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Photometric observations of type II Supernovae 2009af and 2009ay

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Abstract

CCD *BVRI* photometry is presented for type II Supernovae 2009af and 2009ay. Both objects are characterized by fast linear brightness decline at early stages of their evolution and relatively high maximum luminosity. SN 2009af is distinguished by a small brightness drop during the first 200 days after maximum.

1 Introduction

Supernovae (SNe) of type II are characterized by the presence of hydrogen in their spectra and large diversity of photometric properties. Barbon et al. (1979) suggested division of SNe II into two sub-classes: SNe II-P, which show a long-duration plateau in their photometric evolution, and SNe II-L, which have “linear” declining light curves. The physical reasons for this division and the degree of separation of the sub-classes are still a subject of investigations (cf., e.g., Anderson et al. 2014).

Continuing the long-term program of SN observations at Sternberg Astronomical Institute, we carried out photometry of SNe II 2009af and 2009ay.

SN 2009af was discovered by Cortini (2009) on February 16.75 UT at magnitude 15.0 during the supernova search with a 0.35-m telescope at Monte Maggiore Observatory. The SN is located at $\alpha = 2^h03^m36\overset{s}{.}37$, $\delta = +24°04'40\overset{''}{.}9$ (equinox 2000.0), which is $15\overset{''}{.}5$ west and $10\overset{''}{.}4$ north of the center of the galaxy UGC 1551. Ciroi et al. (2009) report that a spectrogram (range 370–720 nm, resolution 1 nm) of SN 2009af, obtained on Feb. 18.76 UT at Asiago Observatory with the Galileo 1.22-m telescope shows it to be a type II supernova about 2–3 weeks after explosion. The spectrum of SN 2009af was obtained at the Kanata Observatory[1] on February 21, it is typical of SNe II and shows similarity to the spectrum of SN 1993J near maximum light.

SN 2009ay was discovered by Puckett and Peoples (2009) at magnitude 16.4 on unfiltered CCD images taken with a 0.35-m reflector at Ellijay on Mar. 20.41 UT in the course of the Puckett Observatory Supernova Search. The new object was located at $\alpha = 17^h48^m22\overset{s}{.}97$, $\delta = +54°08'54\overset{''}{.}7$ (equinox 2000.0), which is $12\overset{''}{.}1$ east and $0\overset{''}{.}4$ north of the center of NGC 6479.

Challis (2009) reports that a spectrum (range 360–800 nm) of 2009ay, obtained on Mar. 25 UT by W. Brown with the F.L. Whipple Observatory 1.5-m telescope, shows it to be a type II supernova. The spectrum shows featureless continuum with hints of broad Hβ and Hγ features. Soderberg and Brown (2009) observed SN 2009ay with the

[1] http://kanatatmp.g.hatena.ne.jp/kanataobslog/20090223/p1

Table 1: Magnitudes of local standard stars

Star	B	σ_B	V	σ_V	R	σ_R	I	σ_I
2009af-1	14.28	0.04	13.71	0.03	13.35	0.03	13.02	0.02
2009af-2	16.04	0.04	14.99	0.02	14.39	0.03	13.85	0.01
2009af-3	16.30	0.05	15.61	0.03	15.21	0.02	14.79	0.05
2009af-4	18.84	0.08	17.20	0.02	16.21	0.02	15.28	0.02
2009ay-1	13.10	0.02	12.47	0.02	12.13	0.01	11.77	0.02
2009ay-2	16.72	0.03	15.52	0.02	14.88	0.01	14.28	0.02
2009ay-3	15.52	0.02	14.92	0.01	14.58	0.01	14.22	0.02
2009ay-4	16.51	0.03	15.73	0.03	15.30	0.03	14.85	0.03
2009ay-5	17.02	0.03	16.48	0.07	15.90	0.03	15.41	0.04
2009ay-6	15.71	0.02	15.03	0.03	14.69	0.02	14.32	0.02

MMT/Blue Channel Spectrograph on Mar. 28.5 UT. They report that the spectrum clearly shows broad P Cygni hydrogen Balmer features superposed on a nearly featureless blue continuum, confirming the earlier report by Challis (2009). From the absorption minimum of the Hβ line, they infer an expansion velocity of 9800 km/s after accounting for the recession velocity of the host galaxy. They further note that the spectrum resembles those of luminous and peculiar type II supernovae 2008es and 2005ap.

2 Observations and Light Curves

We carried out observations of SN 2009af and 2009ay with the following telescopes and CCD cameras: the 60-cm reflector of Crimean Observatory of Sternberg Astronomical Institute (C60), equipped with an Apogee AP-47 CCD camera; the 50/70-cm Maksutov telescope of Crimean Observatory (C50) with a Meade Pictor 416XT camera; the 70-cm reflector in Moscow (M70) with an Apogee AP-7p camera. The images of SN 2009af were obtained also with the 2-m Faulkes North telescope (F200). The standard image reductions and photometry were made using IRAF.[2] Photometric measurements of the SNe were made relative to local standard stars using PSF fitting with IRAF DAOPHOT package. Subtraction of host galaxy background was applied for the images of SN 2009af taken in September and November, 2009. The images used for subtraction were downloaded from the CASU archive[3]. All the images for SN 2009ay were corrected for the host galaxy background; we used the images obtained at the 1-m telescope of the Special Astrophysical Observatory (Russian Academy of Sciences) (SAO RAS) a year after the SN outburst for subtraction.

The magnitudes of local standards were calibrated on photometric nights, when photometric standards were observed at different air masses. They are reported in Table 1. Images of the SNe with marked local standards are shown in Figs. 1, 2. The results of photometry of the supernovae are presented in Tables 2, 3.

The light curves of SN 2009af are presented in Fig. 3. According to Ciroi et al. (2009), the most probable date of explosion is January 31 (JD 2454862). The first set of our

[2]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation

[3]http://casu.ast.cam.ac.uk

Table 2: Observations of SN 2009af

JD 2450000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
4882.21	16.21	0.07	15.70	0.07	15.37	0.06	15.24	0.06	M70
4886.24	16.24	0.08	15.60	0.09	15.12	0.05			M70
4887.23	16.65	0.08	15.77	0.08	15.34	0.09	15.16	0.09	M70
4894.25	17.03	0.12	16.01	0.08	15.50	0.05	15.34	0.05	M70
4905.21			16.17	0.11	15.55	0.08			M70
5076.54					17.12	0.08	16.78	0.12	M70
5078.42					17.28	0.07	16.84	0.10	M70
5091.42	18.69	0.18	17.19	0.06	16.80	0.07			M70
5127.88	19.95	0.06	18.88	0.04	17.85	0.03	17.76	0.04	F200
5143.49			19.16	0.06	18.07	0.04			C60
5144.46			19.14	0.09	17.99	0.05			C60
5145.44			18.99	0.05	18.07	0.04			C60
5150.33	20.06	0.09	19.20	0.04	18.12	0.03	17.77	0.10	C60
5153.35			19.28	0.05	18.21	0.03			C60
5155.95	20.14	0.06	19.12	0.04	18.19	0.02	17.99	0.05	F200
5157.26			19.18	0.08	18.21	0.04			C60

Table 3: Observations of SN 2009ay

JD 2450000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
4917.53	17.23	0.05	16.96	0.05	16.72	0.05	16.59	0.06	M70
4926.37	17.65	0.08	17.33	0.11	17.01	0.06	16.64	0.10	M70
4931.45	17.87	0.08	17.32	0.06	16.95	0.06	16.63	0.06	M70
4934.53	18.26	0.13	17.38	0.12	17.25	0.11	16.92	0.12	M70
4944.46	18.51	0.07	17.61	0.05	17.22	0.04	16.88	0.06	M70
4948.47			17.91	0.15	17.27	0.08	16.98	0.11	M70
4951.40	18.95	0.11	17.99	0.12	17.43	0.06	17.04	0.07	M70
4956.41	19.33	0.12	17.82	0.09	17.45	0.07	17.03	0.12	M70
4970.46			18.07	0.09	17.56	0.05	17.16	0.10	M70
4983.44	19.94	0.14	18.21	0.09	17.76	0.05	17.22	0.08	M70
5001.45					18.85	0.28			C50
5015.38					19.31	0.27			C50
5017.51					19.20	0.16			C50
5043.35					19.43	0.10			M70
5054.32					19.70	0.12			M70
5073.35					19.62	0.11			C60
5080.35					19.60	0.12			C60
5081.36					19.67	0.09			C60

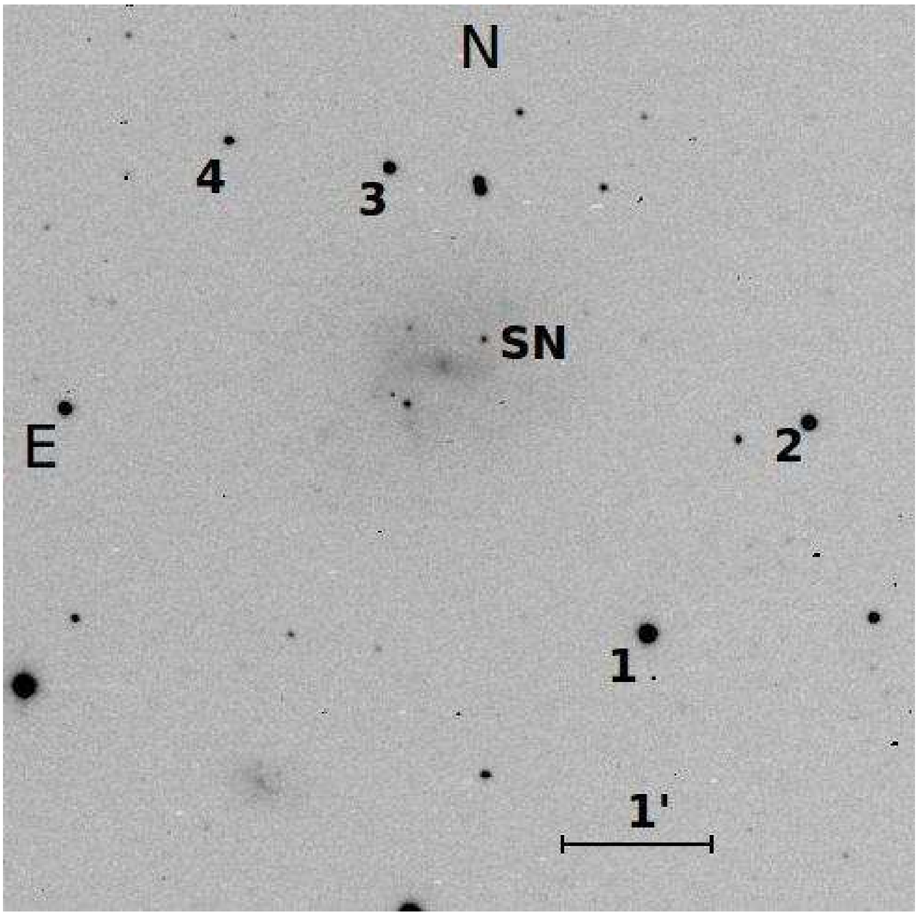

Figure 1. SN 2009af in UGC 1551 with local standard stars.

observations started on February 19 and continued till March 14. The second set covered the period from September 1 to November 21. The maximum light is not traced by our observations, and the small length of the first set and the large gap in the observations do not allow us to perform a complete analysis of the light curves. We may conclude that the early decline after maximum was very fast, the rates (in mag/day) in the BVR bands being 0.08 in B, 0.027 in V, 0.021 in R. After the gap in observations, the rates are: 0.0093 in V, 0.013 in R, and 0.015 in I. The fast early decline allows us to suppose that SN 2009af belongs to the type II-L. Indeed, the light curves of typical SNe II-L 1979C, 1980K, 1998S (Balinskaya et al. 1980; Buta 1982; Fassia et al. 2000) are a good match for the early part of the light curves of SN 2009af. However, the drop of brightness for the first ~200 days past maximum is only $1.6^{\rm m}$ in the I band, $2.0^{\rm m}$ in R, and $3.1^{\rm m}$ in the V band. This is much smaller than usual for SNe II-L. For SN 1980K, the drop in the V band for 200 days is $6^{\rm m}$. For the typical SN II-P 1999em, it is $3.5^{\rm m}$. The behavior of light curves in the R and I bands permits to conclude that there was a time interval of slower brightness decline in the gap between our observations. The spectrum of SN 2009af obtained at the Kanata Observatory suggests similarity to SN IIb 1993J, but the light curves of this SN do not match the light curves of SN 2009af.

The light curves of SN 2009ay are shown in Fig. 4. Unfortunately, the maximum light was also not covered by observations, and only R-band magnitudes are available for the late stage. The early decline was also linear, but slower than for SN 2009af. The

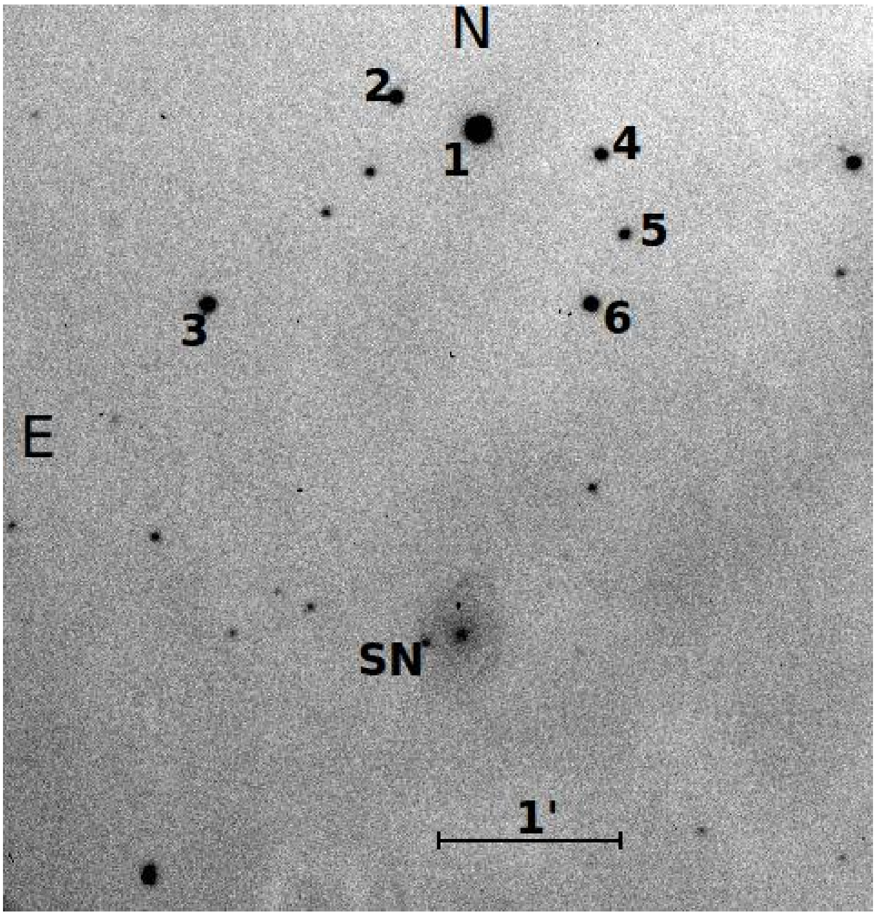

Figure 2. SN 2009ay in NGC 6479 with local standard stars.

estimated rates in the $BVRI$ bands are, respectively, 0.056, 0.021, 0.016 and 0.010. The linear decline continued till JD2454980–90; after that, a fast decline to the tail took place. The rate of decline in the R band on the tail was 0.006, significantly slower than for SN 2009af. There are quite a lot of type II SNe with similar morphology of the light curves; among the sample studied by Anderson et al. (2014), we find SNe 2008K and 2008aw to be the best match for SN 2009ay.

3 Absolute magnitudes

The R-band absolute-magnitude light curves of SNe 2009af and 2009ay are presented in Fig. 5.

We adopted the following distance moduli and Galactic extinction from the NED database[4]: for SN 2009af, $\mu = 32.88$; $A_R = 0.20$; and for SN 2009ay, $\mu = 34.91$; $A_R = 0.09$. The extinction in the host galaxies should not be significant, because the colors of both SNe are similar and not redder than the colors of the type II SN 1999em (Elmhamdi et al. 2003). Besides, there is no clear evidence for the presence of interstellar NaI D absorption lines in the published spectra of SN 2009af. The light curves of SNe 2009af and 2009ay

[4]http://ned.ipac.caltech.edu

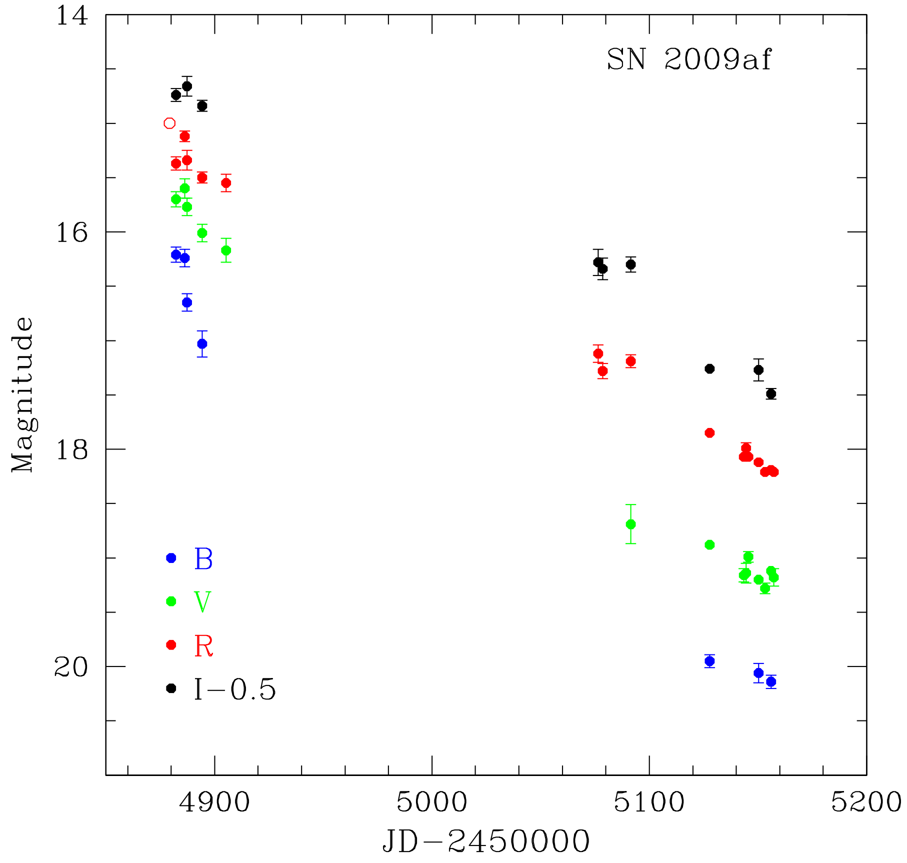

Figure 3. The light curves of SN 2009af. Dots show our data, the circle is the discovery magnitude by Cortini (2009).

are compared to the light curves of type II-L SNe 1979C (Balinskaya et al. 1980), 1980K (Buta 1982) and 1998S (Fassia et al. 2000); type II-P SNe 1999em (Elmhamdi et al. 2003) and 2009bw (Inserra et al. 2012). We conclude that SNe 2009af and 2009ay reach a similar maximum absolute R-band magnitude, about -18.3^{m}. They are fainter than SNe II-L 1979C and 1998S, but brighter than SNe II-P 1999em and 2009bw. SN II-L 1980K is the closest to SNe 2009af and 2009ay among the plotted objects, but the shapes of the light curves are different. The relatively high luminosity of SN 2009af at late stage is also evident.

4 Conclusions

We present the $BVRI$ light curves of two type II SNe, which exhibited fast linear brightness decline at the early stages of their evolution. Unfortunately, the maximum light was not covered by observations, and the large gap in the data for SN 2009af does not permit more definite conclusions. Nevertheless, we show that SN 2009af is different from all the well-studied SNe II-L by its very small brightness drop during the first 200 days of evolution. SN 2009ay can be considered as a transitional object between sub-classes II-P and II-L. SNe 2009af and 2009ay have similar maximum luminosity. It is close to the mean value for SNe II-L according to Richardson et al. (2002), but significantly lower than for

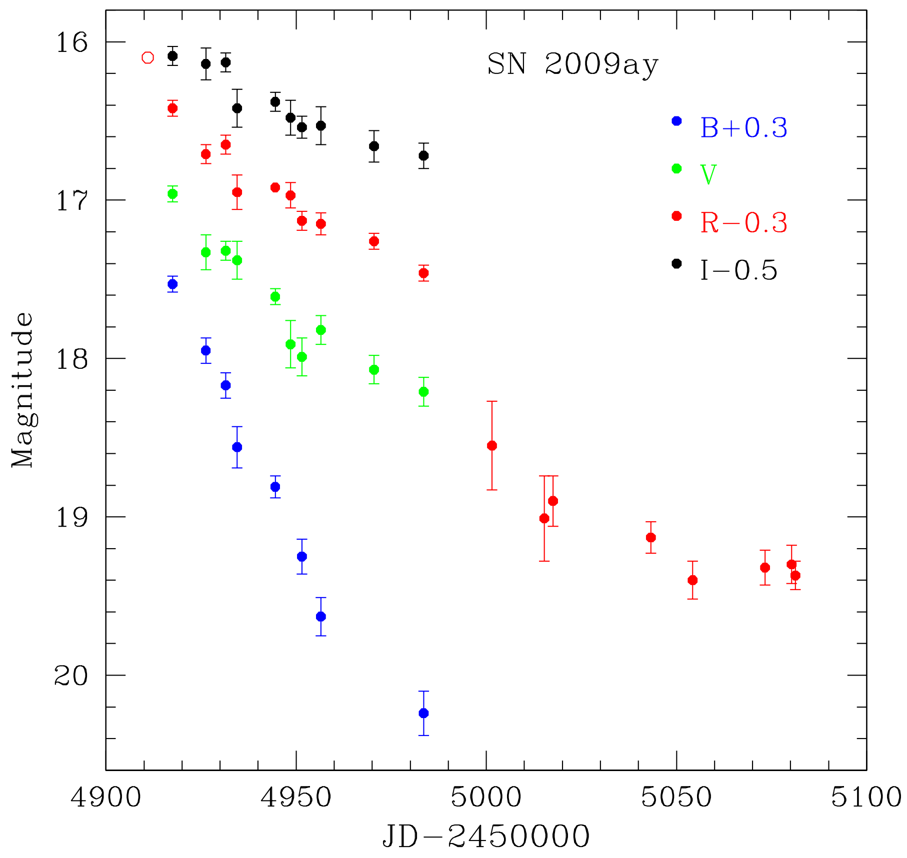

Figure 4. The light curves of SN 2009ay. Dots show our data, the circle is the discovery magnitude from Puckett and Peoples (2009).

the most luminous type II-L SNe 1979C and 1998S. SN 2009ay is much fainter than the extremely luminous SNe II 2008es, 2005ap, though Soderberg and Brown (2009) reported that the spectrum of SN 2009ay showed similarity to the spectra of these objects. Our results emphasize the diversity of type II SNe photometric evolution.

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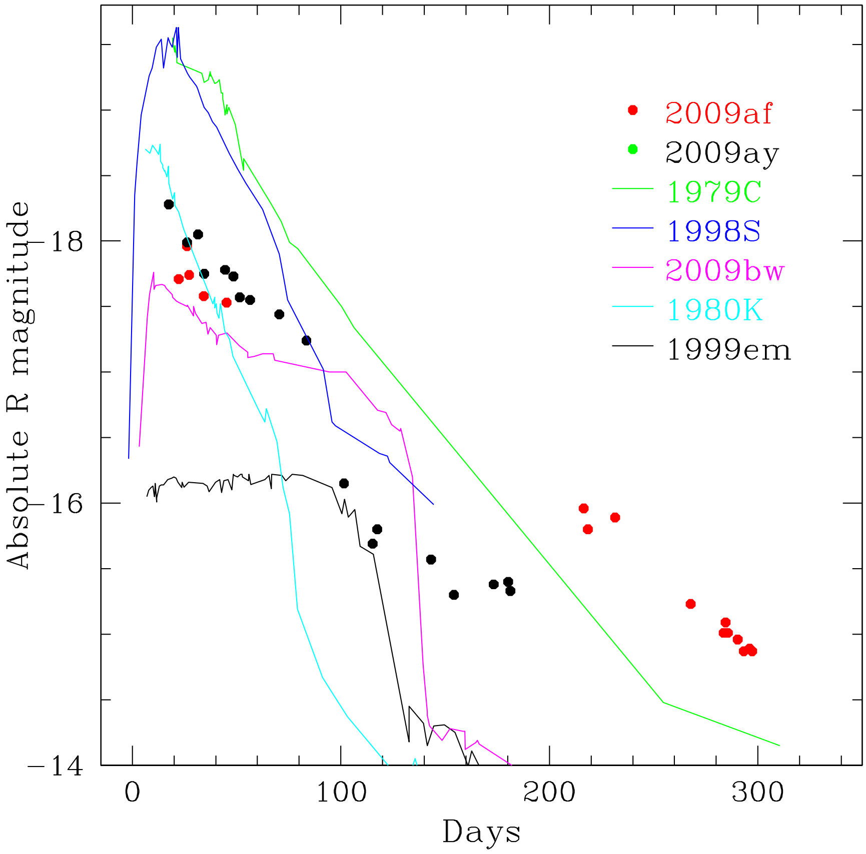

Figure 5. The absolute R-band light curves of SNe 2009af and 2009ay, compared to the light curves of five type II SNe (for SN 1980K, the V-band light curve is plotted).

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