SNe 2005ay and 2005cs: Two interesting II-Plateau events

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Abstract. The $U, B, V, R, I$ light curves of the type IIP supernovae (SNe IIP) SN 2005ay and SN 2005cs, and one spectrum for SN 2005cs, are presented and analyzed. We found both events to be fainter than the average SN IIP, with SN 2005cs showing slight brightening in the second half of plateau stage in the $V, R, I$ bands and a low expansion velocity. The effects of two different plausible distance moduli on the derived physical parameters of SN 2005ay are considered. Two approaches are used to estimate the expansion velocities at the middle of the plateau phase. Based on empirical analytical models we derived constraints on the progenitor properties. The amounts of the ejected $^{56}\text{Ni}$ are also recovered.

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DATA AND MAIN PARAMETERS

SN 2005ay: SN 2005ay was discovered, in the Sc galaxy NGC 3938, on March 27 by D. Rich at magnitude 15.6 on CCD frames taken with a 0.31-m reflector [14]. A spectrum obtained on March 29.98 UT with the Calar Alto 2.2-m telescope indicated a type-II SN nature, taken soon after the explosion [16].

Fig.1 (left) displays the $U, B, V, R, I$ light curves of SN 2005ay. Data of SN IIP 1999gi [9] are shown for comparison. We shifted the light curves of SN 1999gi along the $x$-axis to reach the best agreement at the stage of the steep decline after the plateau. After a clear plateau phase, the light curves show a rapid drop of about 2 mag, followed by a linear tail with an $R$-band decline rate very close to the standard value of 0.01 mag/day, similar to the radioactive decay of $^{56}\text{Co}$. The main estimated data are: 1- Explosion time: ~March 23, 2005 (JD 2453453), 2- Total colour excess: $E(B-V) = 0.1$, 3- Distance Modulus: 30.82, based on the recession velocity of the host corrected for Local Group infall onto the Virgo Cluster as reported in the “LEDA” database¹. However we note here that the host galaxy NGC 3938 belongs to the Ursa Major group. The spiral galaxy NGC 3982, which is also part of the group, has a Cepheid calibrated distance modulus of 31.71 [15]. If assuming the two galaxies have this same distance, then SN

¹ http://leda.univ-lyon1.fr/
2005ay would be intrinsically more luminous, which would increase the synthesized $^{56}\text{Ni}$ mass by a factor of $\sim 2.26$.

**SN 2005cs:** The discovery of SN 2005cs, in the Sbc galaxy M51, was reported by W. Kloehr on June 28 at a magnitude of about 14 [8]. Modjaz et al. (2005)[12] reported the type II nature of the events based on the spectrum obtained on June 30.23 UT with the F. L. Whipple Observatory 1.5-m telescope. Nothing was visible at this location on earlier frames taken by W. Kloehr on May 11 and 26.

The photometry data of SN 2005cs, spanning more than a one year observations, are shown in Fig. 1(right), together with the typical SN IIP 1999em [3]. The type IIP nature of SN 2005cs is clear, with noticeable differences with SN 2005ay. The early magnitudes from amateurs, taken by different and independent observers, may suggest the presence of a narrow peak before the onset of the plateau in the $V$ and $R$ bands at JD 2453551-552. The maximum light in $B$ band was reached on JD 2453553 with $B_{\text{max}} = 14.5$ mag. In the $V$ band, SN 2005cs was brightest at a very early epoch, with $V_{\text{max}} = 14.3$. A similar behavior was observed for SN 1999em at the plateau stage, but the increase in brightness was more pronounced for SN 2005cs. The plateau stage lasted until about day JD 2453660, and then the light curves display a steep decline with a drop of about 2.8 mag, then the exponential tail started. The main adopted data are: 1- Explosion time: $\sim$June 27.3, 2005 (JD 2453548.8), 2- Total colour excess: $E(B-V) \simeq 0.14$ [11], 3- Distance Modulus: $\mu = 29.6$ [6, 11]

The spectrum of SN 2005cs obtained on July 6 (JD 2453558.37) is presented in Fig. 2(left). A spectrum analysis was made by means of the synthetic code SYNOW [5]. The velocities are found to be significantly lower than the values for SN 1999em at similar

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**FIGURE 1.** *Left: UBVRI* light curves of SN 2005ay. Dots show our data, cross is for the discovery magnitude by Rich (2005)[14], the ‘v’ mark is the upper limit from Yamaoka & Itagaki (2005)[18]. The dashed lines are the light curves of SN 1999gi. *Right: BVRi* light curves of SN 2005cs. Dots show our data, crosses are for the observations of amateur astronomers. The dashed lines are the light curves of SN 1999em.
FIGURE 2.  Right: The July 6 Spectrum of SN 2005cs, compared with the SYNOW synthetic spectrum (thin line). Lines that are responsible for the most conspicuous features are indicated. Left: Upper panel: the absolute V-light curves of SNe 2005ay (shorter distance case) and 2005cs, compared to SNe 1987A ($D = 50$ kpc, $A_{V}^{tot} = 0.6$ mag), 1999em ($D = 8.8$ Mpc; $A_{V}^{tot} = 0.31$ mag) and 1999gi ($D = 10.91$ Mpc; $A_{V}^{tot} = 0.65$ mag). For SN 2005ay we plot the shorter distance case. Lower panel: the “$(B-V)$” intrinsic colour evolution of the SNe sample.

epochs. The best fit synthetic spectrum has a blackbody temperature of $T_{bb} = 14500$ K, a photospheric velocity of $V_{phat} = 5000$ km s$^{-1}$, and including 7 ions, namely: H I, Fe II, Ca II, Mg II, Mg I, Sc II and Ni II. The H$\beta$ and H$\gamma$ features are prominent with typical P-Cygni profiles.

The photometric measurements of the two SNe were made relative to comparison stars using PSF-fitting technique, and in some cases using aperture photometry. The background of the host galaxies around the SNe did not present any problems when the SNe were bright, but at late stages it could introduce additional errors. We note here that image substruction technique is more appropriate at late phases, however since the SNe are still visible on our images, the subtraction technique is not possible. Thus, the magnitudes at late stages can be regarded as provisional, and they should be verified later when images without the SNe are obtained and used for image subtraction.

DISCUSSION & RESULTS

The absolute V-light curves of SNe 2005ay and 2005cs, together with those of SNe 1987A, 1999em and 1999gi, are highlighted in Fig. 2 (top panel), while the $(B-V)$ colour evolution is shown in the lower panel. In the following we summarize the main results of our analysis:

A more detailed study of the two events has been presented recently by Tsvetkov et al.(2006)[17].

The ejected $^{56}$Ni mass:

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The radioactive decay phase of SN 2005cs is clearly not well sampled, nevertheless the last two photometric points show a decline rate close to the $^{56}$Co decay. If we rely on these late data, adopting a $^{56}$Ni mass of 0.075 $M_{\odot}$ for SN 1987A [1, 2], a direct shift of the light curve tail of SN 1987A to fit late two points indicates a synthesized amount of $^{56}$Ni of $\sim 0.017 M_{\odot}$. The first 3 data of the radioactive tail may indicate an even lower $^{56}$Ni mass ($\sim 9 \times 10^{-3} M_{\odot}$).

The observed data of SN 2005ay, around day 230 after explosion, span about 8 days of observations. These late data are used as above to recover the $^{56}$Ni mass (i.e. best fit with SN 1987A radioactive tail). This method leads to $\sim 0.023 M_{\odot}$ for the shorter distance and $\sim 0.051 M_{\odot}$ for the larger distance.

As a further check of the derived $^{56}$Ni masses, we make use of the well established correlation between the $^{56}$Ni mass and the absolute $M_V$ at the plateau phase [4, 7]. Using our estimates of $M_V$ during the plateau phase, i.e. $M_V \simeq -15.33$ for SN 2005cs and $M_V \simeq -15.72$; -16.61 for SN 2005ay, the method gives $^{56}$Ni masses of $\sim 0.018 M_{\odot}$ for SN 2005cs and $\sim 0.026 M_{\odot}$ for the shorter distance and $\sim 0.065 M_{\odot}$ for the larger distance for SN 2005ay. This indicates that at least SN 2005cs belongs to the faint tail of the luminosity function of type II SNe while the situation for SN 2005ay depends on the adopted distance.

**The progenitor characteristics:**

The type IIP-analytical model of Popov (1993)[13], and the hydrodynamic models of Litvinova & Nadezhin (1985)[10] are used to derive physical parameters ($E; Me j$ and $R$). The duration of the plateau ($t_p$), the absolute V-magnitude of the plateau ($M_V^p$) and the photospheric velocity ($V_p$) are the input parameters.

We evaluate the photospheric velocity at 50 days using the correlation:

$V_{\text{phot}}(50d) \propto L_0^{0.464 \pm 0.017}$ [7]. We use these estimates, and we adopt a range of $t_p = 80 - 90$ days based on contraints by the early rise seen in both SN light curves. More precise constraints on $t_p$ should come from integrated bolometric light curves. The obvious declines seen in $U$ and $B$ bands would affect the resulting bolometric light curves, indicating shorter plateau than seen in V light curves. The results are summarized in Table 1. We found the estimated mass range for SN 2005cs in agreement with limits
established by using pre-supernova imaging [11].

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