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Optical observations of bright supernovae

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Abstract. The program of CCD photometric monitoring of bright supernovae (SNe) has been carried out at 0.4 – 1.0 meter telescopes of the Sternberg Astronomical Institute, Crimean Astrophysical Observatory and Stará Lesná Observatory since 1998. We have observed more than 300 SNe of different types. We present the light curves of SN Ia 2014J, type II SNe 2009af, 2009ay, 2010jl, 2017eaw, type Ibn SN 2015U, and SLSN-I 2017egm. We discuss the physical parameters of the explosions and latest developments of the SN classification.

Key words: supernovae – photometry

1. Introduction

Supernova (SN) outbursts represent the final, explosive stage in the evolution of certain classes of stars. SNe occur in several spectroscopically distinct varieties. Type I SNe are defined by the absence of hydrogen in their optical spectra, while SNe II exhibit strong lines of hydrogen.

Type II SNe is the most common class of exploding stars. They are thought to arise from the death of massive stars with the mass $M > 8M_{\odot}$, when the nuclear burning does not provide sufficient thermal pressure to balance the gravity of the star. Type I SNe are subdivided into types Ia, Ib, Ic on the basis of the intensity of lines in the near-maximum spectra.

SNe of the type II, Ib and Ic are the result of core-collapse of massive stars (CCSN), while SNe Ia are the thermonuclear explosion of a CO white dwarf, which loses stability by accreting matter from the companion (thermonuclear SN).

Recently, new classes were added to this classification scheme. Extremely luminous SNe with maximum luminosity exceeding the absolute magnitude $M_V \sim -21$ mag were discovered. They are dubbed "Superluminous SNe" (SLSN) and divided into classes SLSN-I (without hydrogen) and SLSN-II (with hydrogen).

2. Observations

Light curves and spectra are the basic observational characteristics of SNe.

Obtaining a good-quality light curve requires continuous monitoring of an object for a period from some months to a few years, while the brightness decreases by 5-10 magnitudes. This is an appropriate task for small telescopes with CCD photometers.

We have carried out the program of systematic CCD photometric observations of SNe since 1998. The description of the program and some results were presented by Tsvetkov et al. (2014). Here we present the data for some interesting objects among those studied in the course of this program during the last 5 years. Their light curves are shown in Fig. 1.

3. Results

3.1. SN 2014J

The photometric and spectroscopic observations of this SN were reported by Tsvetkov et al. (2018a). This is a "normal" SN Ia, whose photometric and spectral evolution are typical for this class of SNe. The interstellar extinction in the parent galaxy is very high, with $E(B-V)_{host} = 1.22$, and we found a low value of a ratio between total and selective extinction $R_V = 1.36$. Continous monitoring did not reveal evidence for microvariability with an amplitude and characteristic time as reported by Bonanos & Boumis (2016).

3.2. SNe 2009af and 2009ay

We carried out $BVRI$ photometry for these type II SNe. The results were presented by Tsvetkov (2014). Both objects are characterized by a fast linear brightness decline at early stages of their evolution and a relatively high maximum luminosity. SN 2009af is distinguished by the low brightness drop during the first 200 days after maximum.

3.3. SN 2010jl

Photometric observations of SN IIn 2010jl were reported by Tsvetkov et al. (2016). The data from Fransson et al. (2014) were also plotted in Fig. 1. SN 2010jl was found to be extremely luminous even among type IIn SNe, with $M_{V(max)} \sim -20$ mag. The optical light curves showed slow decline during the first $\sim$ 175 days. After this epoch the light curves flattened, but at phase $\sim$ 300 days they started to decline considerably. We present evidence that SN 2005kd (Tsvetkov, 2008) is the most similar object to SN 2010jl considering the evolution of luminosity.

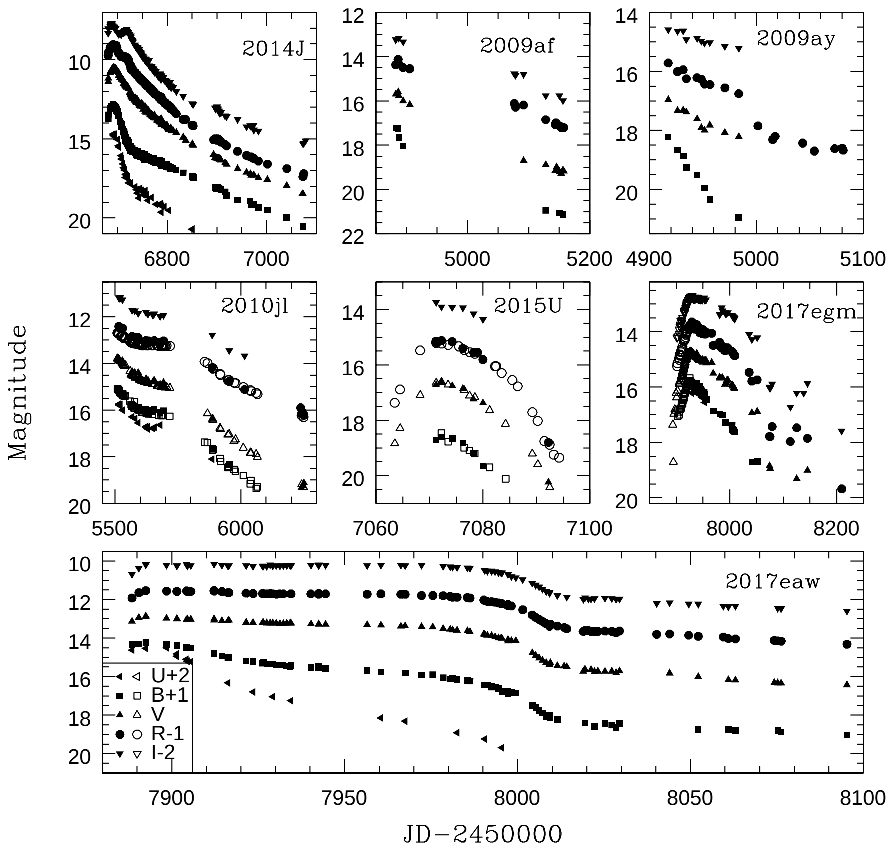

Figure 1. The light curves of selected SNe. The data in different bands are shifted for clear presentation. The shifts are indicated in the bottom plot. Filled symbols show our observations, while open symbols represent data from the literature.

3.4. SN 2015U

The results of photometric monitoring of SN 2015U were presented by Tsvetkov et al. (2015). Observations by Pastorello et al. (2015) were also plotted in Fig. 1. We conclude that SN 2015U exhibits a very high rate of brightness decline, fading by 2.6 mag in the V-band during the first 15 days after maximum. This SN belongs to a rare class of extremely fast declining SNe and is similar to SNe 2002bj (Poznanski et al., 2010), 2005ek (Drout et al., 2013) and 2010X (Kasliwal et al., 2010) regarding the shape of the light curves. The estimate of the peak luminosity for a heavily reddened SN depends strongly on the presently unknown value of R_V. If we assume $R_V = 3.1$, then SN 2015U reached a peak magnitude of $M_R = -20.15$ mag and was definitely much brighter than all other SNe with similar photometric evolution. If $R_V = 1.5$, then the maximum luminosity of SN 2015U $M_R = -18.8$ mag, which still belongs to the brightest objects among SNe of similar classes.

3.5. SN 2017eaw

We presented *UBVRI* photometry of the supernova 2017eaw in NGC 6946, covering ∼200 days after its maximum (Tsvetkov et al., 2018b). The light curves are typical for type II-P SNe, with a plateau lasting about 100 days. Our first observations were made before the maximum light. We determined the time of maximum to be JD2457892.5. The magnitudes at maximum are $U = 12.5, B = 13.22, V = 12.87, R = 12.54, I = 12.18$. The fast decline after the plateau stage started at about JD2457980, and the final linear tail started at JD245810, with $B = 17.3, V = 15.5, R = 14.5, I = 13.8$ mag. The rates of decline on the tail in the B, V, R, I bands are 0.0054, 0.0106, 0.0092, 0.0090 mag day^{-1}, respectively. Assuming the distance of 6.0 Mpc for NGC 6946 (Efremov et al., 2011) and reddening $E(B - V) = 0.30$ mag, we derive absolute magnitudes of SN 2017eaw at maximum light: $M_U = -17.9, M_B = -16.9, M_V = -17.0, M_R = -17.1, M_I = -17.2$ mag.

The light curve shape with a luminous plateau shows that SN 2017eaw is a normal type II-P SN and its presupernova star was a red supergiant (RSG). SNe II-P show a large variety in their light-curve shapes. The main features of the light curves are determined by the initial radius R, total mass of presupernova M, mass of ^{56}Ni and the energy of explosion E (Kasen & Woosley, 2009). We computed the large grid of models in the parameter space ($R, M, ^{56}$Ni, E) to evaluate the best fit model.

For the model calculation, we used the multi-group radiation-hydrodynamics numerical code STELLA (Blinnikov et al., 2006). The preliminary results show that the light curves of SN 2017eaw are best represented by the model with parameters $R = 600R_\odot$, $M = 23M_\odot$, $M_{\rm Ni} = 0.05M_\odot$, $E = 2 \times 10^{51}$ erg.

3.6. SN 2017egm

SN 2017egm was one of the nearest among superluminous SNe of type I. It exploded in a massive, metal-rich spiral galaxy NGC 3191, while most of SLSNe-I discovered earlier were from dwarf, star-forming metal-poor galaxies. We monitored this SN in *UBVRI* bands for more than 200 days after maximum. In Fig. 1 wee plotted also the data from Bose et al. (2018). SN 2017egm reached the peak luminosity of $M_V = -21$ mag. The light curves exhibit linear rise and decline near maximum, while other SLSNe-I show a curvature in their light curves near peaks. On the larger scale, the photometric evolution of SN 2017egm may be considered to be typical for this class of objects.

4. Conclusions

The program of photometric monitoring of SNe with small telescopes proved to be effective. During the last five years we carried out observations of SNe of different types and found some peculiar objects, revealing possibilities for a modification of the existing classification scheme. Comparison of the observed light curves with theoretical models allows to estimate physical parameters of the explosions.

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