Received 22 October; accepted 25 November.

# Photometric Observations and Modeling of Type IIb Supernova 2008ax 

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#### Abstract

CCD UBVRI photometry covering about 320 days is presented for the type IIb SN 2008ax. Its photometric behavior is typical of core-collapse SNe with low amount of hydrogen. The main photometric parameters are derived and a comparison with SNe of similar types is reported. Preliminary modeling is carried out, and the results are compared to the observed light curves. The main parameters of the hydrodynamical models are close to those used for SN IIb 1993J.


## Introduction

The Supernova SN 2008ax was discovered independently by Mostardi et al. (2008) and Itagaki (Nakano and Itagaki 2008) on March 3.45 UT and March 4.62 UT, respectively. The magnitude of the SN at discovery, estimated on unfiltered CCD frames, was about 16. The first detection was only 6 hours after the image with limiting magnitude about 18.5 and showing no sign of the SN was obtained by Arbour (2008). The offsets from the nucleus of the host galaxy NGC 4490 are $53^{\prime \prime} 1 \mathrm{E}, 25 . \prime 8 \mathrm{~S}$. The projected distance from the center is 2.8 kpc , while the radius of the galaxy is about 9 kpc . NGC 4490 is a barred spiral galaxy of type SBcd. SN II-P 1982F was discovered earlier in this galaxy (Tsvetkov 1984). The positions of the two SNe are quite close, SN 1982F occurred $19^{\prime \prime}$ ( 0.9 kpc ) closer to the nucleus at about the same positional angle ( $116^{\circ}$ for $\mathrm{SN} 2008 \mathrm{ax}, 120^{\circ}$ for SN 1982F).

Crockett et al. (2008) identified a source coincident with the position of SN 2008ax in pre-explosion HST observations in three optical filters. The possible progenitor may be a single massive star (initial mass $\sim 28 M_{\odot}$ ), which loses most of its H -rich envelope and explodes as an 11-12 $M_{\odot}$ helium-rich Wolf-Rayet star, or an interacting binary producing a stripped progenitor.

Photometric and spectroscopic observations of SN 2008ax covering first 2 months past discovery were reported by Pastorello et al. (2008) (hereafter P08). The object displayed typical spectral and photometric evolution of a type IIb supernova, consistent with the explosion of a young Wolf-Rayet star.

Roming et al. (2009) (hereafter R09) presented UV, optical, X-ray and radio properties of SN 2008ax. They detected initial fading in UV light curves followed by a rise, reminiscent of the dip seen in type IIb SN 1993J.

## Observations and reductions

We started photometric monitoring of SN 2008ax 4 days after its discovery and continued observations until 2009 January 23. CCD images in $U B V R I$ filters were obtained with the following instruments: the $50-\mathrm{cm}$ reflector of Astronomical Institute of Slovak Academy of Sciences at Tatranska Lomnica with SBIG ST-10XME CCD camera (hereafter S50); the $50-\mathrm{cm}$ meniscus telescope and the $60-\mathrm{cm}$ reflector of Crimean Observatory of Sternberg Astronomical Institute equipped respectively with Meade Pictor 416XT and Apogee AP47 cameras (C50, C60); the 70-cm reflector of Sternberg Astronomical Institute in Moscow with Apogee AP-7 CCD camera (M70); the 1-m reflector of Simeiz Observatory with AP47 camera (C100). The images on 2009 January 23 were obtained at the 2-m Faulkes Telescope North (F200).

The standard image reductions and photometry were made using IRAF ${ }^{1}$.
The galaxy background around SN 2008ax is strong and non-uniform, and we applied image subtraction for most of the frames. Our observations did not allow us to construct good template frames, and we used for subtraction the images of NGC 4490 downloaded from the ING archive ${ }^{2}$.

After subtraction, the magnitudes of the SN were derived by PSF fitting relative to a sequence of local standard stars. The comparison stars are shown on Fig. 1, and their magnitudes are reported in Table 1.


Figure 1. SN 2008ax with local standard stars.

[^0]Table 1: Magnitudes of local standard stars

| Star | $U$ | $\sigma_{U}$ | $B$ | $\sigma_{B}$ | $V$ | $\sigma_{V}$ | $R$ | $\sigma_{R}$ | $I$ | $\sigma_{I}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 11.73 | 0.04 | 11.62 | 0.01 | 11.06 | 0.01 | 10.73 | 0.01 | 10.41 | 0.01 |
| 2 | 13.78 | 0.05 | 12.94 | 0.01 | 11.89 | 0.01 | 11.35 | 0.01 | 10.85 | 0.01 |
| 3 | 13.66 | 0.05 | 13.71 | 0.01 | 13.18 | 0.01 | 12.83 | 0.02 | 12.50 | 0.02 |
| 4 | 14.61 | 0.06 | 14.60 | 0.02 | 13.96 | 0.01 | 13.55 | 0.04 | 13.18 | 0.02 |
| 5 |  |  | 16.25 | 0.03 | 15.20 | 0.02 | 14.57 | 0.03 | 14.03 | 0.03 |
| 6 | 16.58 | 0.07 | 16.02 | 0.03 | 15.00 | 0.02 | 14.47 | 0.02 | 13.93 | 0.03 |

Stars 1-4 were measured photoelectrically in the $B, V$ filters by Tsvetkov (1984); a comparison with the new CCD data reveals good agreement, the mean differences are $\Delta B=-0^{\mathrm{m}} 02, \Delta V=0^{\mathrm{m}} 04$. We may conclude that both calibrations are sufficiently correct.

The results of observations of the SN are presented in Table 2.

## Light and color curves

The light curves of SN 2008ax are shown in Fig. 2. The premaximum rise and the peak have good coverage by observations, and we can determine the dates and magnitudes of maximum light in different bands: $U_{\max }=14.06 ; t_{U \max }=\mathrm{JD} 2454546.9 ; B_{\max }=14.09$; $t_{B \max }=\mathrm{JD} 2454548.2 ; V_{\max }=13.40 ; t_{V \max }=\mathrm{JD} 2454550.3 ; \quad R_{\max }=13.06 ; t_{R \max }=$ JD2454552.4; $I_{\max }=12.73 ; t_{I \max }=\mathrm{JD} 2454552.5$. The dates of maximum in $U B V R I$ bands are in a good agreement with the results by P08 and R09, while for the peak magnitudes, the agreement is slightly worse. The maximum magnitudes from R09 in $b$, $v$ bands are about 0 m 2 fainter than our data, but their $u$ peak magnitude is practically equal to our estimate. The peak $B V$ magnitudes derived by P08 are slightly fainter than our data.

After the maximum, the brightness of the SN declined very fast. At the phase 15 days past maximum, the $B$ magnitude declined by $1^{m} 67$. The fast drop continued for about 25 days, and at about JD 2454580 , the onset of the linear decline is observed. The rates of decline in the JD 2454580-2454680 time interval are (in mag/day): 0.022 in $V$, 0.021 in $R, 0.020$ in $I$. After JD 2454680, the rate slightly decreased; the values for JD 2454680-2454850 are: 0.018 in $V, 0.016$ in $R, 0.017$ in $I$. In the $B$ band, the decline rate is constant for JD 2454580-2454850, being 0.016 .

Fig. 3 presents the comparison of our data with the results by P08 and R09. The photometry by P08 in Sloan $u^{\prime}, r^{\prime}, i^{\prime}$ filters was transformed to $U, R, I$ bands using the relations derived by Chonis and Gaskell (2008). The agreement between our magnitudes and the data from P08 is quite good, some differences are observed near maximum in the $U, R, I$ bands. They may result from errors of transformation from the Sloan to Johnson-Cousins photometric systems. The $b, v$ magnitudes from R09 are significantly fainter than our results, while their $u$ magnitudes agree well with our $U$ data. We also plot in Fig. 3 the $V$-band light curves of SN IIb 1993J and SN Ic 2002ap (Richmond et al. 1996; Foley et al. 2003), aligned to match the peaks of the curves. The shape of the light curve of SN 2002ap is different from that of SN 2008ax: the rise to the maximum is

Table 2: Observations of SN 2008ax

| JD 2454000+ | U | $\sigma_{U}$ | $B$ | $\sigma_{B}$ | V | $\sigma_{V}$ | $R$ | $\sigma_{R}$ | I | $\sigma_{I}$ | Tel. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 532.51 |  |  | 17.25 | 0.08 | 15.92 | 0.03 | 15.35 | 0.04 | 15.09 | 0.04 | S50 |
| 537.59 |  |  | 15.22 | 0.02 | 14.54 | 0.02 | 14.19 | 0.03 | 13.84 | 0.04 | S50 |
| 541.37 | 14.43 | 0.06 | 14.46 | 0.03 | 13.88 | 0.03 | 13.67 | 0.05 | 13.37 | 0.03 | S50 |
| 544.42 | 14.09 | 0.06 | 14.22 | 0.02 | 13.68 | 0.02 | 13.36 | 0.03 | 13.06 | 0.02 | S50 |
| 546.39 | 14.06 | 0.06 | 14.13 | 0.02 | 13.56 | 0.02 | 13.24 | 0.04 | 12.93 | 0.02 | S50 |
| 551.31 | 14.33 | 0.06 | 14.19 | 0.02 | 13.41 | 0.02 | 13.08 | 0.03 | 12.73 | 0.03 | S50 |
| 552.53 | 14.56 | 0.05 | 14.25 | 0.02 | 13.45 | 0.01 | 13.07 | 0.02 | 12.73 | 0.02 | S50 |
| 553.43 | 15.07 | 0.12 | 14.38 | 0.05 | 13.58 | 0.04 | 13.10 | 0.07 | 12.80 | 0.03 | S50 |
| 555.52 | 15.21 | 0.08 | 14.67 | 0.06 | 13.64 | 0.05 | 13.12 | 0.06 | 12.86 | 0.05 | S50 |
| 556.42 | 15.60 | 0.08 | 14.82 | 0.05 | 13.77 | 0.05 | 13.32 | 0.05 | 12.87 | 0.05 | S50 |
| 557.41 | 15.87 | 0.07 | 15.02 | 0.02 | 13.87 | 0.02 | 13.27 | 0.05 | 12.90 | 0.03 | S50 |
| 563.40 | 17.27 | 0.13 | 15.77 | 0.04 | 14.39 | 0.03 | 13.76 | 0.05 | 13.19 | 0.04 | S50 |
| 564.47 |  |  | 15.81 | 0.07 | 14.41 | 0.03 | 13.75 | 0.03 | 13.18 | 0.03 | S50 |
| 570.37 |  |  | 16.21 | 0.10 | 14.71 | 0.02 | 14.05 | 0.05 | 13.40 | 0.03 | S50 |
| 579.38 |  |  | 16.45 | 0.04 | 14.97 | 0.02 | 14.33 | 0.02 | 13.68 | 0.03 | M70 |
| 583.33 |  |  | 16.52 | 0.05 | 15.07 | 0.03 | 14.46 | 0.03 | 13.79 | 0.04 | M70 |
| 585.35 |  |  | 16.49 | 0.05 | 15.05 | 0.03 | 14.42 | 0.03 | 13.77 | 0.04 | M70 |
| 590.30 |  |  | 16.62 | 0.05 | 15.20 | 0.03 | 14.59 | 0.03 | 13.89 | 0.03 | M70 |
| 601.47 |  |  | 16.84 | 0.09 | 15.41 | 0.04 | 14.86 | 0.04 | 14.08 | 0.03 | S50 |
| 602.34 |  |  | 16.99 | 0.04 | 15.50 | 0.03 | 14.89 | 0.02 | 14.17 | 0.03 | M70 |
| 613.32 |  |  | 16.91 | 0.04 | 15.65 | 0.02 | 15.08 | 0.02 | 14.35 | 0.03 | M70 |
| 616.41 |  |  | 17.03 | 0.04 | 15.69 | 0.03 | 15.08 | 0.04 | 14.35 | 0.04 | S50 |
| 623.33 |  |  | 16.96 | 0.05 | 15.87 | 0.03 | 15.31 | 0.02 | 14.56 | 0.03 | M70 |
| 628.44 |  |  | 17.25 | 0.10 | 16.00 | 0.03 | 15.45 | 0.03 | 14.60 | 0.04 | S50 |
| 643.34 |  |  |  |  | 16.37 | 0.03 | 15.73 | 0.03 | 14.97 | 0.06 | C50 |
| 644.32 |  |  |  |  | 16.35 | 0.03 | 15.75 | 0.03 | 15.07 | 0.11 | C50 |
| 647.31 |  |  |  |  | 16.35 | 0.04 | 15.80 | 0.03 |  |  | C50 |
| 647.31 |  |  | 17.53 | 0.05 | 16.41 | 0.02 | 15.85 | 0.02 | 15.00 | 0.04 | C100 |
| 649.30 |  |  |  |  | 16.41 | 0.03 | 15.83 | 0.03 |  |  | C50 |
| 656.30 |  |  |  |  | 16.63 | 0.02 | 15.98 | 0.03 |  |  | C50 |
| 658.30 |  |  |  |  | 16.63 | 0.10 | 16.00 | 0.05 |  |  | C50 |
| 660.33 |  |  |  |  | 16.67 | 0.04 | 16.07 | 0.03 | 15.49 | 0.10 | C60 |
| 674.34 |  |  | 18.25 | 0.14 | 17.01 | 0.06 | 16.33 | 0.04 | 15.55 | 0.03 | S50 |
| 675.32 |  |  |  |  | 17.01 | 0.04 | 16.45 | 0.07 | 15.73 | 0.08 | S50 |
| 677.32 |  |  |  |  | 17.19 | 0.05 | 16.36 | 0.05 | 15.60 | 0.05 | S50 |
| 679.32 |  |  |  |  | 17.31 | 0.07 | 16.52 | 0.06 | 15.73 | 0.16 | S50 |
| 699.28 |  |  |  |  | 17.57 | 0.20 | 16.78 | 0.07 |  |  | M70 |
| 720.24 |  |  |  |  |  |  | 16.99 | 0.07 |  |  | C60 |
| 781.63 |  |  |  |  |  |  | 17.90 | 0.05 |  |  | C60 |
| 783.62 |  |  |  |  | 18.98 | 0.07 | 18.18 | 0.06 |  |  | C60 |
| 855.05 |  |  | 20.90 | 0.18 | 20.45 | 0.07 | 19.22 | 0.03 | 18.77 | 0.03 | F200 |



Figure 2. The light curves of SN 2008ax. The dashed lines show the decline at the tail with rates reported in the text.
faster, and the decline is slower. The second peak on the light curve of SN 1993J matches closely the light curve of SN 2008ax.

The absolute $V$-magnitude light curves of SN 2008ax and several SNe of types IIb, Ib and Ic are compared in Fig. 4.

For SN 2008ax, we adopted the distance modulus $\mu=29.92$ and reddening $E(B-V)=$ 0.3 , as in P08. The light curves of other SNe are taken from Richmond et al. (1996), Qiu et al. (1999), Stritzinger et al. (2002), Foley et al. (2003). With the absolute peak $V$ magnitude of $-17^{\mathrm{m}} 45$, SN 2008ax appears to be quite typical among SNe of similar classes. It is a little fainter than SN IIb 1993J and SN Ib 1999ex, has nearly the same luminosity as SN Ic 2002ap, and is significantly brighter than SN IIb 1996cb.

The color curves are shown in Fig. 5. The evolution of the $B-V$ and $V-R$ colors is similar. Before maximum, SN 2008ax becomes bluer, then quickly reddens, and finally the colors remain nearly constant. The $U-B$ color probably evolves in the same way, but our data spans only the period of fast reddening. The $R-I$ color curve is different, the color before maximum is nearly constant, and then only a slight reddening is observed.


Figure 3. The comparison of our data (dots) with the results from P08 (crosses) and R09 (triangles). The color coding and shifts are the same as in Fig. 2. The solid and dashed green curves present the $V$-band light curves of SNe 2002ap and 1993J.

## Modeling the light curves

We compute the light curves in $U B V R I$ bands using our code STELLA, which incorporates implicit hydrodynamics coupled to a time-dependent multi-group non-equilibrium radiative transfer (Blinnikov et al. 1998). The specific model employed here was Model 13C of Woosley et al. (1994). This model was derived from a $13 M_{\odot}$ main sequence star that lost most of its hydrogen envelope to a nearby companion. The main parameters of the model are: total mass $3.8 M_{\odot}$, radius $600 R_{\odot}$, mass of ${ }^{56} \mathrm{Ni} 0.11 M_{\odot}$, explosion energy $1.5 \times 10^{51}$ erg. The chemical composition is shown in Fig. 6. Fig. 7 gives the resulting light curves, and Fig. 8 presents the light curves for the first 50 days past explosion.

The model light curves give a very good fit to the observed maximum, concerning both the luminosity and the shape. The differences are on the rising branch, where the computed early-time peak is brighter than observed, and on the tail, especially for the $U$ and $B$ bands. We consider the agreement to be quite satisfactory, but we continue the search for models which will give better fits. The results and more detailed discussion of


Figure 4. The absolute $V$-band light curves of SN 2008ax and SNe of types IIb (1993J, 1996cb), Ib (1999ex), Ic (2002ap). Day 0 corresponds to the maxima on the light curves.
the properties of the models and their impact on the possible evolution of the progenitor will be published in a subsequent paper.

Acknowledgements. We thank N.P. Ikonnikova and N.N. Pavlyuk who made some of the observations. The work of D.T. is partly supported by the Leading Scientific Schools Foundation under grant NSh.433.2008.2. I.V. acknowledges financial support from SAI scholarship and from Slovak Academy Information Agency (SAIA). The work of S.B. and P.B. is supported partly by the RFBR grant 07-02-00830-a, by the Leading Scientific Schools Foundation under grants NSh.2977.2008.2, NSh.3884.2008.2, and in Germany by MPA guest program.

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.

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Figure 5. The color curves of SN 2008ax.

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Figure 6. The chemical composition of the model for light curve computation.


Figure 7. The computed light curves compared to our observational data. Day 0 is the time of shock breakout according to P08 (JD 2454528.8).


Figure 8. The model light curves for the first 50 days since explosion.


[^0]:    ${ }^{1}$ 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/ casuadc/archives/ingarch

