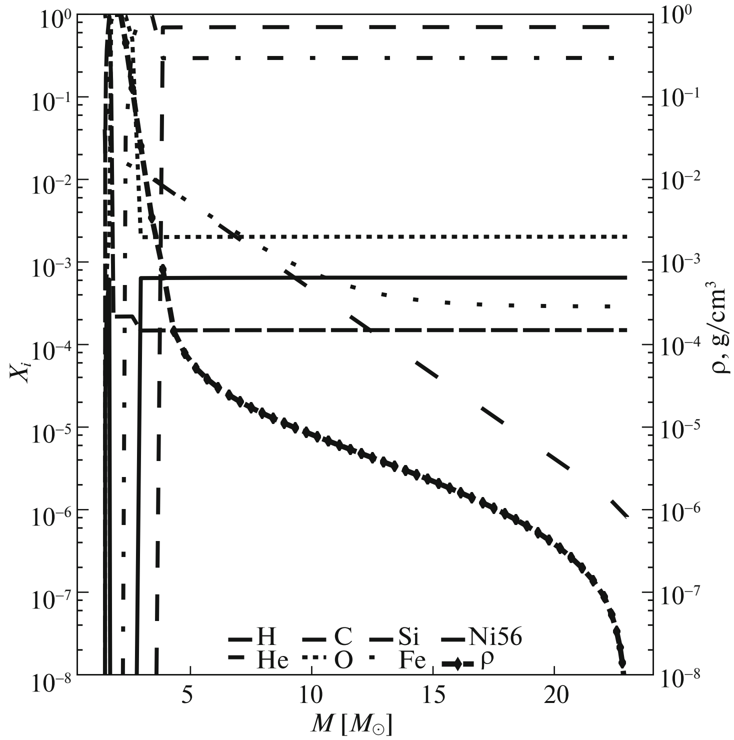

Fig. 4. Density and chemical composition distributions for the R600M23Ni005E20 model.

Taking a distance of 6.0 Mpc for NGC 6946 (Efremov et al. 2011) and reddening $E(B-V) = 0.30$, we can estimate the absolute magnitudes of SN 2017eaw at maximum light: $M_U = -17.9$, $M_B = -16.9$, $M_V = -17.0$, $M_R = -17.1$, and $M_I = -17.2$.

M_B is slightly higher than the mean absolute magnitude for SNe II-P, $M_B = -16.75$ (Richardson et al. 2014).

LIGHT CURVE SIMULATIONS

The shape of the light curves shows that SN 2017eaw is a normal SN II-P, and the presupernova was a red supergiant (RSG). SNe II-P exhibit a great variety of luminosities and light-curve shapes. The main features of the light curves are determined by the initial radius R, the total presupernova mass M, the ^{56}Ni mass, and the explosion energy E (Litvinova and Nadyozhin 1985; Kasen and Woosley 2009).

In our search for the best model we computed a grid of models in (R, M, ^{56}Ni, E) parameter space.

For our computations we used the STELLA multigroup radiation—gasdynamic code (Blinnikov et al. 1998, 2000, 2006).

The presupernova models were constructed by assuming a nonevolutionary hydrostatic equilibrium, as described previously (Baklanov et al. 2005). The shock passage causes a strong mixing in the envelope due to the Rayleigh—Taylor instability. The amount and distribution of ^{56}Ni were adjusted manually to reconcile its radial distribution with the real one. The density and composition distributions for the R600M23Ni005E20 model are shown in Fig. 4.

The SN explosion was simulated by the release of $E_{\rm exp} = 2 \times 10^{51}$ erg $= 2$ foe in the form of a "thermal bomb" in the inner ejecta. The parameters of the R600M23Ni005E20 model are $R = 600\ R_\odot$, $M = 23\ M_\odot$, and $M_{\rm Ni} = 0.05\ M_\odot$, the explosion date is JD 2457878.

We established that the light curves of SN 2017eaw were best represented by the R600M23Ni005E20 model (Fig. 5). The interval between the explosion and peak brightness for the R1100M15Ni005E9 model is larger, which is inconsistent with the observations (Fig. 6).

It should be noted that the photometric data alone do not allow the most adequate model to be chosen uniquely; spectroscopic studies are also needed. However, even our preliminary results allow useful estimates of the main presupernova and SN explosion

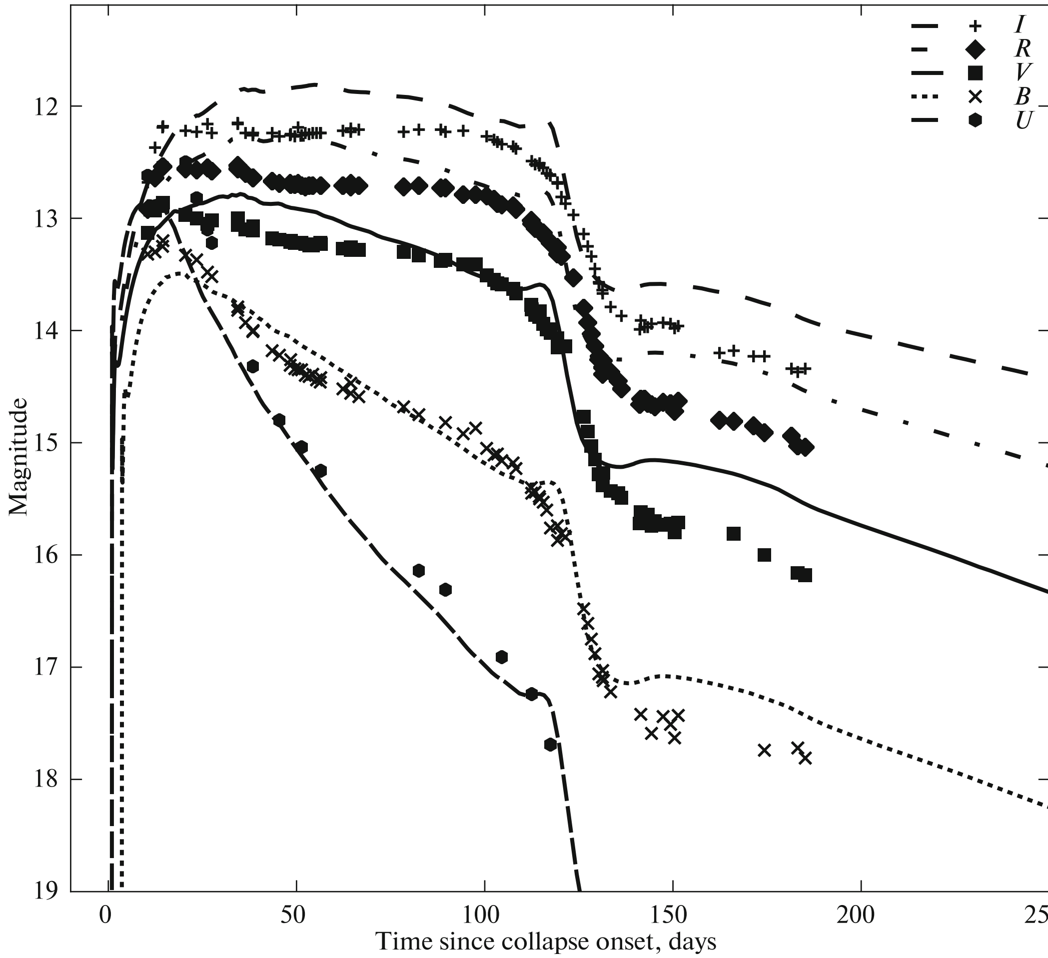

Fig. 5. *UBVRI* light curves of SN 2017eaw for the R600M23Ni005E20 model. The dots are the observations; the lines are the results of our simulations.

parameters to be obtained. The results of our computations agree with the independent results from Utrobin and Chugai (2009) for SN 2004et, which is very similar to SN 2017eaw.

CONCLUSIONS

We presented the light and color curves of SN 2017eaw. Our observations were begun immediately after its discovery, and the ascending branch of its light curves was recorded. The photometric evolution was traced at the plateau stage and until the linear brightness decline. We determined the main light-curve parameters and estimated the luminosity at maximum light. The light-curve shape and peak luminosity of SN 2017eaw are typical of SNe II-P.

We compared the light curves of SN 2017eaw and SN 2004et, which flared up in the same galaxy and belonged to the same type. The two objects have a similar photometric evolution; it can be assumed that the interstellar extinction for them is almost the same.

We presented preliminary results of our light-curve simulations with the STELLA code.

The observations of SN 2017eaw are continued; the results and a more detailed data analysis will be presented in the next paper.

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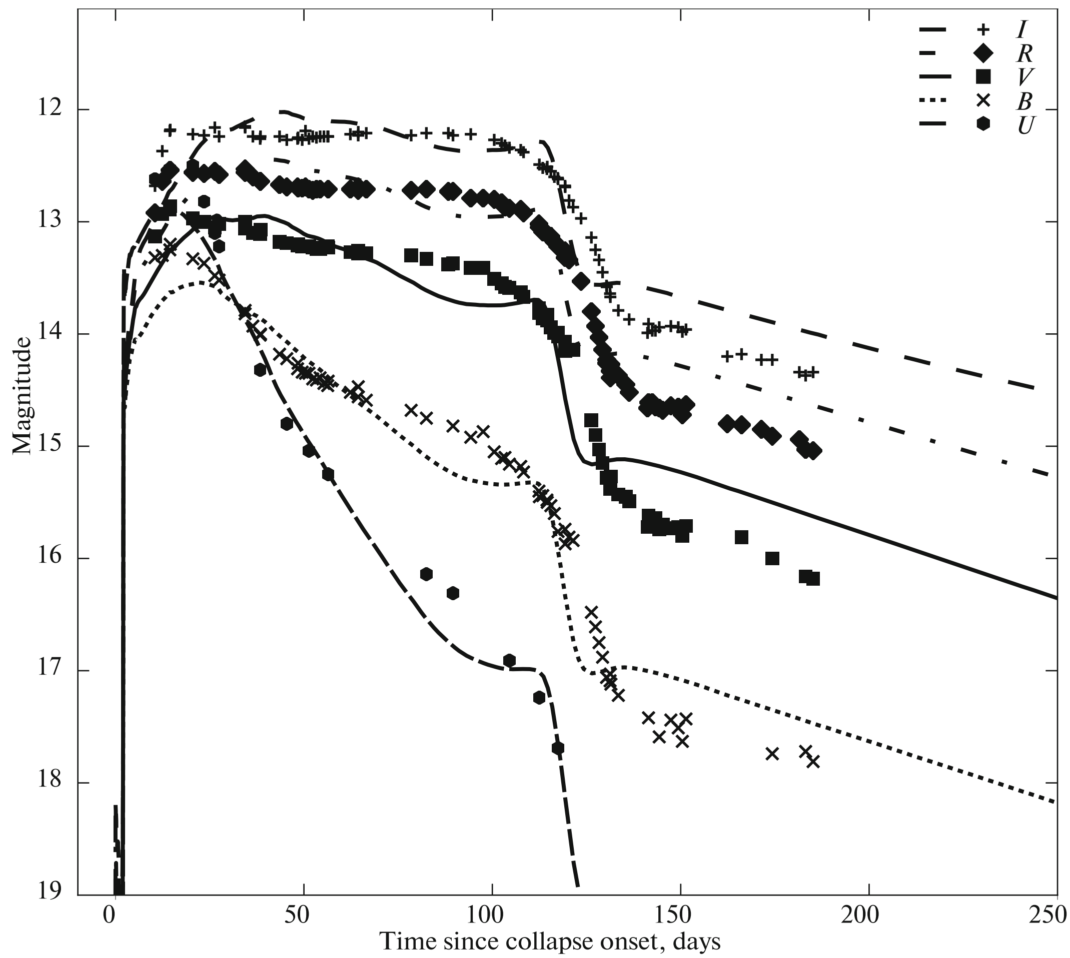

Fig. 6. *UBVRI* light curves of SN 2017eaw for the R1100M15Ni005E9 model.

the Moscow State University. Some of the observations were performed with the Zeiss-1000 telescope at the Simeiz station of the Crimean Astrophysical Observatory, which belongs to the Institute of Astronomy of the Russian Academy of Sciences. We thank I.V. Nikolenko, T.S. Grishina, S.S. Savchenko, E.G. Larionova, E.N. Kopatskaya, G.A. Borman, and A.A. Vasil'eva who participated in the observations and helped perform them.

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