SN 2011ay - a type Ia belonging to the 2002cx-subclass

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I. SN 2011ay – trade card

Discovery: 2011. March 18.18 UT, KAIT/LOSS (Blanchard et al. 2011)
visible magnitude: 17.7 (unfiltered)

Coordinates: α = 07:02:34.06, δ = +50:35:25.0

Host galaxy: NGC 2315

Offset: 9.3" E, 1.4" S

Distance: 86.9 ± 6.9 Mpc (NED)

Spectral classification: Ia pec. (2002cx-subclass) (Pogge et al. 2011, Silverman et al. 2011)

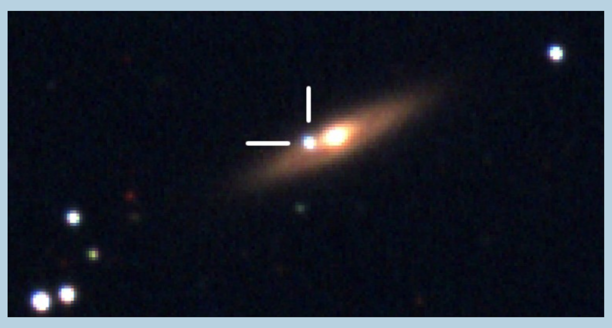


Fig.1. *BVI composite image about the SN 2011ay and its host galaxy on 2011. March 24. (0.6m Schmidt-telescope, Konkoly Observatory, Hungary).*

II. Photometry – light curves and colors

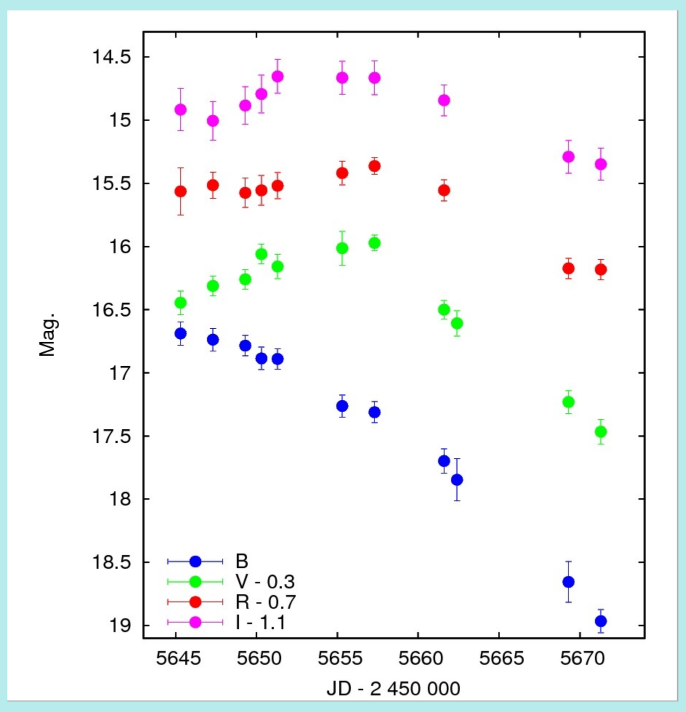


Fig.2. *Standard BVRI light curves of SN 2011ay.*

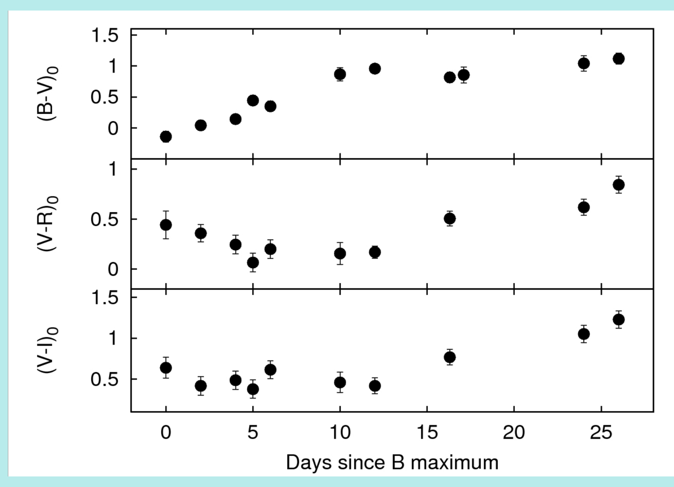


Fig.3. *Color curves of SN 2011ay.*

Ground based photometric observations for SN 2011ay were obtained from the ***Piszkéstető Mountain Station of the Konkoly Observatory, Hungary***. We used the ***0.6/0.9 m Schmidt-telescope*** and the ***1.0m RCC-telescope***, both equipped with Bessel BVRI filters.

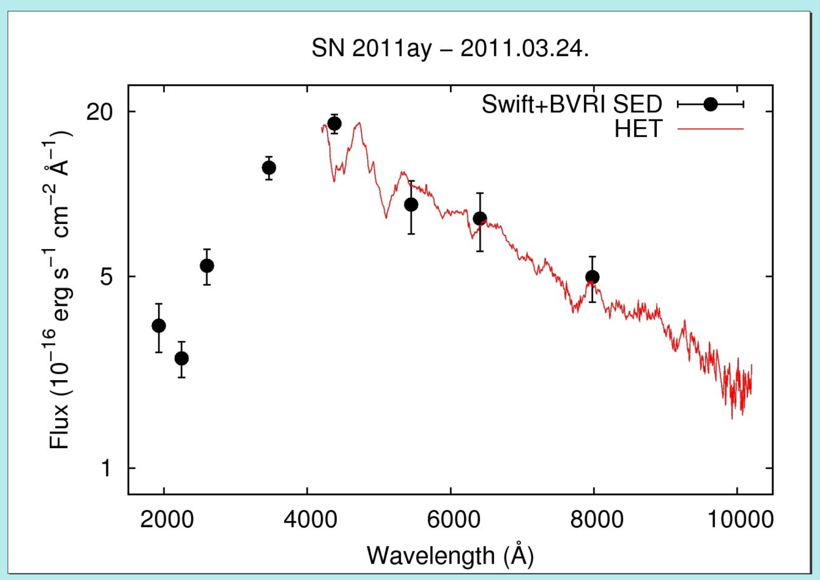
We used the IRAF software to carry out PSF-photometry on the images. While the SN appeared very close to the center of the host galaxy, which is, additionally, an almost edge-on one, the value of background flux was estimated and subtracted manually in every case.

The light curves consisting of standard Johnson-magnitudes and the color curves are shown in Figure 2 and 3, respectively. Unfortunately, we have no data from the first few days after discovery. The first measurements seem to be obtained close to the B maximum, hence its epoch is uncertain (we defined it as the epoch of our first measurement, JD = 2,455,645.3).

Although the ISM in the host galaxy has probably a quite large contribution to the total reddening, we do not have any information about it. Therefore the color curves have been corrected only for galactic reddening, $E(B-V)_0$ = 0.081 (Schlegel et al. 1998).

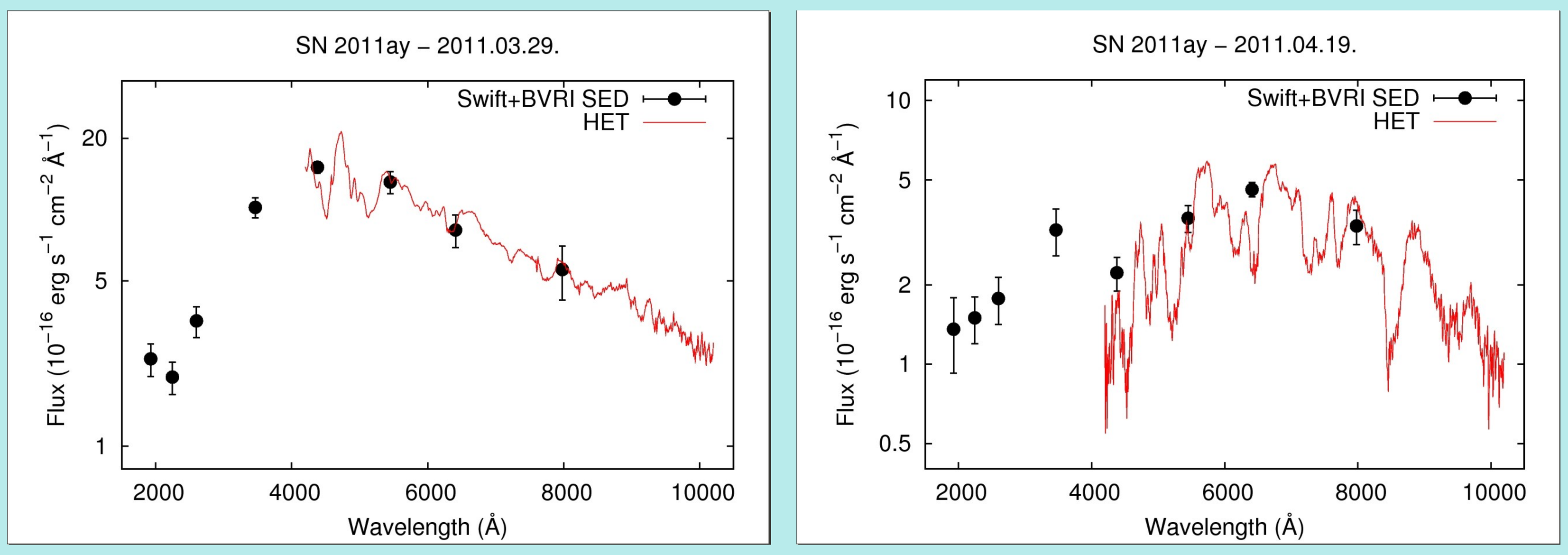
SN 2011ay has a considerably red color, similarly to other peculiar Ia SNe (1991bg, 2002cx, 2005hk). In that case, this effect is probably caused partly by the unrevealed reddening of the host galaxy.

III. Spectroscopic analysis



Optical spectra of the SN 2011ay were obtained with the ***HET Marcario Low Resolution Spectrograph*** (LRS, spectral coverage 4200 – 10200 Å, resolving power Δλ/λ ~ 600) at the ***McDonald Observatory, Texas***, between March 24 and April 19, 2011. These data were reduced with standard IRAF routines.

Fig.4. *Scaled HET spectra and the UV-optical SEDs of SN 2011ay at different epochs since B maximum: 0 days (2011. 03. 24., top left), +5 days (2011.03.29., bottom left), +26 days (2011.04.19., bottom right).*



Based on the quick analysis of an early spectrum, Silverman et al. (2011) classified SN 2011ay as a peculiar Ia belonging to the SN 2002cx-subclass. We studied three of our HET spectra in detail (obtained at 0, +5, and +26 days). Using the Supernova Identification (SNID) code, we got the same result: the spectra are most similar to the ones of SN 2005hk and 2002cx belonging to the mentioned subclass.

We also used **SYN++** and **SYNAPPS** codes to get more information about chemical and physical properties of the ejecta. The spectral composition and evolution – a relatively few Si, dominating Fe II lines, a characteristic Ca II absorption in the later phase – are very similar to the case of SN 2005hk (Sahu et al., 2008), supporting the classification of SN 2011ay.

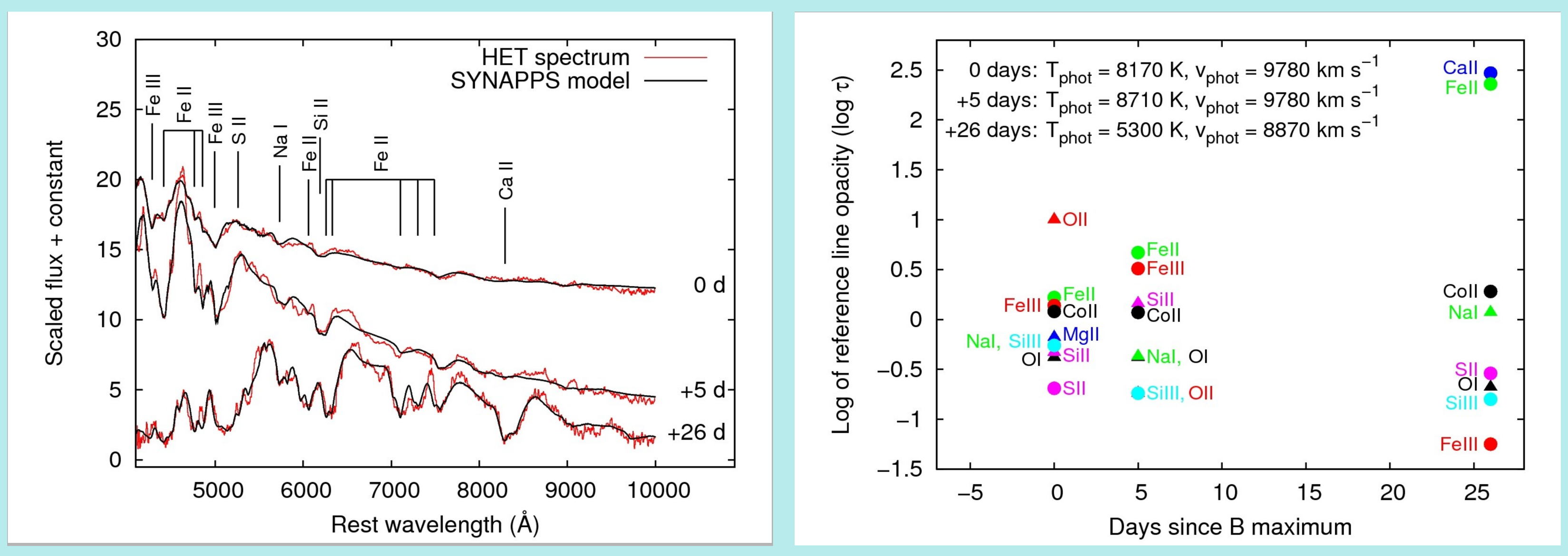
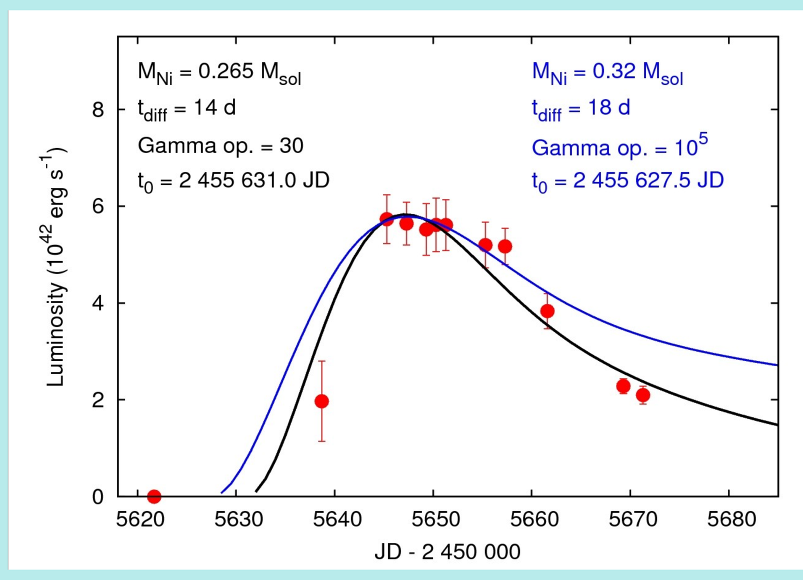


Fig.5. *Results of spectral modeling carried out with SYN++ and SYNAPPS codes: temporal changes of the spectra of SN 2011ay (left) and the line opacities (right).*

IV. Light curve modeling

We applied the simple light curve model of Arnett (1982) to derive the ^{56}Ni mass in the ejecta. The quasi-bolometric light curve and the best-fitting models are shown in Figure 4. We also plotted the two published KAIT-measurement from this period: a non-detection on March 1, and the unfiltered magnitude at the discovery (Blanchard et al. 2011). The luminosity calculated from the latter one was used as a lower limit at this epoch.



We also reduced the available ***Swift/UVOT*** data; UV and U magnitudes were used to calculate the short-wavelength components of the bolometric fluxes. The long-wavelength components were calculated using the Rayleigh-Jeans law. The derived parameters are shown in Table 1.

Fig.6. *Quasi-bolometric light curve of SN 2011ay with the best-fitting Arnett-models (optically thin case – black line; fully absorbing case – blue line). The first two luminosities were calculated from the measurements of Blanchard et al. (2011), see the text for the details.*

V. SN 2011ay – a member of the 2002cx-subclass

Our results, support the classification of SN 2011ay as a member of the peculiar 2002cx-subclass of Ia SNe. There are only a few known objects belonging to this group: they are less luminous than the „normal" Iae, they have relatively Si-poor spectra and the ejecta velocities are (sometimes extremely) low.

Although the spectra of these SNe are very similar, and there is a theory seemed to be acceptable for these objects (failed deflagration of a WD, see e. g. Foley et al., 2009), their known physical properties are quite heterogeneous (see Table 1). In the case of SN 2011ay we found

- **the largest ^{56}Ni mass and peak luminosity in that subclass (together with SN 2009ku);**
- **a small value of gamma-opacity after maximum indicating an ejecta mass lower than usually found in normal Iae;**
- **the highest maximal ejecta velocity in the 2002cx-subclass.**

Our results suggest that it is necessary to discover and study much more 2002cx-like SNe to understand their properties and origin.

Object	v_{max} (km s^{-1})	M_{bol} max.	$M(^{56}Ni)(M_{sol})$	t_{rise} (days)	References
SN 2011ay	***9,800***	***-18.2 ± 0.1***	***0.29 ± 0.03***	***16 ± 2***	***this work***
SN 2002cx	7,000	-17.7	0.15	14 – 22	Li+03, Jha+06
SN 2005hk	6,900	-17.3	0.18	15 ± 1	Phillips+07, Sahu+08
SN 2007qd	2,000	-15.4	0.013 ± 0.002	10 ± 2	McClelland+10
SN 2008ge	–	-17.1	–	9 – 27	Foley+10b
SN 2008ha	3,000	-13.9	0.003 ± 0.001	10	Foley+09, 10a
SN 2009ku	2,000	-18.3	0.3 ± 0.1	18.2 ± 3.0	Narayan+11

Table 1. *Main parameters of SN 2011ay determined via spectral and light curve modeling, comparing to the parameters of other SNe belonging to the 2002cx-subclass.*

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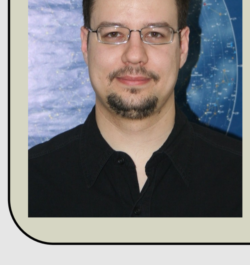

Questions? Comments?
Please let me know!

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