BVR CCD photometric observations of SN 2007gr

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(Conference poster)

Abstract. The paper presents our BVR CCD photometric observations of SN2007gr covering the rising branch, the maximum light and part of the declining section of the light curve. We concluded that the light curve of SN2007gr is typical of SNe Ib/c with a rapid decline after the maximum followed by a much slower decline. The transition between them occurs $\sim$ 30 days after the B maximum and is best defined in B color. The color curves revealed that the SN2007gr becomes monotonically redder from several days before the maximum brightness until 20 d after it. After that the colour indices $B-V$ and $V-R$ gradually turn bluer.
Key words: cataclysmic stars, supernovae

BVR CCD фотометрични наблюдения на Свръхновата SN 2007gr

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В статията представяме BVR CCD фотометрични наблюдения на Свръхновата звезда SN2007gr, покриващи нарастващия клон, максимума и част от намаляващия клон на кривата на блясъка. Формата на получената крива е типична за Свръхнова от тип SNe Ib/c с бързо намаляване на блясъка след максимума, следван от доста по-бавно отслабване. Преходът между тях става $\sim$ 30 d след максимума и е най-добре изразен в B цвят. Наблюдателните данни показват, че SN2007gr монотонно почервенява от няколко дни преди максимума на блясъка до 20 d след него. След това цветните индекси $B-V$ и $V-R$ постепенно стават по-сини.

Introduction

Massive stars (M > 8 $M_\odot$) end their lives as core-collapse supernovae (CC SNe). SNe resulting from stars that had lost their H envelopes before they collapsed are called stripped-enveloped CC SNe. They are classified as Type Ib (He-rich) if the He envelope was still present and Type Ic (He-poor) if it had been lost. The crucial criterion for the subtype is the presence of He lines in the spectra. Stripped-enveloped CC SNe show a large variety of observed properties depending on the physical parameters of the progenitor stars at the time of explosion.

The kinetic energy of SNe of type Ib is relative low ($\sim 10^{51}$ erg) in respect to that of the SNe of type Ic ($\sim 10^{52-53}$ erg). The latter SNe are called "hipernovae" and have been associated with long-duration γ-ray bursts (GRBs). Although both phenomena originate from the core collapse of a massive star, SNe emit mostly in the optical range whereas GRBs emit mostly in the soft- or hard X-rays. Moreover the GRBs generates ultra-relativistic jets which beam the early emission into a narrow cone, while no relativistic outflows have been found in SN Ic explosion despite theoretical expectations and searches.

At present it is not clear the difference between the progenitors that produce type Ib and Ic SNe. It is generally assumed that WR stars are the most promising candidates as these have shed their outer layer of H, as well as varying amounts of their He layer. The H and He layers are primarily shed through strong stellar winds, resulting in WC and WO stars. Alternatively, the outermost layers may be stripped off by a companion star.

1 The star SN2007gr

SN2007gr was discovered on 2007 Aug 15 (Li et al 2007). It exploded near the nucleus of the spiral galaxy NGC 1058 (distance 9.3-10.6 Mpc) which is a member of a group of nearby galaxies. SN2007gr was suggested to be a member of a young cluster (with a turn-off mass of 28 $M_{\odot}$) due to its close location to a bright source.

Chornock et al. (2007) classified SN2007gr as Type Ib/c based on its spectrum obtained a night after the discovery. The later spectral evolution did not show the presence of He, therefore SN2007gr was classified as Type Ic (Valenti et al. 2008). Thus it turned out one of the nearest stripped-envelope SNe ever observed.

Hunter et al. (2010) determined 2007 Aug 13 as the explosion epoch and 2007 Aug 25 as the time of B maximum. They deduced rise times to B-band and R-band maxima of 11.5 d and 14–18 d respectively.

Adopting distance modulus 29.84, Galactic extinction $E(B-V) = 0.062$ and a host galaxy extinction 0.03 Valenti et al. (2008) estimate that the absolute magnitudes of SN2007gr at maximum are $M_R = -17.3$ and $M_B = -16.8$.

The spectrum obtained for 6 d before the maximum brightness shows shallow absorption features. The spectra of SN2007gr several tens days after the maximum reveal dominating line NaID followed by CaII H and K, Fe, etc. (Tarasova 2008) while the spectrum on day 115 shows broad [O I] 6300 feature (Milisavljevic et al. 2009).

The absorption features tend to drift towards the red with time probably as a result of the formation in slower deeper layers of the ejected material. The ejecta velocities measured by features of CaII, MgII, FeII, NaI, SiII, CII are from 15000 km/s to 8000 km/s at maximum light while those after 80 d range from 8000 km/s to 2000 km/s (Hunter et al. 2010). Valenti et al. (2008) estimated an ejected mass of 1.5–3 $M_{\odot}$. It was found that 0.076 $M_{\odot}$ of Ni^{56} was produced in the explosion.

The analysis of the forbidden lines in the spectra leads to the supposition about the carbon-rich highly-evolved compact progenitor of SN2007gr. The observed narrow C I lines of SN2007gr (Valenti et al. 2008, Crockett et al., 2008) are indicative for the particularly slow evolution of the photospheric expansion. The early appearance of CO and its growing up to 138 d (after that it fades) confirms this idea. The temperature of the CO emitting region in SN2007gr is estimated as greater than 2000 K that expands with velocity 2000 km/s. Presence of molecules in the ejecta provides an additional source of cooling that may be conducive to dust formation but there are no signatures of dust in the ejecta of SN2007gr.

The optical spectro-polarimetric data of the Ca near-IR triplet (Tanaka et al. 2009) reveal bipolar explosion viewed from the slightly off-line direction. These data show an asphericity of SN 2007gr (its photosphere is oblate).

Radio-interferometric observations reveal a relativistic expansion in the star SN2007gr with velocity 0.6c. So far SN2007gr is one of the two SNe showing evidence for mildly relativistic expansion. Contrary to the radio data, optical observations of SN2007gr indicate a typical type Ic SN with ejecta velocity 6000 km/s. Paragi et al. (2010) concluded that in SN 2007gr a small fraction (around 10^{-4}) of the ejecta produced a low-energy relativistic bipolar radio jet while the bulk of the ejecta were slower and, as shown by optical spectro-polarimetry, mildly aspherical. Recent studies of the nebular spectra do confirm that around half of all SNe Ib/c are strongly aspherical while the remainder appear to have moderate signatures of asphericality.

2 Our observations

Our CCD photometry of SN2007gr in BVR bands was carried out at Rozhen National Astronomical Observatory with 60-cm Cassegrain telescope using the SBIG STL11000M CCD camera (4008 $\times$ 2672 pixels, 9 μm pixel, field of 17 $\times$ 11 arcmin). The average photometric precision per data point is 0.005–0.008 mag.

Table 1. Colors of the standard stars

Star	V	B-V	V-R	Hunter's name
Std1	15.544	0.538	0.330	std2
Std2	14.431	1.113	0.596	std7
Std3	14.799	0.632	-0.326	std8
Std4	13.675	0.572	0.336	std9
Std5	13.234	0.642	0.376	std10

We used five of the standard stars of Hunter's et al. (2009) for transition from the instrumental system to standard photometric system (Table 1).

The standard photometric program MaxIM DL was used for reduction of our photometric data.

The field of the target and standard stars is shown in Fig. 1. There are several objects of similar high luminosity in the field surrounding the SN location. Some of them are point-like and others are extended. They might be O to F supergiants but it is unlikely to observe such a large number of extremely massive stars during this very short evolutionary supergiant phase in such a small area of the galactic disk. It is suspected that the bright sources are stellar clusters rather than single individual supergiants. On the other hand the nearest bright source is with diameter less than 1 pc and it is more likely a star.

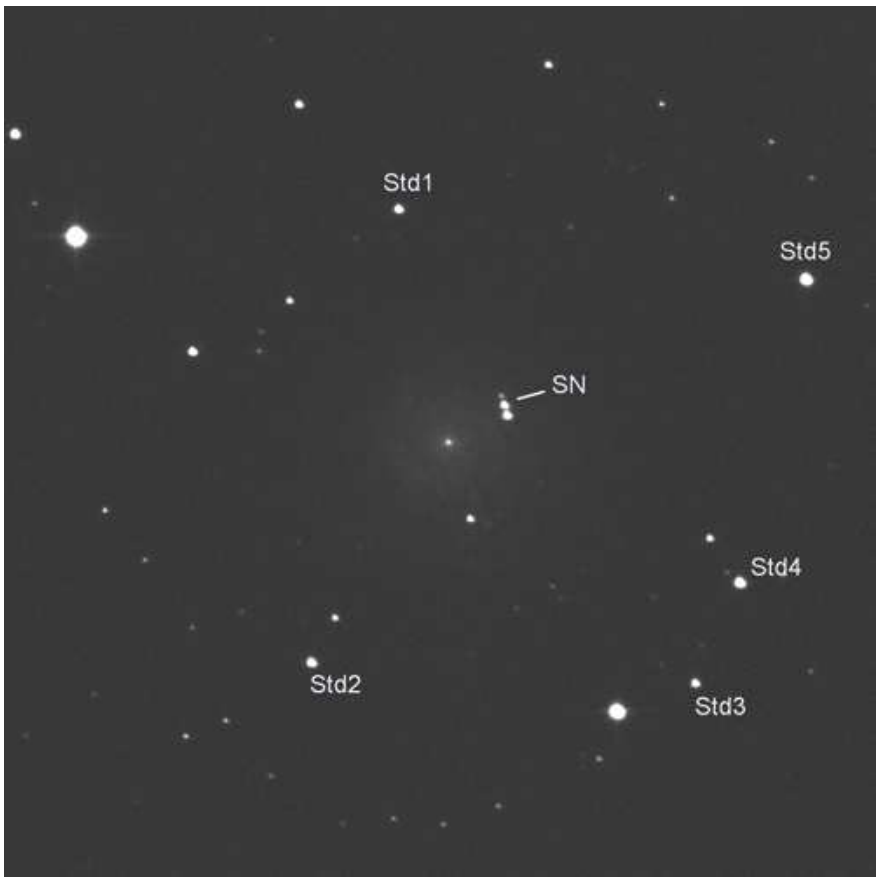

Fig. 1. Part of the observed field with sizes 6.25 x 6.25 arcmin

3 Analysis of the data

Figure 2 presents our BVR photometric data (marked by large empty circles) superposed on the all available photometric data of SN2007gr (marked by small crosses). In fact our observations cover rising branch, maximum light and part of the declining section of the light curve.

It should be noted that while our points in B and V bands almost coincided with those of Hunter et al. (2009) while in order to get coincidence in R band we had to make a -0.12^m shift of our data. We attribute this discrepancy to the fact that our R filter is not standard.

The maximum brightness in BVR colors were respectively 13.43^m, 12.96^m and 12.87^m. They occurred on Aug 24, Aug 26 and Aug 28, i.e. the maximum occurs firstly in B band and around 4 d later in R band. Thus our data

indicated the date of the B maximum a day earlier than that determined by Hunter et al. (2010).

The declined rates of SN2007gr during the fast decline in BVR colors are respectively 0.087^m/day, 0.06^m/day and 0.061^m/day (Fig.2).

Thus we may conclude that the light curves of SN2007gr (Fig. 2) are typical of SNe Ib/c with a rapid decline after the maximum (photospheric phase, < 20 d past explosion) followed by a much slower decline (nebular phase, > 60 d past explosion). The transition between them occurs ~ 30 days after the B maximum and is best defined in B color.

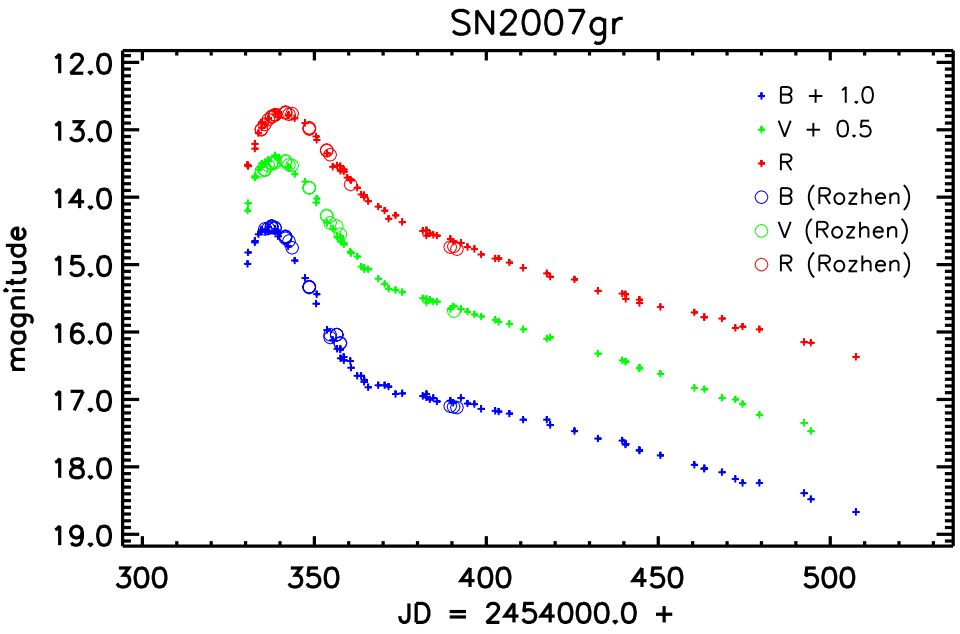

Fig. 2. Photometry of SN2007gr

The color curves (Fig. 3) reveal that the SN2007gr becomes monotonically redder from the date several days before the maximum brightness until 20 d after it. After that the $B-V$ and $V-R$ colour indices gradually turn bluer.

In fact, the photospheric phase of the SN explosion corresponds to the optically thick ejecta and energy produced by the $Ni^{56} \rightarrow Co^{56} \rightarrow Fe^{56}$ radioactive decay, while the nebular phase occurs during the time when the ejecta are optically thin and the emitted luminosity includes the γ-rays from the the Co^{56} decay, by the γ-rays from the electron-positron annihilation and by the kinetic energy of the positrons. The measurement of the slope of the linear late-time tail (nebular phase) as well as the width of the light curve peak during the photospheric phase of the light curves of SN2007gr will allow

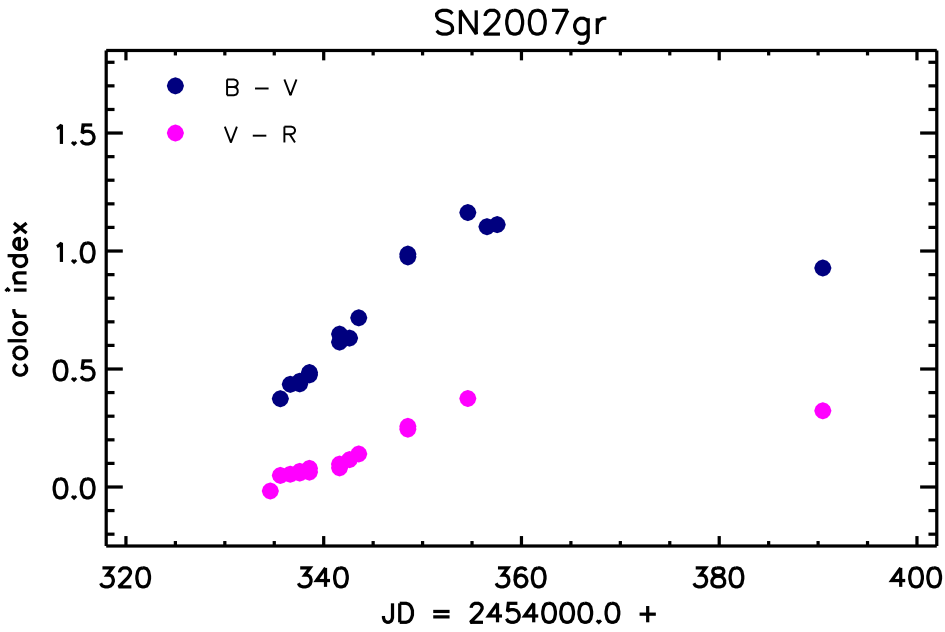

Fig. 3. The B-V and V-R color curves

to determine the ejected mass and kinetic energy of its explosion (Valenti et al. 2008b, Arnett 1982) that is our future goal of investigation.

4 Conclusion

SN 2007gr is interesting object because its light curves were similar to that of the broad-lined "hipernova" SN 2002ap peaking with M_B=−16.8 while its spectra turned out quite different (especially low expansion velocities of SN2007gr). So, SN2007gr may be an important piece in the puzzle of the observed diversity of CC SNe in light curve shape, width of spectral features, carbon abundance and shape of underlying density profiles.

Nowadays, approximately 2.5 years after the explosion, SN2007gr should be weak enough to study its nature, i.e. if it is a compact cluster or a star. We planed photometric observations of this object at the end of 2009 but unfortunately we did not manage to carry out them due to bad atmospheric conditions.

We hope to get a new photometry of the target field as soon as possible in order to check if the nearest bright sources as well as SN2007gr itself are clusters, post-MS supergiants or more massive but extinguished MS objects. In the first case the cluster age would give an estimate of the age and initial mass of the progenitor of SN 2007gr. We plan also wide-field photometric

observations in order to check if SN 2007gr is located in a large, extended star-forming region.

Acknowledgements

The research was supported partly by funds of projects DO 02-362 of the Bulgarian Science Foundation. The use of STL 11000M CCD camera was supported by the grant No F-201/2006 of the National Science Fondation.

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Fig. 4. Dinko Dimitrov gives a talk

Fig. 5. In the Mosque of Shumen (being under repairs))

Fig. 6. In the Mosque of Shumen