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Letter to the Editor

UBVRI photometry of SN 1994D in NGC 4526

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Abstract. In this paper, we present UBVRI photometric results of SN 1994D which covers the period from March 11 to April 4. All these data were obtained with a Ford 2048x2048 CCD, which has been attached to the 60/90 cm Schmidt telescope in Xinglong station, BAO. The light curves indicate that the supernova is a normal type Ia, a good distance indicator of its parent galaxy. The distance modulus of NGC 4526 is given as 30.07 ± 0.42.

Key words: Supernovae – SN 1994D – photometry – distance

1. Introduction

Treffers, Filippenko, Van Dyk, and Richmond (1994) first reported their discovery of SN 1994D on March 7 (UT) 1994. Shanks, Croom, and Tanvir (1994) found that its B-V color is close to the mean of type-Ia supernovae at maximum, which was confirmed by later spectral observations. Kilmartin and Gilmore (1994) provided the position of SN 1994D as $12^h31^m29^s.99$ and $7°58'36''.5$ (epoch 1950.0).

Type Ia supernovae are important in distance determinations. They can be used as standard candles at galaxy distances, but recent observations show that there are also some differences in type-Ia (Leibundgut et al. 1993), which may result from their different environments. SN 1994D will enhance the statistical significance of such effects.

A brief description of our observation on SN 1994D, the data reduction and the derivation of the magnitudes will be made in Section 2; in Section 3, we present our photometric results; finally, the derivation of distance modulus to NGC 4526 is attempted in Section 4.

2. Observations and data reduction

UBVRI photometry of SN 1994D was taken using the 60/90 cm Schmidt telescope in Beijing Astronomical Observatory (BAO), with a Ford 2048x2048 CCD, which has a field of view of 58'x58'. From March 11 to April 4, 1994, 17 nights were used to observe the source, covering the peak phase. In the first night, only the images in U, B and V bands were taken, while in some other nights the supernova was observed 2 to 3 times in all five filters, which allowed us to estimate the photometric accuracy. The exposure times ranged from hundreds to thousands of seconds, depending on the filter used and the weather condition.

Data reduction was made in the usual way: bias subtracted and flat field corrected. But no dark-current subtraction was carried out since it was insignificant for the CCD chip we used. Flat fields were taken each day. For the data of the first several nights (Mar 11 to Mar 18), dome flats were used for all bands. But due to technical reasons, twilight flats were used after Mar 19 as flat fields for the images taken in U, B and V bands, while dome flats were used for the images taken in R and I bands.

Since none of the 17 nights was photometric, we had to rely on differential photometry. The photometric results of ten stars in the vicinity of NGC 4526 were selected from the work of Kilkenny and Malcolm (1984) as our reference. The (V-I) indices of star No.4 and star No.12 were not used due to their large uncertainty.

Accurate photometry of this supernova is really difficult. We can choose one of the two classical methods which are widely used in the literature, aperture photometry or PSF fitting. It is difficult to derive an appropriate PSF in our case, for the 1.67"/pixel resolution makes the star images severely undersampled. And there are also some problems if we choose aperture photometry. SN 1994D is very close to the center of its parent galaxy, only 9" west and 7" north of the nucleus (Treffers et al. 1994). This would make direct background subtraction very uncertain, for the background determination would be severely affected by the light from the galaxy. Thus a slightly different approach was adopted.

The trick is to ultilize the symmetric configuration of the galaxy. NGC 4526 is an S0 galaxy with a dust ring near the nucleus (Burstein et al. 1979; Michard 1985; M.-P., Véron-Cetty and P., Véron 1988). From the images we obtained, we argue that the galaxy is highly (although not

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Table 1. Magnitudes of SN 1994D

UT (March)	U (mag)	UT (March)	B (mag)	UT (March)	V (mag)	UT (March)	R (mag)	UT (March)	I (mag)
11.72	12.61	11.70	13.01	11.69	13.00	-	-	-	-
12.72	12.22	12.68	12.76	12.64	12.75	12.61	12.61	12.63	12.64
12.77	12.23	12.82	12.71	12.85	12.67	-	-	12.88	12.59
14.67	11.78	14.65	12.30	14.64	12.31	14.63	12.16	14.63	12.20
14.73	11.73	14.76	12.30	14.77	12.28	14.78	12.18	14.78	12.24
14.82	11.73	14.84	12.25	14.84	12.29	14.85	12.15	14.85	12.23
15.61	11.60	15.65	12.12	15.66	12.16	15.67	12.01	15.68	12.18
15.74	11.55	15.71	12.13	15.73	12.18	15.73	11.98	15.69	12.20
15.82	11.62	15.81	12.09	15.80	12.15	15.79	12.01	15.79	12.12
16.79	11.49	16.81	12.04	16.82	12.05	16.83	11.92	16.84	12.11
17.78	11.41	17.76	11.94	17.76	12.01	17.83	11.86	17.84	12.11
18.60	11.46	18.58	11.93	18.57	11.92	18.56	11.85	18.60	12.01
18.76	11.41	18.81	11.89	18.83	11.93	18.84	11.85	18.85	12.15
19.78	11.36	19.82	11.89	19.83	11.88	19.84	11.79	19.84	12.10
22.67	11.44	22.75	11.89	22.74	11.90	22.78	11.80	22.79	12.10
23.66	11.61	23.64	11.93	23.64	11.88	23.63	11.81	23.66	12.17
24.73	11.66	24.77	11.94	24.78	11.95	24.79	11.87	24.77	12.32
25.61	11.68	25.64	12.07	25.65	11.94	25.66	11.92	25.66	12.47
25.67	11.68	25.71	12.07	25.71	11.93	25.72	11.95	25.72	12.41
26.65	11.80	26.60	12.13	26.59	12.05	26.58	11.95	26.58	12.57
-	-	26.70	12.16	26.69	11.98	26.69	11.94	26.68	12.45
28.64	12.04	28.62	12.28	28.61	12.02	28.61	12.08	28.60	12.60
29.67	12.17	29.76	12.36	29.77	12.20	29.78	12.32	29.79	12.78
32.66	12.59	32.73	12.65	32.72	12.38	32.75	12.36	32.75	12.68
35.62	13.10	35.59	13.15	35.55	12.50	35.57	12.57	35.52	12.63

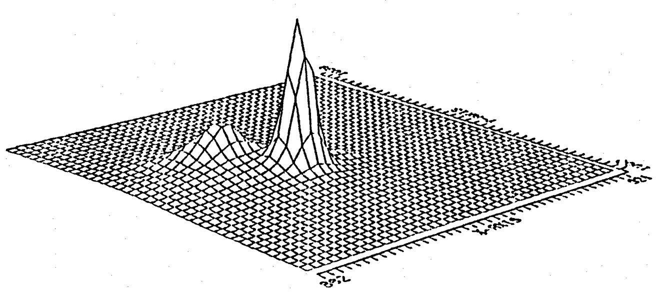

Fig. 1. Surface map of original image of NGC 4526 and SN 1994D in the B-band

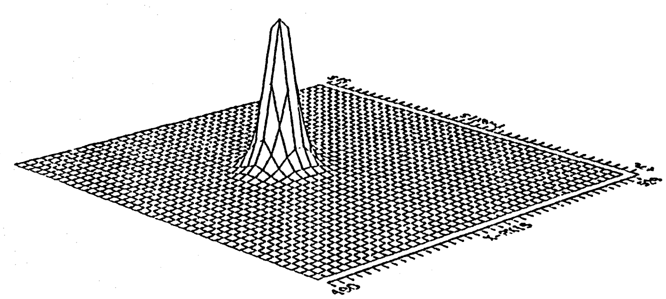

Fig. 2. Surface map of the substracted B-band image, only supernova has remained.

fully) minor-axis-symmetric. It can be divided into two parts along its minor axis, one containning the supernova and the other not. The highly symmetric configuration of the galaxy makes it a reasonable assumption that these two halfs are identical as far as the surface brightness distribution is concerned.

The procedure of background subtraction is as follows: the galaxy was truncated along its minor axis, and only the half without the supernova left; then this half was mirror-reflected to the otherside of the minor axis, and a fully minor-axis-symmetric image, a "false galaxy", was constructed. This "false galaxy" was then subtracted from the true image, and the supernova was left alone without the galaxy background. This procedure was done for all the images, and the results for U, B, V and R images are really satisfactory (Fig. 1 and Fig. 2), although not so good for the images in I band. Once the galaxy was subtracted from the images, aperture photometry was carried out. The photometry and the final conversion to the system of Kilkeny and Malcolm (1984) were done with IRAF packages APPHOT and PHOTCAL.

3. Results

Table 1. presents the final photometric results. We simply give the magnitude for each image we have taken. Fig. 3 shows the plot of our data with that of others.

The error embedded in our data is mainly introduced by three sources. First, the flat-field corrections may bring about 2% uncertainty; Second, the magnitudes of our reference stars have an accuracy of 0.07, 0.03, 0.03, 0.03, and 0.02 mag in U, B, V, R, and I, respectively. The third error comes from the method of background determination, which are 2%-4% in the U, B, V, and R-bands and could be as large as 15% in the I-band. So the final internal error estimate is about 0.08 mag in U, 0.05 mag in both B and V, 0.06 mag in R, and 0.10-0.20 mag in I.

Table 2 displays the color of the supernova. We averaged each night's data. The data are plotted in Fig. 4.

Table 2. Color of SN 1994D

UT(in March)	U-B	B-V	V-R	V-I
11.7	-0.40	0.01	-	-
12.7	-0.51	0.02	0.10	0.10
14.7	-0.54	-0.01	0.13	0.07
15.7	-0.52	-0.05	0.17	0.00
16.8	-0.56	-0.01	0.14	-0.06
17.8	-0.53	-0.07	0.15	-0.10
18.7	-0.47	-0.02	0.07	-0.15
19.8	-0.53	-0.02	0.09	-0.22
22.7	-0.45	0.00	0.10	-0.20
23.6	-0.32	0.05	0.06	-0.30
24.8	-0.29	-0.01	0.08	-0.37
25.7	-0.39	0.14	0.00	-0.51
26.6	-0.34	0.13	0.07	-0.49
28.6	-0.24	0.27	-0.06	-0.61
29.8	-0.19	0.17	-0.12	-0.58
32.7	-0.06	0.27	0.02	-0.30
35.6	-0.06	0.65	-0.07	-0.13

Our observation started about 9 days before maximum brightness came, and extended more than two weeks after then. With so nicely sampled data, we can determine position of the maximum brightness properly. Table 3 shows the results. The peak B magnitude is in good agreement with the mean value of 11.82 ± 0.08 for the supernovae found in E/S0 galaxies in the Virgo cluster (Leibundgut and Tammann 1990).

Table 3. Magnitudes and dates in maximum

	U	B	V	R	I
date(in March)	19.6	20.4	22.0	20.6	19.6
magnitude	11.39	11.86	11.85	11.77	12.04

Before the supernova reached the maximum, the brightness increased quickly at -0.18, -0.16, -0.15, -0.15 and -0.14 mag/day in U, B, V, R and I, respectively. After the maximum, the brightness declined with a rate of 0.110, 0.087, 0.057, 0.056 and 0.080 mag/day in U, B, V, R and I, respectively, which was somewhat slower than the rate of brightness increase. The decline rates are high in U, a little slower in B, which is the same as the mean rate 0.087 mag/day (Barbon et al. 1973), and slow in V and R. The light curves of SN 1994D fall 1.23 and 0.78 mag during the first 15 days after maximum in B and V, respectively, and the width of the V light curve measured

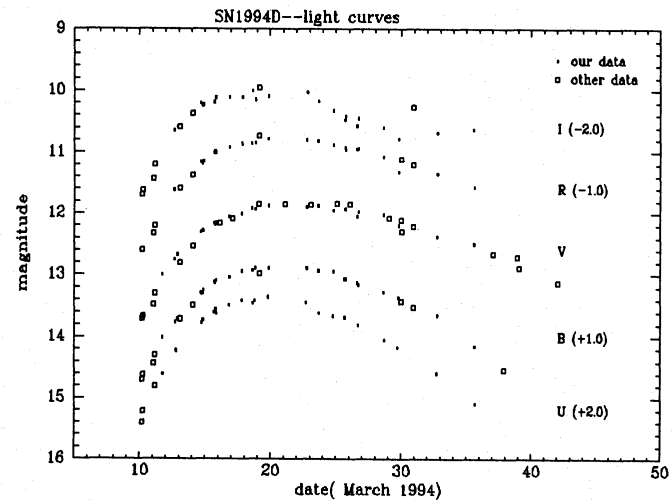

Fig. 3. The light curves of SN 1994D in U, B, V, R, and I. The solid points are our data and open ones are from other sources (Shanks and Croom 1994; Walker 1994; Heraudeau et al. 1994; Mikuz et al. 1994a and 1994b; Argyle and Morrison 1994) Magnitude scale is according to the V-band, and the U, B, R, and I are shifted by +2,+1,−1,−2 mag, respectively.

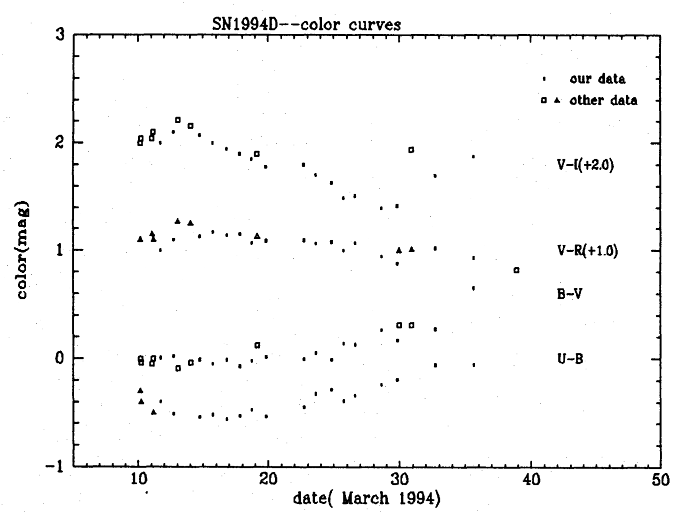

Fig. 4. The colors of SN 1994D. Solid points are ours and open ones from the literature. Only V-R and V-I have been shifted +1 and +2 mag respectively. B-V and U-B use original scale.

one magnitude below maximum is approximately 27 days. All these are not so much different from the value of the light curve templates for SNe Ia of Leibundgut (1988), where the decreases are 1.22 and 0.64 mag for B and V, and the width of V curve is about 33 days, and quite similar to SN 1989B (Barbon et al. 1990) in NGC 3627 and SN 1981B (Buta and Turner 1983) in NGC 4536, which are classified as normal Ia supernovae (Branch et al. 1993). We could not find out the change of decline rate, since we didn't observe the supernova long enough.

The light curves for U-B and B-V colors increased even after the maximum, while that for V-R and V-I colors declined after then. The U-B evolution indicates that the supernova was quite blue after it exploded, about 0.1 mag bluer than that of SN 1981B. The increase of B-V is also similar to SN 1981B, which B-V was nearly 0.0 and went up about 6-7 days later after maximum. The V-R curve went down slowly and changed little during the observation. Since there is a large uncertainty in the I-band, the behavior of V-I is difficult to determine especially when the supernova became fainter.

4. Distance modulus

The spectrum of SN 1994D three weeks after maximum taken with the 2.16m telescope at BAO (Jiang et al. 1994) resembles the features of two normal type Ia supernovae SN 1981B (Branch et al. 1983) and SN 1989B (Barbon et al. 1990) in the same phase, which confirms that SN 1994D is a normal type Ia supernova. With nine nearby (with distance modulus < 32) type Ia supernovae, including SN 1981B and SN 1989B, Phillips (1993) derived a relation between decline-rate and peak-luminosity. It is reasonable to apply the same relation to SN 1994D. From the parameters given in Table 2 of the Phillips' paper and our $\Delta m_{15}(B) = 1.23$, we can easily find out the peak absolute magnitude is $B_{max} = -18.41 \pm 0.41$.

But to get the distance modulus in a reasonable way, the reddening (interstellar reddening and the reddening of the host galaxy) should be taken into account first. We have derived the equivalent width of the doublet NaI D lines, which is 0.2$\AA$ at a rough estimate, from the low dispersion spectrum taken by Jiang et al. (1994). For the two NaI D lines, Herbig (1975) has derived a linear relationship between E(B-V) and their equivalent width separately. The combination of the two NaI D lines' equivalent widths would follow the same relationship with only the coefficient a little different. We found that in Michael et al. (1989) the equivalent width of doublet NaI D lines was given as 3.1$\AA$, and E(B-V) was given as 0.8 mag. Thus we found the reddening in our case as roughly $E(B - V) = 0.05$ mag. We lately found that this value was in good agreement with King et al. (1994).

So in our case, the distance modulus is 30.07 ± 0.42 after the reddening correction. This value agrees with 30.25 ± 0.46 (Michard 1979a), 30.23 ± 0.63 (Michard 1979b), 30.49 ± 0.25 (de Vaucouleurs and Olson 1984), and 29.96 ± 0.5 which can be deduced from Hanes' (1977) paper by using the weighted mean apparent magnitude of the globular clusters in NGC 4526 and the mean absolute magnitude in our galaxy, but somewhat different from 31.47 ± 0.37 (de Vaucouleurs and Olson 1982), 31.13 (Tully 1988) and 29.30 (Bottinell et al. 1984). According to Branch and Miller (1993), its small distance to us and the low luminosity would classify SN 1994D as a member of the subluminous group.

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