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The Light Curves of Two Type II-P Supernovae: 2012ch and 2012fs

D. Yu. Tsvetkov[1], N. N. Pavlyuk[1], P. V. Baklanov[1,2,3], V. M. Lipunov[1]

[1] M.V.Lomonosov Moscow State University, Sternberg Astronomical Institute, Universitetskii pr.13, 119234 Moscow, Russia

[2] National Research Center "Kurchatov Institute", 123182 Moscow, Russia

[3] Lebedev Physical Institute, Russian Academy of Sciences, 119333 Moscow, Russia

Abstract

Photometric observations of SNe 2012ch and 2012fs show light curves characteristic of type II-P Supernovae. The interstellar extinction for both SNe was estimated by comparison of their color curves with those for well-studied SNe II-P. The absolute magnitudes at the plateau stage are $M_R = -17\overset{m}{.}1$ for SN 2012ch and $M_R = -16\overset{m}{.}9$ for SN 2012fs, which is close to mean values for the objects of this class. We performed modeling of the light curves of SN 2012ch with the STELLA code, the optimal model has the following parameters: total mass $19M_\odot$, radius $900R_\odot$, explosion energy 1.5×10^{51} erg, mass of ^{56}Ni $0.07M_\odot$.

1 Introduction

Type II Supernovae are the result of explosions of massive stars ($M >\sim 8M_\odot$) that retained their hydrogen envelopes (e.g. Smartt et al. 2009). Among these objects, the most frequent ones are type II-P SNe, which have nearly constant brightness for a time interval of $\sim$ 100 days after maximum (Anderson et al. 2014, Smith et al. 2011). The length of the plateau phase and luminosity at the plateau exhibit significant diversity, which is related to the physical parameters of the exploding stars (e.g. Litvinova and Nadezhin 1985). It is important to expand the sample of well-studied type II SNe also because SNe II have been established as useful independent distance indicators (Hamuy & Pinto 2002).

We present photometry of two type II-P SNe: SN 2012ch and SN 2012fs, for which very few data have been reported, although they were quite bright at maximum.

SN 2012ch was discovered in unfiltered Catalina Sky Survey (CSS) images obtained on May 17.38 UT. The position of the transient was $\alpha = 15^h06^m02^s.54$, $\delta = +41^\circ25'32''.7$ (J2000); the offset from the center of the host galaxy was $1''\!.0$ West, $2''\!.1$ South, and its brightness, $16\overset{m}{.}4$ (Drake et al. 2012). A spectrum of the object was obtained on May 18 with the F.L. Whipple Observatory's 1.5-m telescope, it showed that the object was a type II-P supernova before maximum light. A good fit was found to the spectra of SN II-P 1999em at 4 days before maximum, and the velocity of Hα absorption was measured as 14200 km s^{-1} (Marion 2012). The host galaxy is WISEA J150602.64+412535.3 at $z = 0.008608$, according to the NASA/IPAC Extragalactic Database (NED)[1].

SN 2012fs was discovered by the Italian Supernovae Search Project (ISSP) at brightness about $16\overset{m}{.}5$ on two unfiltered CCD images, taken with the 0.28-m telescope of the Col Druscié Observatory on Oct. 7.960 UT. The new object was located at $\alpha = 0^h37^m39^s.38, \delta =$

[1] https://ned.ipac.caltech.edu/

Table 1: Magnitudes of local standard stars for SN 2012ch

Star	B	V	R	I
1	15.40 (0.02)	14.77 (0.01)	14.40 (0.01)	14.06 (0.01)
2	15.94 (0.02)	15.31 (0.02)	14.97 (0.02)	14.62 (0.02)
3	17.55 (0.04)	16.35 (0.03)	15.63 (0.02)	15.07 (0.02)
4	16.53 (0.02)	15.22 (0.02)	14.40 (0.03)	13.79 (0.02)
5	17.99 (0.04)	16.98 (0.03)	16.38 (0.03)	15.86 (0.03)

Table 2: Magnitudes of local standard stars for SN 2012fs

Star	B	V	R	I
1	14.51 (0.04)	13.75 (0.01)	13.31 (0.01)	12.93 (0.01)
2	16.11 (0.04)	15.39 (0.02)	14.95 (0.02)	14.56 (0.01)
3	17.76 (0.04)	16.73 (0.02)	16.13 (0.01)	15.64 (0.04)
4	17.61 (0.04)	16.75 (0.01)	16.31 (0.02)	15.81 (0.05)

$+10^\circ 21' 29''.0$ (J2000), which is $6''$ West and $1''$ North of the nucleus of the galaxy IC 35 (Dimai 2012).

An optical spectrum of SN 2012fs, obtained on Oct. 9 with the New Technology Telescope, showed that SN 2012fs was a type II-P supernova, the best fit was to the spectrum of SN 2004et within a few days from explosion (Inserra et al. 2012).

Two spectra of SN 2012fs were presented by Lin et al. (2024), they appear typical of SNe II-P; the explosion date was estimated as JD 2456199 (Sept. 29).

2 Observations and reductions

Photometric CCD observations of SNe 2012ch and 2012fs in the $BVRI$ bands were performed with the 60-cm telescope of the Crimean Astronomical Station of Sternberg Astronomical Institute (SAI CAS).

Images of SN 2012fs were also obtained at the 70-cm telescope in Moscow, SN 2012ch was observed on one epoch at the 50-cm telescope of SAI CAS.

The unfiltered observations with MASTER telescopes (Lipunov et al., 2010) were carried out at Tunka, Amur, and Kislovodsk sites.

The standard image reductions and photometry were made using IRAF[2]. Photometric measurements of the SNe were made relative to local standard stars using PSF fitting with the IRAF DAOPHOT package. The galaxy background was subtracted using images of the host galaxies obtained at the SAI CAS 60-cm telescope two years after discovery of the SNe.

The images of SNe 2012ch and 2012fs and local standard stars are presented in Figs. 1, 2. The stars for SN 2012ch were calibrated using APASS[3] and PanSTARRS[4] databases, the gri magnitides were converted to the Johnson–Cousins $BVRI$ magnitudes using relations from Jester et al. (2005) and Kostov & Bonev (2018).

The comparison stars for SN 2012fs were calibrated using observations of Landolt standards. The magnitudes of local standard stars are reported in Tables 1, 2. The errors are presented in parentheses in both tables.

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

[3]https://www.aavso.org

[4]https://catalogs.mast.stsci.edu/panstarrs/

Table 3: $BVRI$ photometry of SN 2012ch

JD−2456000	B	V	R	I	Tel.
071.17			15.80 (0.05)		M40
076.27			15.73 (0.06)		M40
101.13			15.85 (0.05)		M40
154.36		16.63 (0.04)	16.01 (0.03)		C60
156.29		16.56 (0.04)	16.04 (0.04)		C50
166.32	18.20 (0.10)	16.90 (0.03)	16.21 (0.03)	15.70 (0.07)	C60
167.39		16.97 (0.03)	16.24 (0.03)	15.80 (0.08)	C60
170.25	18.40 (0.10)	16.97 (0.03)	16.30 (0.03)	15.87 (0.06)	C60
171.33		17.06 (0.06)	16.33 (0.03)	15.93 (0.10)	C60
174.34		17.14 (0.03)	16.47 (0.03)		C60
176.33	18.62 (0.17)	17.31 (0.04)	16.54 (0.03)	16.04 (0.07)	C60
177.36		17.32 (0.04)	16.60 (0.03)	16.09 (0.10)	C60

Table 4: $BVRI$ photometry of SN 2012fs

JD−2456000	B	V	R	I	Tel.
206.09			17.48 (0.08)		M40
216.16			17.49 (0.06)		M40
217.26			17.55 (0.04)		M40
236.32	19.10 (0.10)	18.05 (0.04)	17.55 (0.04)	17.27 (0.15)	C60
237.32	19.02 (0.18)	18.08 (0.05)	17.60 (0.06)		C60
240.30	19.15 (0.16)	18.05 (0.04)	17.61 (0.05)	17.37 (0.26)	C60
241.31	19.14 (0.13)	18.06 (0.03)	17.62 (0.03)	17.32 (0.20)	C60
243.32	19.18 (0.14)	18.09 (0.04)	17.60 (0.04)		C60
244.31		18.10 (0.04)	17.60 (0.04)	17.26 (0.15)	C60
245.27		18.05 (0.06)	17.59 (0.04)		C60
249.32	19.42 (0.08)	18.15 (0.06)	17.62 (0.04)	17.40 (0.11)	C60
250.32	19.25 (0.13)	18.06 (0.04)	17.58 (0.04)	17.22 (0.10)	C60
252.27	19.27 (0.13)	18.17 (0.05)	17.66 (0.04)	17.28 (0.10)	C60
254.23	19.28 (0.18)	18.27 (0.06)	17.63 (0.05)	17.16 (0.11)	C60
281.24			17.40 (0.20)		M70

The magnitude estimates of the SNe on unfiltered MASTER images were made using the R-band magnitudes of local standards.

The photometry is presented in Tables 3, 4, the identification of telescopes is given by codes: M70 is the 70-cm reflector in Moscow; M40 are the 40-cm MASTER telescopes; C60 is the 60-cm telescope of the SAI CAS; C50 is the 50-cm telescope of the SAI CAS.

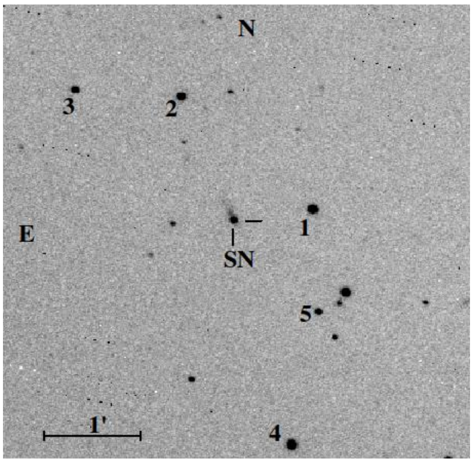

Figure 1.
SN 2012ch and local standard stars.

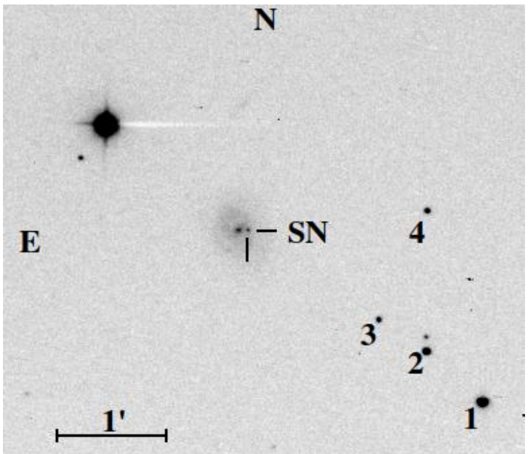

Figure 2.
SN 2012fs and local standard stars.

3 The light and color curves

The light curves for SNe 2012ch and 2012fs are presented in Figs. 3, 4, they appear typical of SNe II-P. For SN 2012ch, the discovery magnitudes and comparison to our early data allow us to conclude that the end of brightness increase and start of the plateau phase occurred at about JD 2456067. The description of the classification spectrum by Marion et al. (2012) and comparison to the data for SN 1999em (Elmhamidi et al. 2003, Leonard et al. 2002) permit us to estimate that the explosion occurred in the time interval

JD 2456054–2456058, assuming that the rise of luminosity was similar for SNe 2012ch and 1999em. The rise time ∼10 days is within the range of this quantity for SNe II-P according to Gall et al. (2015). The data from continuous monitoring with the C60 telescope shows that, in this time interval, SN 2012ch exhibited a fast brightness decline after the plateau. We estimate that the end of the plateau occurred at about JD 2456150, and the length of the plateau was ∼93 days, which is a typical value for SNe II-P.

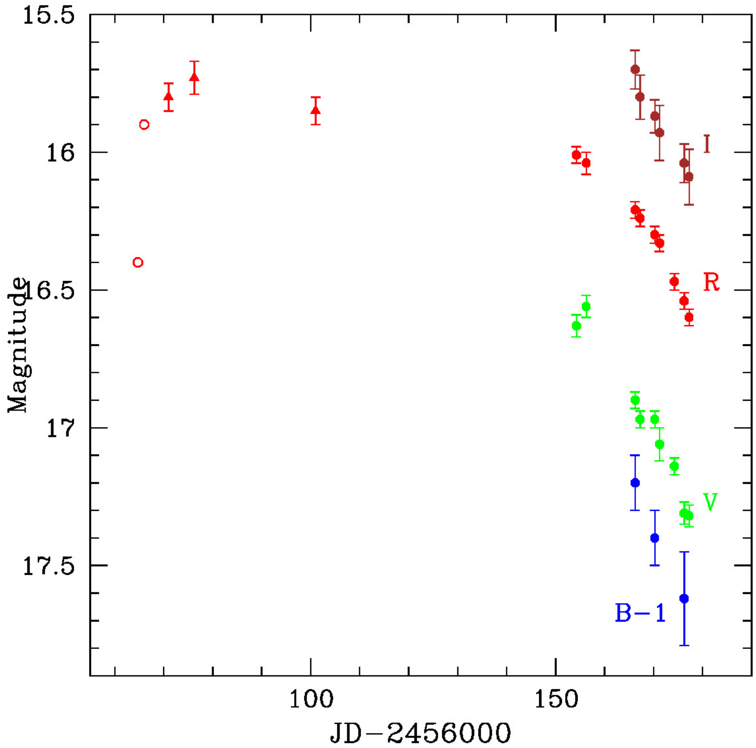

Figure 3.
The light curves of SN 2012ch. Dots are observations with the C60 and C50 telescopes; triangles are data from the MASTER telescopes; circles are magnitude estimates at the discovery.

The data for SN 2012fs indicate that all our observations were obtained at the plateau phase. The discovery magnitude and other estimates by amateurs show very large scatter, up to 2^{m}. We suppose that this is the result of difficulty of measuring the SN near the nucleus of the galaxy, in the region of high background surface brightness. The explosion epoch can be estimated only using the data on SN spectra. The results of Inserra et al. (2012) suggests the explosion date about JD 2456200 (Sept. 30), while Lin et al. (2024) determined that the explosion occurred on JD 2456199 (Sept. 29). Both estimates are in a good agreement, and we accept JD 2456199.5 as an explosion epoch. SN 2012fs was discovered on Oct. 7.96 (JD 2456208.46), but out first images were obtained 2 days earlier, on JD 2456206.09, and at that time, the SN has already reached the plateau. The rise time from these data is about $6^{d}.5$, which is also within the range of this quantity for SNe II-P according to Gall et al. (2015). Unfortunately, we have no data after the phase ∼80 days and cannot determine the length of the plateau.

The color curves for SNe 2012ch and 2012fs are presented in Fig. 6, they are compared to those for type II-P SNe 1999em, 2004et, 2012aw, and 2017eaw (Elmhamidi et al. 2003; Maguire et al. 2010; Bose et al. 2013; Tsvetkov et al. 2018; Buta & Keel 2019).

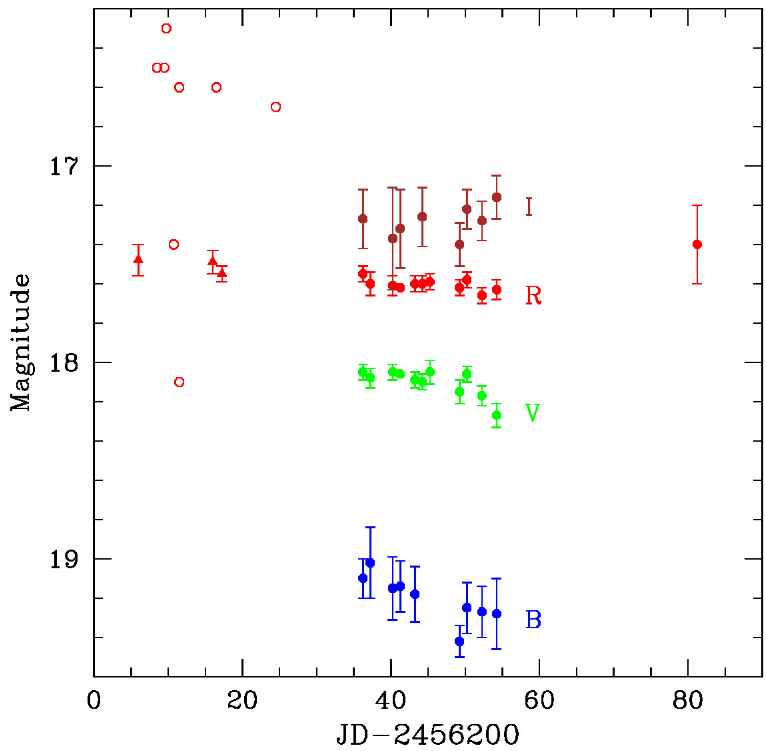

Figure 4.
The light curves of SN 2012fs. Dots are observations with the C60 and M70 telescopes; triangles are data from the MASTER telescopes; circles are the discovery magnitude and estimates by amateurs, reported in CBET No. 3278.

The color curves for the SNe from the comparison sample were corrected for extinction, the values were taken from the papers cited above. All four color curves show similar behavior, with constant reddening during the displayed time interval. The comparison shows that the colors of SN 2012fs clearly demonstrate a significant color excess, while it is negligible for SN 2012ch. We estimate the color excess for SN 2012fs as $E(B-V) = 0^{\rm m}.22 \pm 0^{\rm m}.07$, while the Galactic extinction for the host galaxy is $E(B-V) = 0^{\rm m}.16$ from the NED. We conclude that small extinction in the host galaxy, $E(B-V) \approx 0^{\rm m}.06$, is also present. For SN 2012ch, the Galactic extinction is $E(B-V) = 0^{\rm m}.016$ (NED), and the extinction in the host galaxy is negligible.

The distances to the host galaxies of SNe 2012ch and 2012fs were calculated from their redshifts, corrected for the motion relative to the cosmic microwave background (NED), using $H_0 = 73$ km s^{-1} Mpc^{-1}. The resulting distance moduli are $\mu = 32.84$ for SN 2012ch and $\mu = 33.82$ for SN 2012fs. Using the distances and extinction derived above, we obtain the absolute magnitudes of the SNe at the plateau stage: $M_R = -17^{\rm m}.1$ for SN 2012ch, $M_R = -16^{\rm m}.9$ for SN 2012fs. The mean maximum absolute magnitude in the V band for SNe II, according to Anderson et al. (2014), is $\overline{M_V} = -16^{\rm m}.74$. The color curves presented in Fig. 6 show that the mean color index $(V-R)$ at the start of the plateau stage for SNe II-P is about $0^{\rm m}.15$, so the mean maximum magnitude in the R band is $\overline{M_R} = -16^{\rm m}.9$. We conclude that the maximum luminosity of the SNe 2012ch and 2012fs is very close to the mean value for this class of objects.

Our study of the two type II-P SNe, 2012ch and 2012fs, shows that these objects present quite typical photometric behavior, although our data are quite sparse and do not cover all important stages of their evolution.

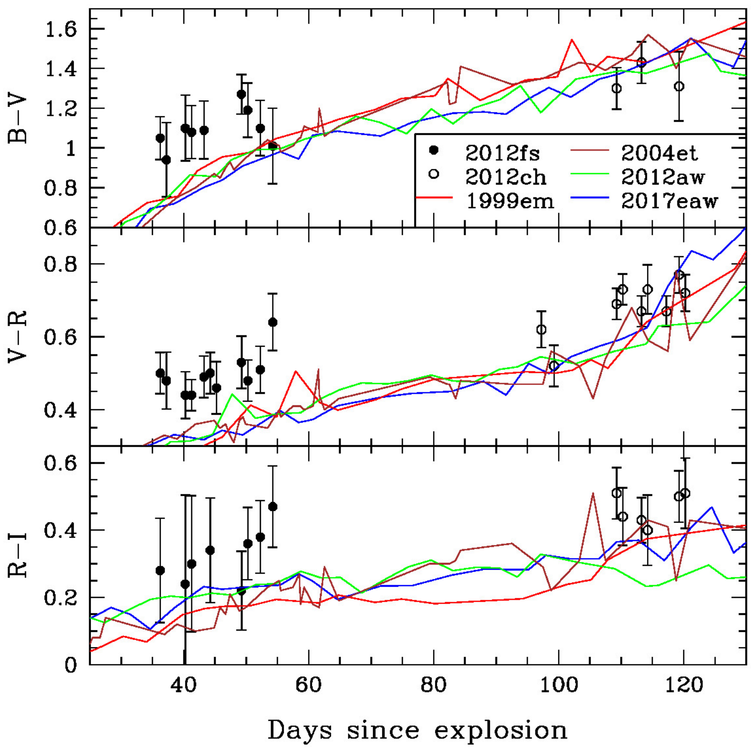

Figure 5.
The color curves of SNe 2012ch and 2012fs, and their comparison to those for four SNe II-P.

4 Modelling the light curves for SN 2012ch

The data for SN 2012ch allows us to determine such important parameters as the length of the plateau and luminosity on the plateau. We attempted modelling the light curves with the STELLA code that incorporates implicit hydrodynamics coupled to a time-dependent multi-group non-equilibrium radiative transfer (Blinnikov et al. 1998, 2000, 2006; Baklanov et al. 2005).

The explosion is initiated by energy release at the center of the pre-supernova. A neutron star with mass $1.55 M_\odot$ forms in the center. We varied main parameters of the model: mass $M_{\rm tot}$ and radius R_0 of the pre-supernova, explosion energy $E_{\rm burst}$, and mass of synthesized ^{56}Ni $M_{\rm Ni}$; we calculated a grid of models searching for better fit to the observed light curves. The light curves and photospheric velocity for the optimal model are presented in Fig. 6. The parameters of this model are: $R_0 = 900_\odot$, $M_{\rm tot} = 19 M_\odot$, $M_{\rm Ni} = 0.07 M_\odot$, $E_{\rm burst} = 1.5 \times 10^{51}$ erg. The single velocity estimate for SN 2012ch is based on blueshift of Hα absorption (Marion 2012). Dessart and Hillier (2005) showed that, at that phase, the photospheric velocity was about 1.5 times lower than the Hα velocity, so the agreement between our model and observations is satisfactory. The derived model parameters are quite typical of type II-P supernovae.

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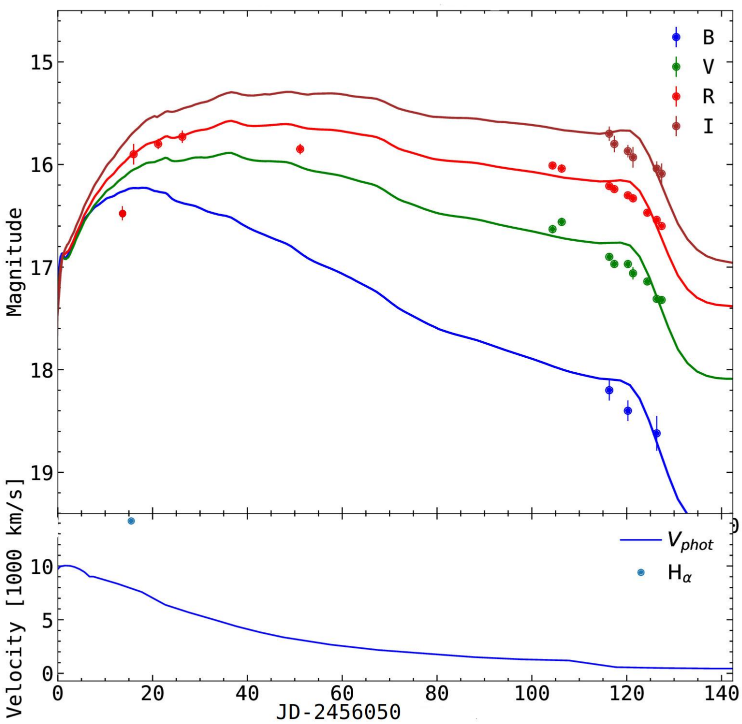

Figure 6.
The *BVRI* light curves and photospheric velocity of the optimal model (curves) for SN 2012ch compared to observations (dots).

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