Peremennye Zvezdy (*Variable Stars*) **30**, No. 2, 2010

Received 10 March; accepted 15 March.

SN 2008fv: the Third Type Ia Supernova in NGC 3147

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Abstract

Multiple outbursts of type Ia SNe in one galaxy present a unique opportunity to study the homogeneity of these objects. NGC 3147 is only the second known galaxy with three SNe Ia, another one is NGC 1316. We present CCD $UBVRI$ photometry for SN Ia 2008fv and compare the light and color curves of this object to those for SNe Ia discovered in NGC 3147 earlier: 1972H and 1997bq. The photometric properties of SNe 1997bq and 2008fv are nearly identical, while SN 1972H exhibits a faster-declining light curve.

SN 2008fv

SN 2008fv was discovered by K. Itagaki on unfiltered CCD images exposed with a 0.6-m reflector around September 27.78 UT at magnitude 16.5. The new object was located at $\alpha = 10^{\rm h}16^{\rm m}57\overset{\rm s}{.}28$, $\delta = +73°24'36\overset{''}{.}4$ (J2000.0), which is 16″ east and 34″ north of the center of the galaxy NGC 3147 (Nakano 2008).

Challis (2008), on behalf of the CfA Supernova Group, reported that a spectrum (range 350–880 nm) of SN 2008fv, obtained on September 30 with the MMT at Mt. Hopkins, showed it to be a normal type-Ia supernova about one week before maximum light. This is the fourth SN discovered in NGC 3147, the former were SN I 1972H (Goranskij 1972; Barbon et al. 1973), SN Ia 1997bq (Laurie and Challis 1997; Jha et al. 2006), and SN Ib 2006gi (Itagaki 2006; Elmhamdi et al. 2010).

We started photometric monitoring of SN 2008fv soon after its discovery, on October 3, with the remotely controlled telescope of the Tzec Maun Observatory. Later we also observed the SN with four other telescopes at three different locations. The data on the telescopes and detectors are presented in Table 1.

All image reductions and photometry were made using IRAF.†

The image of NGC 3147 obtained at C60 in the R band is presented in Fig. 1. SN 2008fv and the sites of three previous SNe are marked, as well as the local standard stars. The magnitudes of these stars are reported in Table 2, they were calibrated on 12 photometric nights during monitoring SNe 2006gi and 2008fv. Stars 1 and 3 were also used as standards for the photometry of SN 2006gi (Elmhamdi et al. 2010).

SN 2008fv is projected on the spiral arm, and the subtraction of galaxy background is necessary for reliable photometry. The template images were constructed from frames obtained in November 2006 at C60 while monitoring SN 2006gi. After template subtraction, the magnitudes of the SN were derived by PSF fitting relative to a sequence of local standard stars.

†IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation.

Table 1: Telescopes and detectors used for observations

Telescope	D(cm)	F(cm)	CCD camera	Filters	Location	Code
Maksutov–Newton	35	133	SBIG ST-10E	VR	Mayhill, New Mexico, USA	TM35
Cassegrain	70	1050	Apogee AP-7p	$UBVRI$	Moscow, Russia	M70
Cassegrain	60	750	Apogee AP-47p	$BVRI$	Nauchny, Crimea, Ukraine	C60
Maksutov	50	200	Meade Pictor 416XT	VRI	Nauchny, Crimea, Ukraine	C50
Newton	50	250	SBIG ST-10XME	$UBVRI$	Tatranska Lomnica, Slovakia	S50

Table 2: Magnitudes of local standard stars

Star	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I
1	13.88	0.05	13.40	0.01	12.58	0.01	12.12	0.01	11.75	0.01
2			14.91	0.02	14.15	0.02	13.71	0.01	13.37	0.03
3			17.28	0.05	16.43	0.04	15.95	0.03	15.45	0.04

The observations of SN 2008fv at TM35 in the VR filters are presented in Table 3, and the photometry in the $UBVRI$ filters obtained with other telescopes is reported in Table 4.

The light curves are shown in Fig. 2. The maximum phase in the V and R bands is well-sampled by the observations, and we can derive the dates and magnitudes of maximum light: $V_{max} = 14.44$ on JD 2454752, $R_{max} = 14.37$ on the same date. The rate of early decline in the V band corresponds to $\Delta m_{15}(V) = 0.65$. From the list of type Ia SNe presented by Hicken et al. (2009), we select three SNe with similar $\Delta m_{15}(V)$ and best-observed light curves: 1992bc, 2006ax, 2007af (Hamuy et al. 1996; Hicken et al. 2009). We fit the light curves of SN 2008fv to those for the three SNe listed above and find that, in the V band, the fits for all the three objects are equally good. In the B band, SN 1992bc provides the best fit, while in the R band, SN 2006ax gives the best result. The I-band light curve cannot be fitted well by any of these SNe, but SN 2006ax provides a slightly better match.

After JD 2454820, the V and R light curves show a linear decline with the rate 0.022 mag day^{-1}, which is quite normal for SNe Ia at this stage.

SN 1972H

SN 1972H was discovered by Goranskij (1972) on a plate exposed on 1972 August 3.9 UT at the Crimean observatory of the Sternberg Astronomical Institute. Photographic photometry in a band close to B was reported by Goranskij (1972), and in the B, V filters by Barbon et al. (1973). The magnitudes of the SN were eye-estimated on the plates relative to sequences of local comparison stars, which were calibrated photographically. While compiling the data on the light curves of SNe, we recalibrated these standards using photoelectric and photographic photometry and measured the plates obtained by Goranskij (1972) with a microphotometer (Tsvetkov 1985). Now we calibrate these stars

Table 3: Observations of SN 2008fv at TM35

JD 2454000+	V	σ_V	R	σ_R	JD 2454000+	V	σ_V	R	σ_R
742.86	14.89	0.03	14.73	0.02	773.93	15.36	0.03	15.12	0.06
746.92	14.56	0.02	14.44	0.02	776.86	15.57	0.03	15.16	0.02
747.90	14.52	0.02	14.43	0.01	777.85			15.18	0.01
748.91	14.47	0.02	14.36	0.01	778.98	15.65	0.03	15.23	0.01
749.91	14.47	0.02	14.37	0.02	779.98	15.71	0.03		
752.88	14.45	0.02	14.39	0.01	781.89	15.85	0.03	15.41	0.02
755.94	14.52	0.02	14.44	0.03	786.93	16.18	0.04	15.73	0.04
756.93	14.59	0.05	14.56	0.02	787.97	16.35	0.03	15.78	0.04
759.82	14.72	0.03	14.68	0.02	791.98	16.40	0.04	15.99	0.06
761.95	14.82	0.03	14.81	0.02	795.98	16.49	0.04	16.08	0.03
762.92	14.91	0.02	14.89	0.02	799.02	16.62	0.05	16.20	0.02
763.97	14.96	0.02	14.97	0.01	801.99	16.66	0.05	16.33	0.04
766.93	15.12	0.02	15.08	0.02	803.00	16.48	0.12	16.33	0.03
767.95	15.17	0.03	15.10	0.01	804.98			16.58	0.11
768.92	15.20	0.02	15.10	0.01	806.96	17.02	0.10	16.46	0.09
771.93	15.31	0.03	15.14	0.01					

Table 4: Observations of SN 2008fv at other telescopes

JD 2454000+	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
755.33	14.89	0.07	14.89	0.03	14.37	0.03	14.41	0.02	14.65	0.07	M70
759.66	14.97	0.08	15.03	0.03	14.62	0.03	14.60	0.03	14.99	0.05	S50
778.45					15.56	0.03	15.20	0.02	14.80	0.05	C50
779.56			16.88	0.04	15.65	0.02	15.22	0.02	14.68	0.07	C60
780.49			17.00	0.04	15.70	0.02	15.31	0.02	14.78	0.03	C60
781.59			17.13	0.03	15.79	0.03	15.36	0.02	14.80	0.03	C60
782.41			17.05	0.04	15.86	0.03	15.44	0.02	14.81	0.04	C60
783.55			17.17	0.05	15.91	0.03	15.49	0.02	14.91	0.04	C60
784.49			17.25	0.07	15.94	0.03	15.56	0.02	14.96	0.05	C60
786.42			17.20	0.06	16.04	0.04	15.67	0.02	15.09	0.06	C60
795.36			17.67	0.04	16.47	0.03	16.14	0.02	15.60	0.05	C60
796.48			17.53	0.03	16.51	0.03	16.17	0.03	15.66	0.05	C60
799.41							16.28	0.05			S50
845.22							17.87	0.10			M70
866.21							18.08	0.09			M70
868.20							18.28	0.09			M70
894.36					18.98	0.06	18.90	0.07			M70

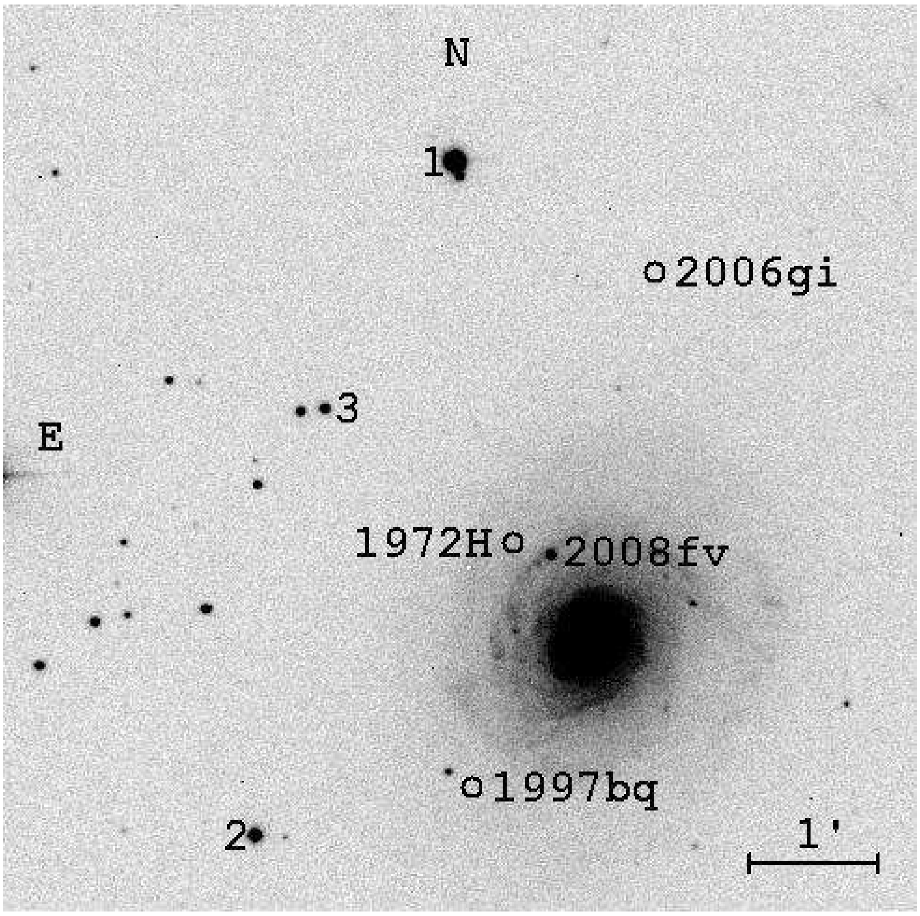

Figure 1. SN 2008fv in NGC 3147. Circles indicate the sites of previous SNe, the local standard stars are marked.

again on our CCD frames relative to our local standards 1 and 2. The results confirm the conclusion by Tsvetkov (1985) that the calibration of Barbon et al. (1973) in the B band is quite accurate, but in the V band their magnitudes are systematically too faint by about $0\overset{m}{.}15$. However, for some of the comparison stars the random errors of our photographic photometry are found to be quite large. We combine old plate measurements with the new calibration of local standards and obtain new magnitudes for SN 1972H, which are reported in Table 5. We correct the magnitudes of Barbon et al. (1973) for the systematic errors of their comparison-star photometry. The resulting light curves for SN 1972H are shown in Fig. 3.

Unfortunately, no spectroscopic observations were reported for SN 1972H. The classification as type I was proposed by Barbon et al. (1973) and was based on the shape of the light curve. We attempted to fit the data for SN 1972H to the light curves of SNe Ia, IaPec(1991bg class), and Ib/c, and found that the best match was achieved for fast-declining SNe Ia, such as 1994D and 2007gi (Richmond et al. 1995; Altavilla et al. 2004; Zhang et al. 2010). Besides, there is a clear indication of a hump on the V-band light curve, which is never observed for SNe Ib/c or IaPec. Thus, we may conclude that the probability of SN 1972H being a normal SN Ia is very high. The fitting of light curves of SNe 1994D and 2007gi indicates that SN 1972H reached maximum light around JD 2441530 with $B_{max} = 15.2, V_{max} = 14.7$. The match for the V-band curve is good for the whole period covered with observations, while in the B band, the tail of the light curve

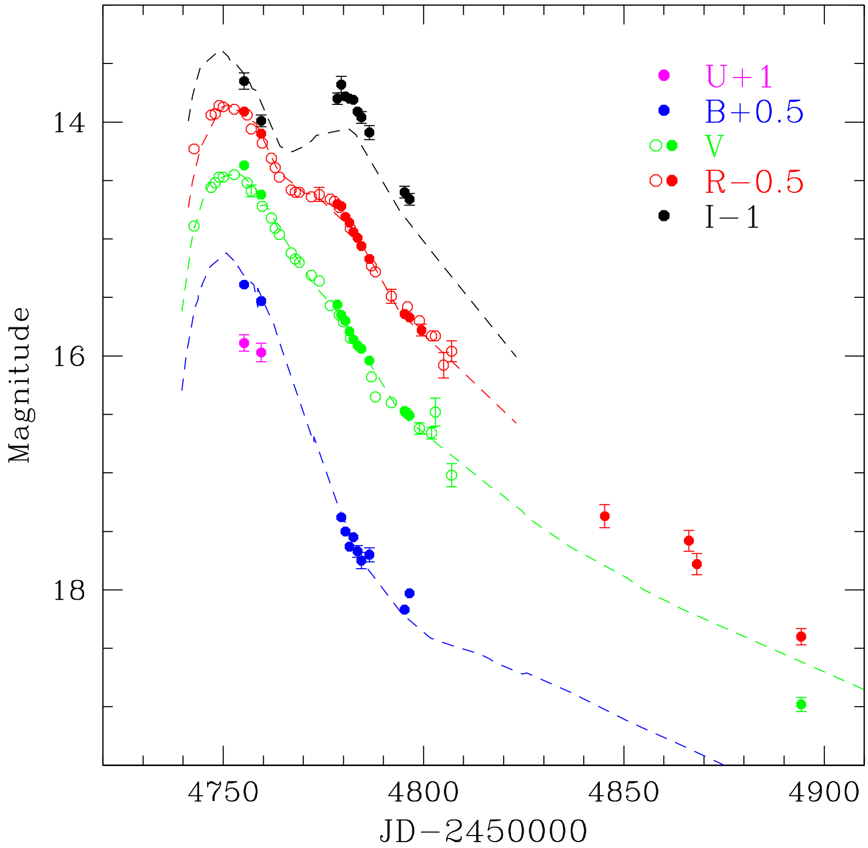

Figure 2. The light curves of SN 2008fv. Circles show data obtained at TM35, dots are for observations at other telescopes. The error bars are plotted only if they exceed the size of a symbol. The dashed lines are the light curves of SN 1992bc (B and V bands) and SN 2006ax (R and I bands).

for SN 1972H is not fitted by the curve of SN 1994D, and only the start of the tail is fitted by the curve of SN 2007gi. We may suppose that the decline rate at the tail for SN 1972H is slower than usual, or that there are large errors of the photographic magnitudes at the late stage, perhaps due to the galaxy background.

Comparison of light and color curves for the three SNe

The light curves of SNe 1972H, 1997bq (Jha et al., 2006), and 2008fv in the B and V bands are compared in Fig. 4.

The curves were shifted only in time to match the dates of maximum in the V band. The striking similarity of the V-band light curves for SNe 1997bq and 2008fv is the most interesting result. The light curves in the B band are also similar, but they are not so well-sampled, and the similarity is not so evident as for the V curves. SN 1972H clearly shows faster declining light curves with fainter maxima. The light curves of SNe 1997bq and 2008fv in the R and I bands are compared in Fig. 5. Again we see a nearly perfect agreement between these objects, there is only a slight difference of the R curves at phases 10–20 days past maximum.

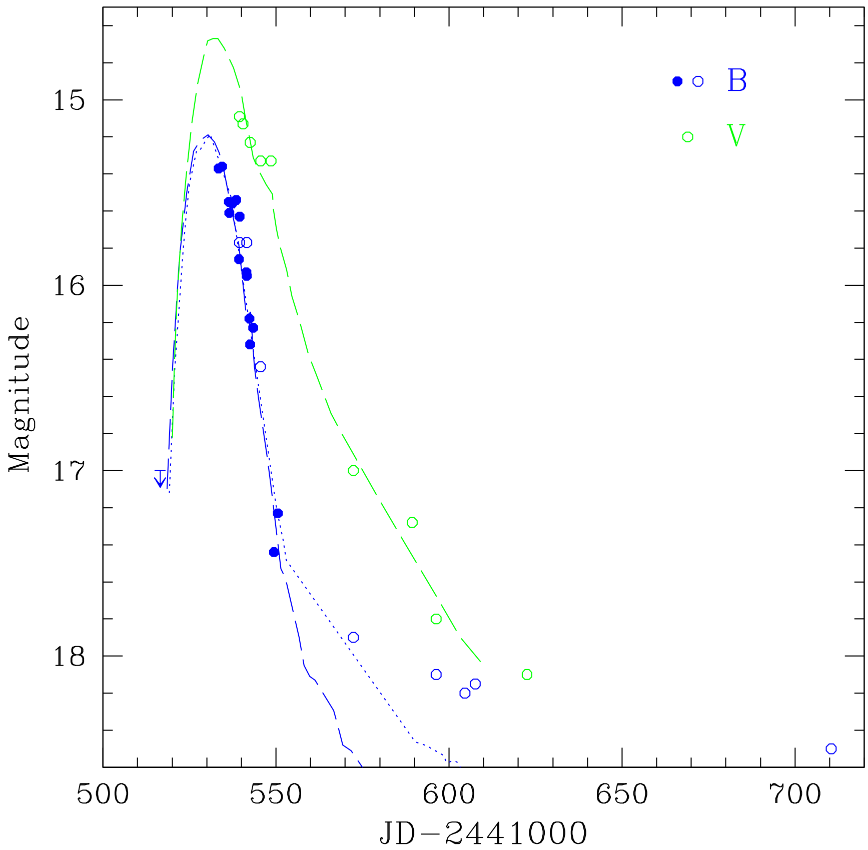

Figure 3. *BV* light curves of SN 1972H, showing our photometry (dots) and that of Barbon et al. (1973) (circles). Dashed lines are the *BV* light curves of SN 1994D, dotted line is the *B*-band light curve of SN 2007gi.

The color curves are presented in Fig. 5. As expected, the color curves of SNe 1997bq and 2008fv are nearly identical, the difference can be noticed only for the $(V-R)$ curve 10–20 days past maximum. These SNe are clearly reddened, the comparison of $(B-V)$ color after phase 30 days with the "Lira–Phillips relation" (Phillips et al. 1999) allows to estimate $E(B-V) = 0.2$. The $(B-V)$ color of SN 1972H is significantly redder than the curve for SN 1994D at the phase of early decline, but later, the color becomes even bluer than the "Lira–Phillips relation". Note, however, that colors derived from photographic photometry may have large errors. So we cannot make any reliable estimate of reddening for SN 1972H and only suppose that $E(B-V)$ probably is in the $0-0\overset{m}{.}2$ range.

Among the three SNe, the rate of decline in the V band can be directly determined only for SN 2008fv. Observations of this SN in the B band started after maximum. SN 1972H was discovered after maximum, and we have only an upper limit to constrain the rising branch of the light curve. SN 1997bq have well-observed parts of their light curves before and after maximum, but there is a gap around maximum light.

From the fitting of template light curves, we can estimate that, for SN 1972H, $\Delta m_{15}(B) \approx 1.35$, $\Delta m_{15}(V) \approx 0.8$; for SN 2008fv, $\Delta m_{15}(B) \approx 0.85$. Jha et al. (2006) estimate $\Delta m_{15}(B) = 1.01$ for SN 1997bq, and we suppose that in the V band its light curve is identical to that for SN 2008fv, with $\Delta m_{15}(V) = 0.65$.

If we assume, for NGC 3147, the distance modulus $\mu = 33.2$ and the galactic extinction

Table 5: Photographic observations of SN 1972H

JD 2441500+	B	JD 2441500+	B
16.5	>17	39.5	15.63
33.4	15.37	41.4	15.93
34.4	15.36	41.5	15.95
36.4	15.55	42.3	16.18
36.5	15.61	42.5	16.32
37.3	15.56	43.4	16.23
38.5	15.54	49.4	17.44
39.3	15.86	50.5	17.23

$A_V^{gal} = 0.077$, as in Elmhamdi et al. (2010), the maximum absolute magnitudes for SNe 1997bq and 2008fv (uncorrected for extinction in the parent galaxy) are $M_B = -18.7$, $M_V = -18.84$, and for SN 1972H, $M_B = -18.1$, $M_V = -18.6$. If we compare these data to the plots of SN Ia absolute magnitudes versus $\Delta m_{15}(B)$ reported by Hicken et al. (2009), we find that they are within the scatter of points presenting M_B and M_V, not corrected for the host-galaxy extinction, but are significantly fainter than the mean values of M_B^0 and M_V^0.

After correction for the host galaxy extinction with $E(B-V) = 0.2$ and $R_V = 3.1$, we obtain $M_B^0 = -19.4$, $M_V^0 = -19.38$ for SNe 1997bq and 2008fv, which is very close to the ridge line of the relations between M_B^0, M_V^0 and $\Delta m_{15}(B)$. For SN 1972H, we can estimate the host galaxy extinction, comparing its M_B and M_V to mean values of M_B^0 and M_V^0 for $\Delta m_{15}(B) = 1.35$. The comparison yields $A_B \approx 0.9$ and $A_V \approx 0.5$, which correspond to the color excess $E(B-V) \approx 0.2$. Such color excess means that the $(B-V)$ color for SN 1972H is significantly bluer than the "Lira–Phillips relation" at the tail stage. But these colors may have large errors, and even with smaller color excess (the lower limit is about $0\overset{m}{.}1$ mag), the absolute magnitudes of SN 1972H are still within the range of dispersion on the relation between M_B^0, M_V^0 and $\Delta m_{15}(B)$.

Let us also consider the locations of the SNe in the host galaxy. SN 2008fv is in the spiral arm at the distance of $R = 7.5$ kpc from the center of the galaxy, while the radius of the galaxy is 24.5 kpc. SN 1972H exploded in an interarm region, only 3.2 kpc from the site of SN 2008fv, at $R = 9.9$ kpc. SN 1997bq was located outside the region of spiral structure, at $R = 16.0$ kpc. And the only core-collapse SN in NGC 3147, SN Ib 2006gi, exploded at $R = 30.9$ kpc, well outside the boundaries of the galaxy.

The comparison of photometric data for the three type Ia SNe discovered in NGC 3147 reveals a very high similarity between two of them: SNe 1997bq and 2008fv. Not only photometric parameters, but the host-galaxy extinction is also the same for the two objects. This is quite surprising, taking into account the different environments of these objects in the host galaxy. The maximum luminosity of SNe 1997bq and 2008fv fits very well to the relation of absolute magnitude versus the initial decline rate. The data for SN 1972H are of lower quality and do not permit a definite determination of photometric parameters, but the most probable value of absolute magnitude is also in agreement with the above-mentioned relation. The results confirm the usefulness of type Ia SNe for providing accurate distance estimates required for measuring cosmological parameters.

Acknowledgements. We are grateful to S.Yu. Shugarov and I.M. Volkov, who made some of the observations. The work of D.T. was partly supported by the Leading Scientific Schools Foundation under grant NSh.433.2008.2.

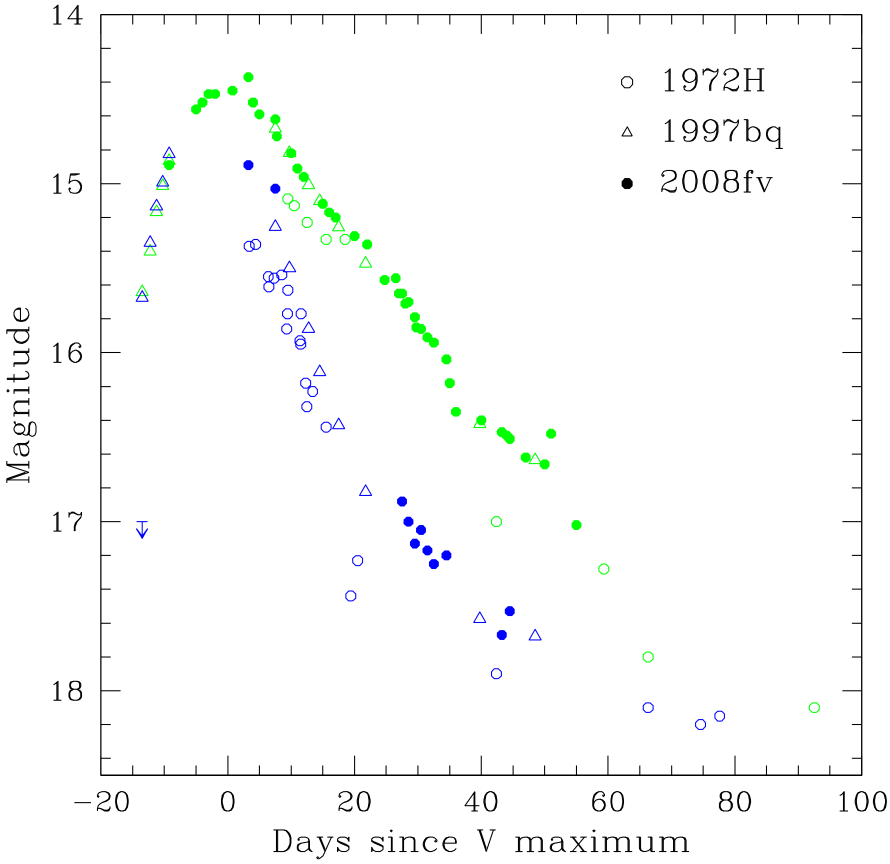

Figure 4. The light curves of SNe 1972H, 1997bq, and 2008fv in *B* (blue) and *V* (green) bands.

References:

Altavilla, G., Fiorentino, G., Marconi, M., et al., 2004, *MNRAS*, **349**, 1344
Barbon, R., Ciatti, F., Rosino, L., 1973, *Astron. Astrophys.*, **29**, 57
Challis, P., 2008, *CBET*, No. 1522
Elmhamdi, A., Tsvetkov, D., Danziger, I.J., Kordi, A., 2010, preprint, arXiv:1001.0945
Goranskij, V.P., 1972, *Astron. Tsirk.*, No. 723, 1
Hamuy, M., Phillips, M.M., Suntzeff, N.B., et al., 1996, *Astron. J.*, **112**, 2408
Hicken, M., Challis, P., Jha, S., et al., 2009, *Astrophys. J.*, **700**, 331
Itagaki, K., 2006, *IAUC*, No. 8751
Jha, S., Kirshner, R.P., Challis, P., et al., 2006, *Astron. J.*, **131**, 527
Laurie, S., Challis, P., 1997, *IAUC*, No. 6616
Nakano, S., 2008, *CBET*, No. 1520
Phillips, M.M., Lira, P., Suntzeff, N.B., et al., 1999, *Astron. J.*, **118**, 1766
Richmond, M.W., Treffers, R.R., Filippenko, A.V., et al., 1995, *Astron. J.*, **109**, 2121
Tsvetkov, D.Yu., 1985, *Variable Stars*, **22**, 191
Zhang, T., Wang, X., Li, W., et al., 2010, *PASP*, **122**, 1

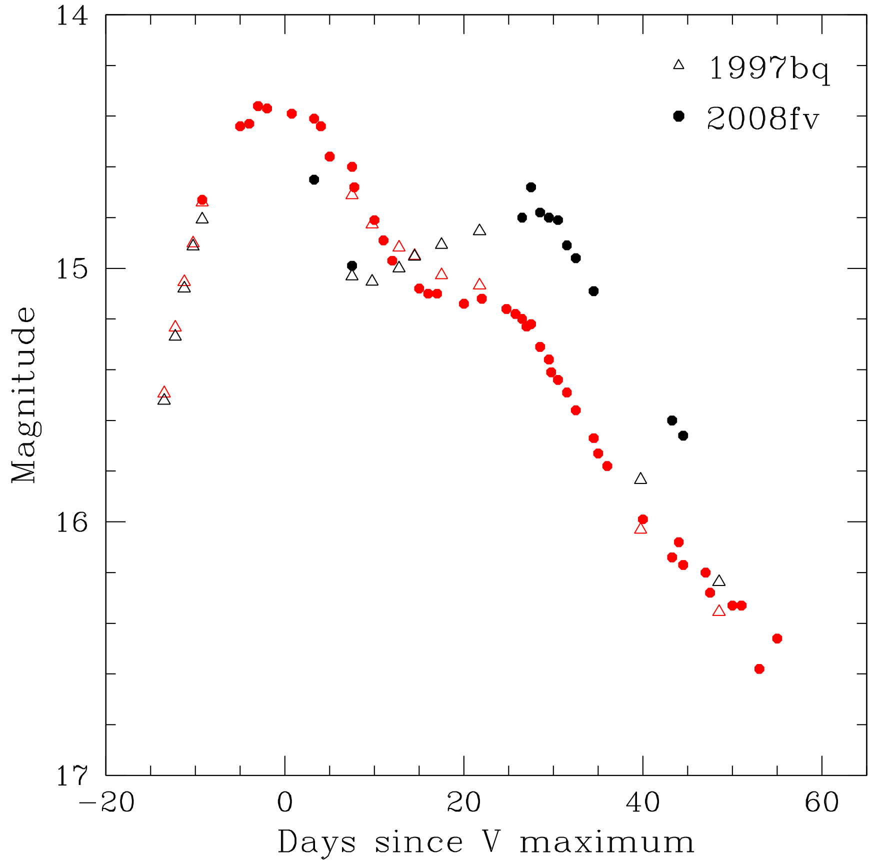

Figure 5. The light curves of SNe 1997bq and 2008fv in R (red) and I (black) bands.

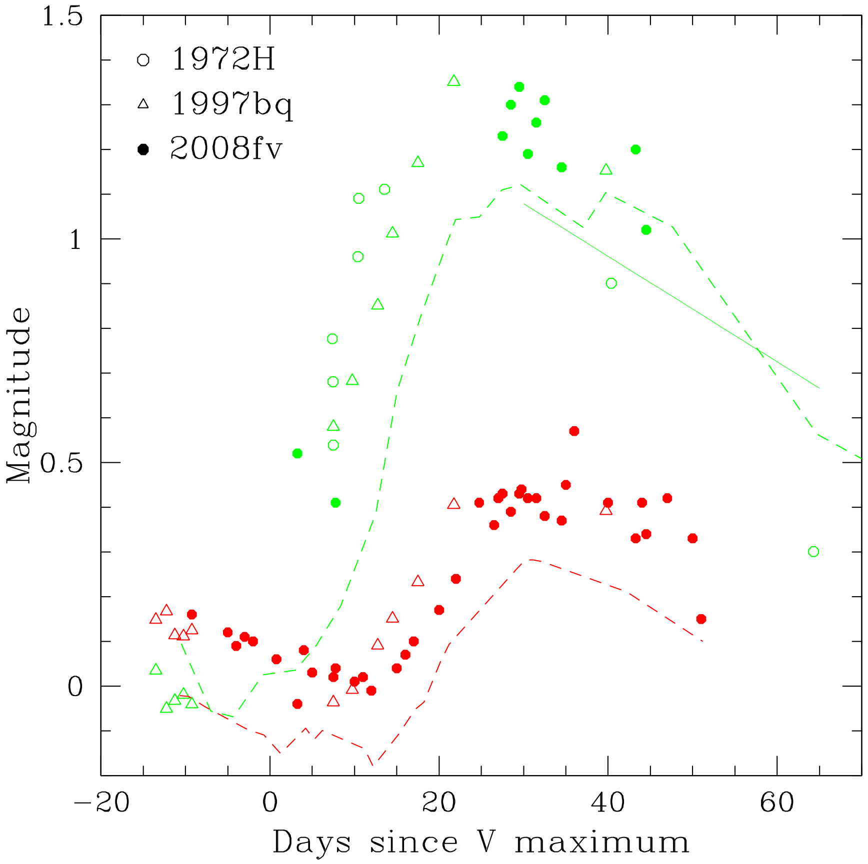

Figure 6. The $(B-V)$ (green) and $(V-R)$ (red) color curves for SNe 1972H, 1997bq and 2008fv. The green dashed line is the $(B-V)$ color curve of SN 1994D, the red dashed line is the $(V-R)$ color curve of SN 2006ax. The solid green line presents the "Lira–Phillips relation".