IRSTI 41.23.29

SN2017ein: bolometric light curve and physical parameters

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Apparent stellar magnitudes observed at Maidanak observatory for SN2017ein – peculiarly faint core-collapse supernova rumored to have images of progenitor – are processed to get exact photometric data. Technique of photometry is described and the data itself is presented. Based on photometric data of B and R bands we used the regressional equation proposed by Lyman and Bersier to reconstruct the quasi-bolometric light curve. Reconstructed light curve has a peak luminosity of $\sim 3.3 \cdot 10^{41}$erg/s which is almost an order of magnitude lower than typical values for such supernovae. Further, we used reconstructed bolometric values to estimate physical parameters using simple one-component models for photospheric and nebular phases. Fitting the models to reconstructed quasi-bolometric light curve allows us to estimate physical parameters. Such estimation yields $0.037 M_{\odot}$ for nickel-56 mass, $1.246 M_{\odot}$ for ejected mass and $1.641 \cdot 10^{51}$ erg for final kinetic energy of ejecta. Ejecta mass looks very small for proposed progenitor candidate, but some explanations for such discrepancy are already proposed.

Key words: supernova, light curve, curve fitting, stripped-envelope, core-collapse.
PACS number(s): 97.60.Bw, 02.60.Ed

1 Introduction

Obtaining the data by observing supernovae is the main method of fact-checking theoretical models of stellar explosions and generation of heavy elements. Moreover, such data are also used to estimate progenitor parameters to check and clarify our theories of stellar evolution.

To determine physical parameters of explosion and progenitor we need detailed photometric and spectroscopical data, which are not always accessible. However, some methods exist, that allow to estimate SN parameters by using well-studied SNe as templates or using simple empirical models of light curves [1, 2].

In this paper, we used the second approach to estimate progenitor parameters of supernova SN2017ein. Possible progenitor candidate for SN2017ein has been reported to be found on pre-explosion images by Van Dyk et al. [13], which gives some opportunity to check and compare modelling results with observation data.

In Section 2 we describe observation technique and present photometric data obtained on Maidanak astronomical observatory.

Section 3 is dedicated to data processing. Methods of quasi-bolometric light curve reconstruction and fitting to the simple light-curve model are described and results are presented.

In Section 4 we discuss the results and outline further research direction.

2 Observations

The observations of SN 2017ein with the 1.5 m AZT-22 Telescope at the Maidanak Astronomical Observatory (MAO) [3], Uzbekistan, began on 2017 May 25 and the last image was obtained on 2017 July 31. The AZT-22 instrument equipped with a FLI MicroLine 3k×3k CCD was used. A field of view of CCD is 13 arcmin×13 arcmin at 0.215 arcsec/pixel. More details on the telescope and the instrument may be obtained from http://www.maidanak.uz.

The Maidanak astronomical observatory (MAO) of the UBAI has a high quality astroclimate – about 90% of possible clear night time in summer with median seeing 0.69 arcsec [4]. Coupled with its location, MAO is very attractive for being involved in observation programs requiring uninterrupted monitoring of celestial objects.

The supernova SN 2017ein was discovered by Ron Arbour on UTC 23:46 May 25, 2017, in the nearby galaxy NGC 3938. The object was observed (pre-discovery) on UTC 18:29 May 25 at Maidanak observatory [5]. Optical spectra obtained by Xiang et al. [15] on May 26 have indicated the supernova to be of Type Ic, about one week before maximum.

Table 1 – Photometry of SN2017ein

JD	B mag	m_B err	R mag	m_R err	V mag	m_V err	I mag	m_I err
2457899,27	18,432	0,073	17,717	0,025	-	-	-	-
2457901,25	17,719	0,030	16,651	0,011	17,003	0,014	-	-
2457902,23	17,368	0,027	16,345	0,010	16,713	0,012	-	-
2457903,28	17,028	0,089	16,068	0,029	16,154	0,013	-	-
2457904,24	16,724	0,026	15,831	0,009	15,960	0,014	-	-
2457905,24	16,479	0,023	15,604	0,009	15,655	0,008	-	-
2457906,26	16,196	0,016	15,338	0,006	15,314	0,009	-	-
2457909,25	15,939	0,018	15,024	0,008	15,298	0,007	-	-
2457910,25	15,930	0,013	14,946	0,005	15,241	0,007	-	-
2457911,25	15,900	0,013	14,907	0,006	15,200	0,005	-	-
2457912,23	15,890	0,011	14,816	0,005	15,189	0,007	-	-
2457913,21	15,969	0,014	14,812	0,005	15,207	0,007	-	-
2457914,23	16,059	0,015	14,830	0,005	15,238	0,007	-	-
2457915,23	16,082	0,015	14,784	0,005	15,350	0,006	-	-
2457916,22	16,175	0,015	14,779	0,005	15,369	0,024	-	-
2457917,22	16,318	0,013	14,857	0,005	15,347	0,008	-	-
2457918,21	16,379	0,012	14,846	0,004	15,486	0,007	-	-
2457919,21	16,430	0,023	14,863	0,007	15,554	0,008	-	-
2457920,21	16,600	0,016	14,937	0,005	15,665	0,009	-	-
2457921,24	16,702	0,019	14,993	0,005	15,751	0,010	-	-
2457922,20	16,833	0,023	15,082	0,005	15,889	0,014	-	-
2457923,20	16,954	0,030	15,158	0,007	15,890	0,009	-	-
2457925,19	17,132	0,028	15,233	0,006	16,044	0,009	-	-
2457926,21	17,291	0,028	15,384	0,006	16,215	0,035	-	-
2457927,23	17,310	0,040	15,425	0,018	16,298	0,014	-	-
2457929,23	17,394	0,131	15,574	0,024	16,435	0,021	-	-
2457930,20	17,526	0,048	15,603	0,009	16,604	0,018	-	-
2457932,19	17,673	0,079	15,736	0,013	16,683	0,014	-	-
2457933,24	17,832	0,050	15,905	0,010	16,725	0,015	-	-
2457934,20	17,935	0,046	15,981	0,009	16,828	0,014	-	-
2457935,19	17,967	0,049	16,048	0,009	16,736	0,020	-	-
2457937,21	18,015	0,066	16,133	0,008	16,864	0,016	15.408	0.007
2457938,21	18,018	0,060	16,094	0,012	16,935	0,017	15.462	0.009
2457939,22	18,128	0,057	16,196	0,010	16,981	0,018	15.507	0.009
2457941,19	18,219	0,062	16,251	0,010	16,958	0,023	15.535	0.008
2457942,21	18,166	0,091	16,304	0,010	17,006	0,036	15.538	0.009
2457943,22	17,969	0,130	16,313	0,013	17,048	0,065	15.623	0.019
2457946,18	18,213	0,247	16,386	0,027	17,110	0,020	15.631	0.019
2457947,22	18,261	0,082	16,409	0,033	17,081	0,027	15.658	0.010
2457950,18	18,266	0,111	16,473	0,014	17,186	0,023	15.649	0.012
2457951,19	18,345	0,087	16,450	0,015	17,192	0,041	15.748	0.010
2457952,19	18,352	0,167	16,547	0,013	17,242	0,023	15.749	0.018
2457953,18	18,378	0,081	16,557	0,024	17,275	0,028	15.770	0.011
2457954,17	18,357	0,106	16,599	0,015	17,319	0,042	15.831	0.013
2457956,18	18,364	0,153	16,648	0,015	17,254	0,031	15.833	0.017
2457957,19	18,559	0,146	16,652	0,022	17,390	0,023	15.839	0.011
2457958,17	18,463	0,085	16,674	0,016	17,279	0,035	15.891	0.010
2457959,18	18,442	0,146	16,734	0,014	17,360	0,053	15.878	0.017
2457961,18	18,391	0,175	16,740	0,023	17,368	0,028	15.906	0.019
2457964,17	18,527	0,128	16,775	0,032	17,411	0,037	15.921	0.013
2457965,16	18,590	0,164	16,761	0,019	-	-	16.038	0.015
2457966,16	-	-	16,849	0,021	-	-	-	-

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 comparison stars [11]. Photometry of the SN 2017ein is presented in Table 1.

3 Data processing

3.1 Bolometric light curve reconstruction.

In order to reconstruct bolometric light curve from B and R band magnitudes we adopted the technique described by Lyman et al. [8]. As stated in subsection 4.5 of [8], bolometric correction for B band magnitude ($\mathrm{BC}_B = \mathrm{M}_{\mathrm{bol}} - M_B$) can be calculated as:

$$BC_B = c_0 + c_1(B - R) + c_2(B - R)^2 \qquad (1)$$

where coefficients c_0, c_1, c_2 depend on the type of supernova. Based on spectral classification by Xiang et al. [15] we choose values for core-collapse supernovae $c_0 = -0.029$, $c_1 = -0.302$, $c_2 = -0.22$ (refer to Table 2 of [8]).

Resulting bolometric light curve is graphed on Figure 2 along with R and B band luminosities. It is really quite faint as stated by Xiang et al. [15] with maximum luminosity reaching □$3.3\cdot 10^{41}$ erg/s. Light curve is broad, maximum is reached on day 16.

3.2. Estimating physical parameters

To obtain estimates on physical parameters of SN we use Arnett's [2] model for photospheric phase ($t \leq 30$days) and model by Sutherland, Wheeler [10] for nebular phase ($t \geq 60$ days) . Similar approach was applied for SN2003jd by Valenti et al. [12], however they applied the models separately for each part. In our case, both phases were fitted simultaniously.

Following assumptions are made for photospheric phase:

- expansion of ejecta is homologous and spherically symmetric;
- optical opacity is constant;
- initial radius is small;
- ejecta is optically thick (so diffusion approximation is used for photons).

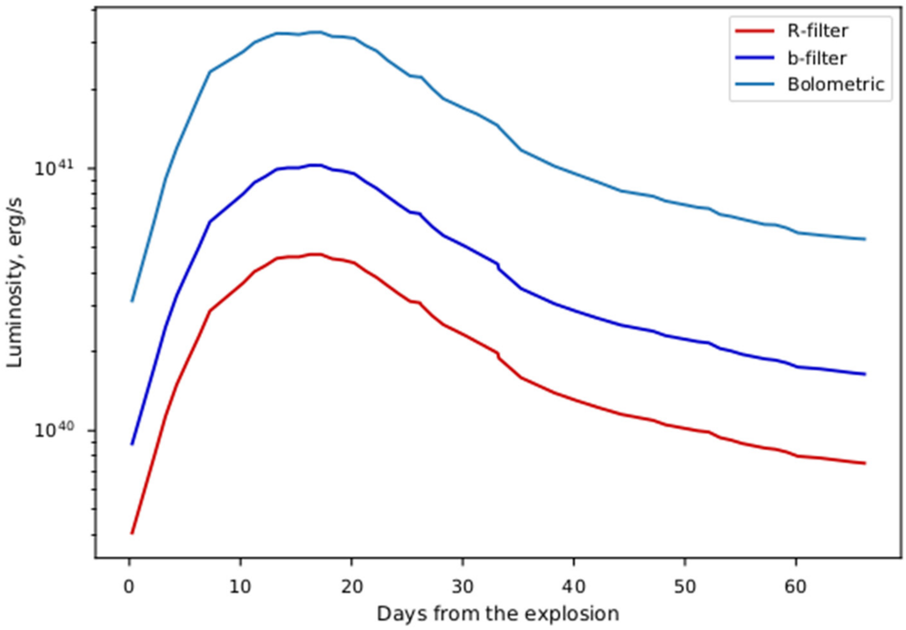

Figure 1 – R, B and bolometric light curves of SN2017ein

Main difference from Arnett's proposal is that both 56 Ni and 56 Co are counted towards energy emission, as proposed by Valenti et al. [12].

For late stages of light curve (nebular phase) the energy output is mediated by 56 Ni → 56 Co → 56 Fe radioactive decay [10]. Gamma-radiation from Ni and Co decay was taken into account, as well as gamma-radiation from electron-positron annihilation and kinetic energy of positrons. For detailed explanation one may refer Sutherland and Wheeler [10] and Appendix of [12].

Main reason for simultaneous fitting of both phases was lack of observational data for nebular phase: there are very few points in that part of the curve, which may cause very large errors if fitted separately.

Estimates obtained from fitting are $M_{\text{Ni}} = 0.037M_{\odot}$,$M_{\text{ej}} = 1.246M_{\odot}$ and $Ek = 1.641 \cdot 10^{51}$ erg.

Best-fit model curve along with observation data is presented on Figure 2.

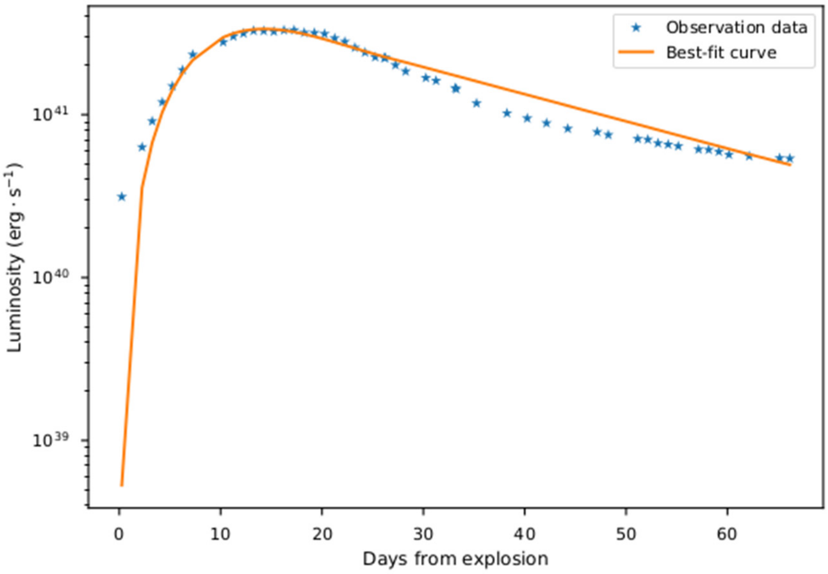

Figure 2 – Fitting the bolometric light curve of SN2017ein

4 Conclusions

Bolometric light curve reconstructed from B-R magnitudes is faint - maximum luminosity is about $3.3 \cdot 10^{41}$ erg/s. Simultaneous fitting of models proposed by Arnett (for photospheric phase) and Sutherland and Wheeler (for nebular phase) yields the$M_{\text{Ni}} = 0.037M_{\odot}$,$M_{\text{ej}} = 1.246M_{\odot}$, and$Ek = 1.641 \cdot 10^{51}$ erg which indicate a low-mass progenitor. However, this contradicts the report about progenitor candidate [13]. As stated in the report, possible progenitor had absolute magnitudes of $M_V \sim -6.4$ and $M_I \sim -6.3$ which are characteristic for giant stars with several tens of solar masses. However, according to Xiang et al. [15] low luminosity of SN might be caused by significant host-galaxy extinction, and the same cause may lead to underestimation of parameters. Further examination of observational data is needed to make a final decision. Hydrodynamic modeling of light curve [6, 7, 8, 14] is planned to further clarify the case.

Acknowledgements

The idea for the study was hinted at by Viktoriya Morozova of Princeton University.

Data for the analysis was obtained at Maidanak observatory. We express our gratitude to technical staff of observatory for the data and to acad. Shukhrat Ehgamberdiev for permission to use the data.

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