Revised photometry and color distribution of Type Ia supernovae observed at Asiago in the seventies.

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Abstract. Following recent claims regarding possible errors in the photometry of SNe carried out at Asiago observatory during the 70’s, which produced very blue (B – V) color at maximum for some objects, we present the result of new CCD photometry of the sequences around 16 type Ia supernovae.

Except for a few cases, e.g. SN 1970J and SN 1972J for which a large zero point error has been found, the new data show that the old Asiago observations have been carried out properly and that their accuracy was comparable to that expected for a photometry based on photographic transfers. This result is also substantiated by comparison with the re-calibration of some Asiago sequences made photo-electrically by Tsvetkov.

New light curves of the SNe have been determined and B magnitudes and (B-V) colors at light peak derived. With the new data the color distribution of the SNe studied here becomes narrower and moves to the red by only 0.06 mag, showing no more very blue objects except for one, still uncertain, case. As far as the use of SNIa as standard candles is concerned, we show that the utilization of all SNe in the M_B vs. (B-V)_max plane reduces the uncertainties due to the photometry.

Key words: supernovae and supernova remnants: general – supernovae; individual: 1957B, 1960F, 1960R, 1965I, 1968E, 1969C, 1970J, 1971G, 1971L, 1972H, 1972J, 1972R, 1973B, 1973N, 1974G, 1974J, 1975G, 1975N, 1975O, 1975P, 1976B, 1976J, 1977F, 1981B, 1983U, reddening E(B – V), suffered by a given SN Ia, two different approaches have been adopted so far. One may infer the reddening through the use of a relation between the intensity of the interstellar absorption lines and the total E(B – V) as suggested by Barbon et al. (1990). Since this technique applies to SN spectra having sufficient resolution and good signal to noise ratio, it has been used only for a limited number of SNe (e.g. Patat et al. 1996). Alternatively, the extinction may be estimated from the observed SN color if one assumes that all SN Ia at a given phase, for instance at maximum light, have the same intrinsic (B–V)_0 color. In this case the problem becomes the determination of the intrinsic SN Ia color at maximum.

The most common approach is to adopt as reference the color of the bluest objects in a given sample of SN Ia, assuming that they are those less affected by reddening. However this approach is seriously endangered by possible photometric errors. This may explain the quite different intrinsic (B – V)_0 values which have been derived in the past, e.g.: −0.20 (Pskovskii 1968), −0.15 (Barbon et al. 1973), −0.27 (Cadonau et al. 1981), −0.25 (van den Bergh & Pazder 1992), −0.16 (Della Valle & Panagia 1992), −0.15 (Branch & Tammann 1992), +0.03 (Branch & Miller 1993) and +0.09 (Sandage & Tammann 1993). As it can be seen, (B – V)_0 ranges about 0.35 mag with recent estimates being, on the average, redder.

It is worth noting that since A_B = R_B × E(B – V) and R_B ∼ 4.0 (Savage & Mathis 1979), even small errors in the adopted (B – V)_0 reference color have strong impact on the derived absolute magnitude M_B.

Since SN events are rare, one is often forced to use data which, admittedly, are of poor photometric quality in order to build a statistical significant sample. If some observations are affected by systematic errors, these may severely bias the estimate of (B – V)_0. In fact, several authors (Sandage & Tammann 1993, Branch & Miller 1993, Vaughan et al. 1993, Schaefer 1993) have noticed

1. Introduction

The correction for reddening is a crucial step when using SNe Ia as distance indicators. To estimate the amount of reddening E(B – V), suffered by a given SN Ia, two different approaches have been adopted so far. One may infer the reddening through the use of a relation between the intensity of the interstellar absorption lines and the total E(B – V) as suggested by Barbon et al. (1990). Since this technique applies to SN spectra having sufficient resolution and good signal to noise ratio, it has been used only for a limited number of SNe (e.g. Patat et al. 1996). Alternatively, the extinction may be estimated from the observed SN color if one assumes that all SN Ia at a given phase, for instance at maximum light, have the same intrinsic (B–V)_0 color. In this case the problem becomes the determination of the intrinsic SN Ia color at maximum.

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that most of the bluest SN Ia have been observed photographically at the Asiago Astrophysical Observatory in the seventies and they raised the possibility that these observations were affected by systematic errors. Since for most of these "blue" SNe the only available photometry is that collected at Asiago and bearing in mind the importance of SNIa in the determination of the extragalactic distance scale, it appears of great interest to check the accuracy of these old measurements.

The intensive program of photometric and spectroscopic monitoring of SNe started at the Asiago Astrophysical Observatory in the early 60's. Before the introduction, in the mid eighties, of CCD's the photometry of SNe was obtained by photographic observations mainly using the 67/92 cm Schmidt telescope and the 122 cm reflector. The SN magnitudes were estimated by comparison with local sequences which, in turn, were calibrated by means of photographic transfers from standard fields, usually photoelectrically observed Selected Areas. To calibrate the local sequences, the photographic plates were measured with a Becker iris photometer, whereas SN magnitudes, especially for objects lying on the luminous background of their parent galaxies, were often obtained by eye comparison with the local sequences.

Prompted by the aforementioned criticism, we decided to verify the old Asiago photometry by re-calibrating the local comparison sequences used to derive the SN magnitudes. The comparison of the new measurements with those reported in the original papers will provide us a quantitative estimate of the reliability of the old SN data and, in turn, will allow us to correct the light curves. We note that many sequences were already re-calibrated by Tsvetkov at the Crimean Observatory (for the individual references see Table 1 and 2) who, however, used a photographic technique similar to that adopted at Asiago for the majority of stars, namely those fainter than B=14.5 mag.

To calibrate a significant sample of the local sequences, several nights of good photometric quality are needed, which it is not presently the case at Asiago due to the increasing light pollution and deteriorating sky conditions. Therefore, among the SNe studied at Asiago, we selected those accessible from ESO–La Silla (δ < +30°) which resulted in a sample of 16 SNe covering about 25 years of observations and requiring the re-calibration of about a hundred stars of the local comparison sequences. These are listed in Tab. I whereas Table 2 reports the SNe observed at Asiago not included in the present sample but with standard sequences re-calibrated by Tsvetkov. Codes of the original papers are reported in col.3 (A1–A9) along with those of the Tsvetkov's papers (col.7, T1–T6). The passbands of observations (Col. 4), the number of stars in the comparison sequence (Col. 5), the number of photographic transfers (Col. 6) are also reported.

In the next Section we describe the observations and the data reductions, in Sect. 3 we compare the revised magnitudes of the local standard stars with those reported in the original papers, in Sect. 4 the light and color curves of the SNe are re-calibrated and in Sect. 5 we discuss the effects of the corrections on the SN color distribution.

2. Observations and data reductions

The observations have been conducted at ESO - La Silla during two different runs, between March 7–12, and November 30 – December 3, 1994. B and V imaging of the sample stars have been obtained using the 0.92 m ESO–Dutch telescope equipped with the TK coated 512 × 512 CCD #29 in the first run and with the similar CCD #33 in the second one. The pixel scale was 0″.44 and the field 3′.3 × 3′.3. Typically the stars of each local comparison sequence were spread about half a degree in the sky hence it has been necessary to take several frames (up to 7, in the case of SN 1971G) in order to measure all the stars

| Table 1. SNe with re-calibrated local comparison sequences. |
|-----------------|---------|----------|--------|--------|-------|
| SN   | Galaxy   | Ref.*   | Band   | N.S.  | N.T.  | Ref.* |
| 1957B | NGC 4374 | A1      | mpg    | 8     | 4     | T1    |
| 1960F | NGC 4496 | A1      | mpg    | 5     | 1     | T2    |
| 1960R | NGC 4382 | A1      | mpg    | 8     | 5     | T2    |
| 1965L | NGC 4753 | A2      | B, V   | 4     | 3     | T3    |
| 1968E | NGC 2713 | A2      | B, V   | 7     | 3     | T4    |
| 1970J | NGC 7619 | A3      | B, V   | 9     | 4     | T1    |
| 1971G | NGC 4165 | A3      | B, V   | 8     | 6     | T1    |
| 1972J | NGC 7634 | A3      | B, V   | 9     | 4     | T1    |
| 1973B | Anon 1512+02 | A4 | B | 3  | –  | – |
| 1975N | NGC 7723 | A4      | B, V   | 4     | 6     | T1    |
| 1975O | NGC 2487 | A4      | B, V   | 6     | 7     | –     |
| 1976B | NGC 4402 | A4      | B, V   | 7     | 6     | –     |
| 1976J | NGC 977  | A4      | B, V   | 4     | 1     | –     |
| 1977F | M+5-26-14 | A4 | B | 3  | 1  | – |
| 1981B | NGC 4536 | A5      | B, V   | 8     | –     | T5    |
| 1983U | NGC 3227 | A6      | B, V   | 6     | –     | –     |

NOTE: (*) coded as in the References

| Table 2. SNe Ia observed at Asiago not included in our sample but re-calibrated by Tsvetkov. |
|-----------------|---------|----------|--------|--------|-------|
| SN   | Galaxy   | Ref.*   | Band   | N.S.  | N.T.  | Ref.* |
| 1969C | NGC 3811 | A7      | B, V   | 8     | 1     | T4    |
| 1971L | NGC 6384 | A3      | B, V   | 8     | 4     | T4    |
| 1972H | NGC 3147 | A8      | B, V   | 6     | 3     | T4    |
| 1972R | NGC 2841 | A8,A1   | B, V   | 9     | 8     | T6    |
| 1973N | NGC 7495 | A9      | B, V   | 10    | –     | T1    |
| 1974G | NGC 4414 | A9      | B, V   | 10    | 5     | T1    |
| 1974J | NGC 7343 | A9      | B, V   | 7     | –     | T1    |
| 1975G | M+09-23-25 | A4 | B, V | 4  | –  | T1 |
| 1975P | NGC 3583 | A4      | B, V   | 6     | –     | T1    |

NOTE: (*) coded as in the References
of the sequences. The brightness of the measured stars ranged from B~10 down to B~19 mag and accordingly the exposure times ranged from 3 secs up to 20 min.

In addition to the program stars, a number of photometric standard fields (Landolt [1992]) has been frequently monitored during the two runs. Most of the nights were photometric and the few observations obtained in non-photometric conditions have been rejected. In a number of cases, the same program star has been observed several times in the same or different nights and the observed magnitudes have been averaged.

The frames have been flat-fielded and bias corrected by means of standard routines in the ESO–MIDAS environment. In all cases the stars were located relatively far from the SN parent galaxy, and it was therefore safe to measure the star flux by means of plain aperture photometry with the background estimated in a circular annulus centered on the star. The diaphragm size was chosen according to the seeing, which ranged from 1'' to 2'' (FWHM).

The instrumental magnitudes have been transformed into B and V magnitudes using the fitting coefficients derived from the observations of the standard fields, after including airmass correction ($K_B$=0.27, $K_V$=0.12 mag airmass$^{-1}$).

The transformation equations turned out to be:

$$ B = C_B + b + 0.10(\pm 0.01) \times (B - V) \quad (1) $$
$$ V = C_V + v + 0.03(\pm 0.01) \times (B - V) \quad (2) $$

where $b$, $v$ are the instrumental magnitudes corrected for atmospheric extinction, $C_B$ and $C_V$ are the zero points showing small variation from night to night and the color terms were averaged on all the nights (in parenthesis is their r.m.s. scatter).

To estimate the internal errors, we performed artificial star experiments by introducing, in the original frames, stars of known magnitudes: the standard deviation of the magnitude of the recovered artificial stars was found 0.01 mag at B=12.0 and 0.05 mag at B=18.0.

It is worthwhile to note that recently Schaefer [1996] has re-calibrated, also using a CCD detector, the sequence of SN 1960F. His estimates of the magnitudes of the sequence stars are always within 0.05 mag from those presented in this work.

### 3. Re-calibration of the local sequences

The re-calibrated CCD magnitudes for the program stars included in the sample are reported in Tab. 3. B magnitudes are in column 3 and $B - V$ colors in column 4. For comparison, in column 5 and 6 the original estimates are also reported. Notice that these latter ones for SNe 1957B, 1960F and 1960R were in the $m_{pg}$ system (Bertola [1964]).

In principle, two types of errors can affect photometric data: a) systematic errors possibly related to the reproduction of the photometric system; b) random errors dependent on the detector type, method of measurement etc. The calibration of the zero point of the photometric system for each sequence is also affected by errors due to the photographic transfer. As a first step we want to verify that the latter ones are random errors.

To this purpose we calculated, for each sequence reported in Table 3, the average zero-point offset of the calibration of the $B$ magnitudes and of the ($B - V$) colors, $\Delta B^* = < B^*_A - B^*_C >$ and $\Delta(B - V)^* = < (B - V)^*_A - (B - V)^*_C >$ and the relative dispersions. The results are reported in Tab. 4 in which at the bottom line are given the averages of these quantities on all sequences. The average magnitude and color offsets, $\Delta B^* = -0.09 \pm 0.07$ and $\Delta(B - V)^* = -0.05 \pm 0.06$ respectively, show no evidence of systematic effects in the transfer of the magnitudes of the local sequences. Moreover, the average dispersion $\sigma_B^* = 0.17$ gives a good estimate of the internal errors of the Asiago original photometry, assuming that the errors of the CCD photometry are negligible.

As we mentioned in the introduction, in a series of papers Tsvetkov (1982, 1983, 1985a, 1985b, 1986, 1996) re-calibrated many of the original Asiago comparison sequences. His photometry was obtained using a EMI photomultiplier coupled to the 60 cm telescope (Crimean Observatory) for stars brighter than $V=14.5$ and using a 15'' or 26'' diaphragm, according to the seeing. Fainter stars were measured on photographic plates taken with the 50 cm Maksutov telescope using a Racine wedge. Many of these sequences, those accessible from La Silla, have been re-calibrated also by us (see Tab. 1). Since in the following we will refer also to these data, it is of interest to verify how they compare with our more accurate CCD estimates. It turns out that the average magnitudes and color offsets between Tsvetkov’s data and those of this work, $\Delta B^* = < B^*_T - B^*_C > = -0.02 \pm 0.04$ and $\Delta(B - V)^* = < (B - V)_T - (B - V)_C > = -0.04 \pm 0.02$, are negligible. In analogy to what was done in Tab. 4, we derived also an estimate of the internal error of the Tsvetkov photometry, $\sigma_B^* = 0.10$, therefore about half that of the Asiago photometry. In conclusion, even if the Tsvetkov photometry has not the same accuracy as the new CCD estimates, we will use it to check the Asiago photometry of the sequences we could not measure in La Silla. For these sequences, the Asiago magnitude and color offsets, relative to the re-calibration by Tsvetkov, are reported in Tab. 5.

For the combined sample of Tables 4 and 5, the distribution of the zero point offsets is displayed in Fig. [1]. It is confirmed what stated before: the distributions of the magnitude and color offsets are quite broad, indicating that the random errors in the calibration of the zero points are relatively large, the average error being $\sim 0.2$ mag. On the contrary, there are no evidences of system-
Table 3. Re-calibrated $B^*$ magnitudes and $(B - V)^*$ colors for the stars of the local sequences. For comparison, also the Asiago original data are given. Identification charts are found in the original papers (Table 1).

| SN     | star | this work $B_{\ast}$ | this work $(B - V)_{\ast}$ | Asiago photographic $B_{\ast}$ | Asiago photographic $(B - V)_{\ast}$ |
|--------|------|-----------------------|-----------------------------|---------------------------------|--------------------------------------|
| 57B    | a    | 12.41 0.49            | 12.40                       | 12.40                           | 0.49                                 |
|        | b    | 13.86 0.90            | 13.83                       | 13.83                           | 0.90                                 |
|        | c    | 14.20 0.52            | 14.20                       | 14.20                           | 0.52                                 |
|        | e    | 15.66 0.71            | 15.45                       | 15.45                           | 0.71                                 |
|        | f    | 15.95 0.85            | 15.75                       | 15.75                           | 0.85                                 |
|        | g    | 16.39 0.57            | 16.06                       | 16.06                           | 0.57                                 |
|        | h    | 16.55 1.08            | 16.24                       | 16.24                           | 1.08                                 |
|        | i    | 16.93 0.81            | 16.68                       | 16.68                           | 0.81                                 |
| 60F    | a    | 9.72 0.53             | 9.76                        | 9.76                            | 0.53                                 |
|        | b    | 12.26 0.88            | 12.45                       | 12.45                           | 0.88                                 |
|        | c    | 12.68 0.69            | 12.73                       | 12.73                           | 0.69                                 |
|        | d    | 14.42 0.77            | 14.53                       | 14.53                           | 0.77                                 |
|        | e    | 15.29 0.76            | 15.50                       | 15.50                           | 0.76                                 |
| 60R    | a    | 12.37 0.62            | 12.45                       | 12.45                           | 0.62                                 |
|        | b    | 13.58 0.72            | 13.40                       | 13.40                           | 0.72                                 |
|        | c    | 14.30 0.67            | 14.10                       | 14.10                           | 0.67                                 |
|        | d    | 14.76 0.74            | 14.50                       | 14.50                           | 0.74                                 |
|        | e    | 14.87 0.78            | 14.68                       | 14.68                           | 0.78                                 |
|        | f    | 15.24 0.70            | 14.92                       | 14.92                           | 0.70                                 |
|        | g    | 16.40 0.07            | 15.94                       | 15.94                           | 0.07                                 |
|        | h    | 17.07 0.78            | 16.25                       | 16.25                           | 0.78                                 |
| 65I    | a    | 12.47 1.23            | 12.20                       | 12.20                           | 1.23                                 |
|        | b    | 13.41 1.10            | 13.40                       | 13.40                           | 1.10                                 |
|        | c    | 13.76 0.72            | 13.40                       | 13.40                           | 0.72                                 |
|        | d    | 14.34 0.64            | 14.25                       | 14.25                           | 0.64                                 |
| 68E    | a    | 14.97 0.53            | 14.90                       | 14.90                           | 0.53                                 |
|        | b    | 13.58 0.71            | 15.47                       | 15.47                           | 0.71                                 |
|        | c    | 15.75 0.95            | 15.75                       | 15.75                           | 0.95                                 |
|        | d    | 15.92 0.54            | 15.93                       | 15.93                           | 0.54                                 |
|        | e    | 16.29 0.72            | 16.30                       | 16.30                           | 0.72                                 |
|        | f    | 16.86 0.66            | 16.93                       | 16.93                           | 0.66                                 |
|        | g    | 16.99 0.79            | 17.12                       | 17.12                           | 0.79                                 |
| 70J–72J| a   | 14.51 0.71           | 13.85                       | 13.85                           | 0.71                                 |
|        | b    | 14.99 0.68            | 14.35                       | 14.35                           | 0.68                                 |
|        | c    | 15.81 0.60            | 15.15                       | 15.15                           | 0.60                                 |
|        | d    | 16.27 0.59            | 15.50                       | 15.50                           | 0.59                                 |
|        | e    | 16.71 0.52            | 15.90                       | 15.90                           | 0.52                                 |
|        | f    | 16.99 0.64            | 16.25                       | 16.25                           | 0.64                                 |
|        | g    | 17.41 0.71            | 16.85                       | 16.85                           | 0.71                                 |
|        | h    | 17.91 0.50            | 17.30                       | 17.30                           | 0.50                                 |
|        | i    | 18.62 1.57            | 17.80                       | 17.80                           | 1.57                                 |
|        | l    | 18.74 1.54            | 18.25                       | 18.25                           | 1.54                                 |
| 71G    | a    | 13.87 0.95            | 13.60                       | 13.60                           | 0.95                                 |
|        | b    | 14.56 0.83            | 14.30                       | 14.30                           | 0.83                                 |
|        | c    | 14.94 0.65            | 14.65                       | 14.65                           | 0.65                                 |
|        | d    | 15.16 0.93            | 15.05                       | 15.05                           | 0.93                                 |
|        | e    | 16.20 0.94            | 16.15                       | 16.15                           | 0.94                                 |
|        | f    | 16.62 0.41            | 16.60                       | 16.60                           | 0.41                                 |
|        | g    | 17.33 0.53            | 17.15                       | 17.15                           | 0.53                                 |
|        | h    | 17.88 0.51            | 17.65                       | 17.65                           | 0.51                                 |

# Original photometry in the $m_{ps}$ system.

### The CCD image shows that this is a galaxy, not a star.

#### Because of the large discrepancy $(B^*_{CCD} - B^*_{As} = 2.98$ mag) most likely the star was misidentified on the published map (Ciatti & Rosino 1978). For this reason it has been excluded from the discussion.
Table 4. Zero point offsets, $\Delta B^*$ and $\Delta (B-V)^*$, and dispersions of the original photometry with respect to the CCD data for each of the re-calibrated sequences.

| SN    | $\Delta B^*$ | $\sigma_B$ | $\Delta (B-V)^*$ | $\sigma_{B-V}$ |
|-------|--------------|------------|------------------|----------------|
| 1957B | $-0.17$      | 0.14       | $-0.25$          | 0.26           |
| 1960F | $+0.12$      | 0.08       | $-0.22$          | 0.06           |
| 1960R | $-0.29$      | 0.26       | $-0.38$          | 0.17           |
| 1970J | $-0.17$      | 0.10       | $+0.08$          | 0.21           |
| 1971G | $-0.16$      | 0.11       | $-0.13$          | 0.19           |
| 1975N | $-0.33$      | 0.11       | $-0.11$          | 0.10           |
| 1976B | $-0.16$      | 0.22       | $-0.14$          | 0.06           |
| 1976J | $+0.51$      | 0.59       | $+0.13$          | 0.24           |
| 1977F | $-0.12$      | 0.15       |                 |                |
| 1981B | $+0.05$      | 0.15       | $+0.03$          | 0.05           |
| 1983U | $+0.09$      | 0.10       | $+0.10$          | 0.11           |

$\Delta B^*$ | $\sigma_B$ | $\Delta (B-V)^*$ | $\sigma_{B-V}$ |
|----------|---------|------------------|---------------|
| $-0.09$  | 0.17    | $-0.05$          | 0.15          |
| $\pm0.07$| $\pm0.06$|                   |               |

# Original photometry in the $m_{pg}$ system.

Table 5. Zero point offsets and dispersions of the original photometry with respect to Tsvetkov’s re-calibration of the sequences of Table 2.

| SN    | $\Delta B^*$ | $\sigma_B$ | $\Delta (B-V)^*$ | $\sigma_{B-V}$ |
|-------|--------------|------------|------------------|----------------|
| 1969C | $+0.12$      | 0.19       | $+0.03$          | 0.28           |
| 1971L | $+0.28$      | 0.10       | $+0.17$          | 0.32           |
| 1972H | $0.00$       | 0.14       | $-0.20$          | 0.06           |
| 1972R | $+0.13$      | 0.12       | $-0.19$          | 0.18           |
| 1973N | $+0.25$      | 0.13       | $+0.37$          | 0.22           |
| 1974G | $-0.08$      | 0.09       | $-0.15$          | 0.16           |
| 1974J | $+0.07$      | 0.12       | $+0.19$          | 0.14           |
| 1975G | $+0.21$      | 0.13       | $-0.12$          | 0.13           |
| 1975P | $-0.12$      | 0.12       | $+0.02$          | 0.11           |

$\Delta B^*$ | $\sigma_B$ | $\Delta (B-V)^*$ | $\sigma_{B-V}$ |
|----------|---------|------------------|---------------|
| $+0.10$  | 0.13    | $+0.01$          | 0.18          |
| $\pm0.05$| $\pm0.07$|                   |               |

More cumbersome is the case of SNe 1970J and 1972J for which we could not find an obvious explanation for the very large calibration error. A check of the Asiago Observatory archive has shown that the calibration of the comparison sequence was obtained through 4 photographic transfers from SA 68, which was observed in the same nights and at similar zenith distance as the SN field. Another possibility investigated was that of errors in the reference magnitudes of the stars of SA 68 (Stebbins et al. 1950). To our knowledge, the only recent photometry of the SA 68 stars was published by Doroshenko (1994), who found small differences with respect to the values of Stebbins et al. (note that the different star identifications may be confusing). The comparison sequences of the other SNe included in the sample which have been calibrated with transfers from SA 68, do not show the severe errors of the sequence of SN 1970J. Therefore the origin of the errors affecting SNe 1970J and 1972J remains unknown.

In principle, systematic errors may correlate with the brightness of the stars or with their colors. To investigate the first possibility, in Fig. 3 we plot the differences $B_{as}^*$ - $B_{CCD}^*$ and $(B-V)_{as}^*$ - $(B-V)_{CCD}^*$ as a function of $B_{CCD}^*$ for all of the stars of Tab. 3. As it can be seen, the dispersion of the Asiago photometry increases as the sequence stars become fainter and it might also be present a slight dependence on magnitude, mainly induced by the sequences measured in the seventies which were, in the average, fainter and therefore more affected by random errors.
4. Re–calibration of the light curves

We have seen that, for each sequence, there is a significant dispersion around the zero point offset (col.3 of Tab. 4), that is the magnitude corrections were different even for stars of the same sequence. Since the SN magnitudes, at each phase, have been obtained by interpolation between the couple of comparison stars close in brightness to the SN, the correction of the magnitudes and colors of the SN is not simply a zero point correction.

In principle, to re–draw the SN light curves it would be better to derive new estimates of the SN magnitudes against the re–calibrated local sequence stars, possibly using modern technique, e.g. digitizing the plates with a PDS machine and measuring the SN intensities with suitable software. However our experience show that: a) the internal errors originally made in the comparison were small (∼ 0.1 mag) compared to the errors of the calibration of the sequence; b) there is an intrinsic limit for the photometric accuracy which can be achieved using photographic plates, in particular those obtained with our Schmidt telescope (∼ 0.05 mag); c) the procedure is time consuming implying the digitizing of hundreds of plates.

For these reasons we decided to correct the SN photometry adopting the original estimates of the SN magnitudes relative to the comparison stars, that is, if \( m_{SN} \) is the original SN measure, \( m_A, m_B \) the original magnitudes of the comparison stars (\( m_A \leq m_{SN} \leq m_B \)) and \( m'_A, m'_B \) the re-calibrated magnitudes for the same stars, the corrected SN magnitude \( m'_{SN} \) is obtained through the relation:

\[
m'_{SN} = m'_A + (m_{SN} - m_A) \times \frac{\Delta m'}{\Delta m}
\]  

where \( \Delta m = (m_B - m_A) \) and \( \Delta m' = (m'_B - m'_A) \). This relation is correct only if the ranking in the comparison sequence remain the same, that is \( m'_A < m'_B < m'_C \ldots \). Moreover, it is not safe to apply the formula if \( \Delta m' \) is very different from \( \Delta m \). In these cases, to correct the SN magnitude, we just referred to one comparison star, namely that closest in brightness to the SN. This is equivalent to putting \( \Delta m = \Delta m' \) in Eq. 3. The same approach is followed in the few cases in which one of the two stars of the comparison sequence have not been re–observed. In these and in cases in which extrapolation is needed, the result are considered uncertain.

We remind that the original photometry of SNe 1957B, 1960F and 1960R was in the \( m_{pg} \) system, whereas the stars of the sequences were re-calibrated in the B system. Second order corrections due to the color terms resulted smaller than the accuracy of the measurements, therefore they were neglected. Following these prescriptions, the photometric observations of all the SNe listed in Tab. 4 have been re–calibrated.

Having re-calibrated the old SN light curves, we can now derive new estimates of \( B \) and \( (B-V) \) at maximum light. Generally, these have been obtained by a best fit to the \( B \) and \( B-V \) light curves of the typical SN Ia SN 1992A (Suntzeff 1994, Kirshner et al. 1993). Whereas in most cases the corrections to be applied are fully consistent with the estimates of the errors reported in the original papers (∼ 0.2 mag), there are cases in which the deviations are severe.
The first case is that of SN 1970J which, on the basis of the original photometry was estimated ∼ 0.7 mag and ∼ 0.3 mag brighter in the B and V, respectively, and this resulted in a \((B-V)_{\text{max}}\) ∼ 0.4 mag too blue. Fig. 4 shows the new light and color curve of this SN as an example of the new re-calibrations. There is another source of photometry for this SN (Dubyago & Tokhtsev 1975), which is in agreement with the original Asiago data. This is not surprising since they used the same local sequence and it demonstrates that at least the Asiago estimates of the SN with respect to the sequence were correct. It is worth to note that at late phases, the re-calibrated B light curve appears ∼0.6 mag brighter than the template. This effect, which is found in many other photographic light curves, is probably due to errors related to the poor contrast of the SN against the parent galaxy background (cfr. Boisseau
Fig. 4. Example of re-calibration: light and color curves of SN 1970J. Overimposed (dotted line) is a best fit to the light and color curves of SN 1992A (Suntzeff 1995).

\& Wheeler [1991]. Unfortunately, the comparison sequence of SN 1970J was used also to estimate the magnitudes of SN 1972J which, in turn, resulted affected by the same errors.

Also SN 1975O had a \( (B - V)_{\text{max}} \) color \( \sim 0.3 \) mag too blue in the original photometry compared with the recalibrated value. In this case, the difference is not due to a systematic calibration error of the sequence, but to random errors in the V magnitude of stars \( a \) and \( c \) which conspired to give different extrapolated maxima.

We can also re-calibrate the SNe which sequences have been re-measured by Tsvetkov, using the same procedure described above. SN 1972H turns out to be \( \sim 0.4 \) mag redder in proximity of maximum light. The fit to the templates was quite uncertain, due to the fact that the first observation has been obtained two weeks after maximum. The color drift is due to the revised V magnitudes of stars \( a \) and \( b \). Small variations are seen in the early observations of SN 1973N, but around two months after maximum, when the SN was close to the plate limit \( (B \sim 18.5) \), the B magnitudes were too faint by \( \sim 0.2 \) mag and the Vs were too bright by the same amount. The new fittings give a \( (B - V)_{\text{max}} \) bluer by 0.4 mag with respect to previous estimates.

Puzzling is also the case of SN 1974J. The original photometry indicated a fairly blue color at maximum \( ((B - V)_{\text{max}} = -0.28) \) raising, as stressed by Sandage \& Tammann [1993] and Vaughan et al. [1995], doubts on the photometry. The re-calibrated light curves are even bluer, with a revised color estimate \( (B - V)_{\text{max}} = -0.4 \) mag. Both the original and the re-calibrated light curves show a very flat peak, especially in the B band, which clearly deviates from the behavior of the template and causes the fit to be very uncertain. However, we remind that the errors in the Tsvetkov re-calibration, although smaller that those of the original Asiago photometry are not negligible (see Tab. 5). Only CCD re-calibration of the sequence and a new reduction of the original plates may clarify if something is wrong, if any, with this SN.

The revised estimates of \( B_{\text{max}} \) and \( (B - V)_{\text{max}} \), are reported in Tab. 3, along with the estimated errors on \( (B - V)_{\text{max}} \) as deduced by the fitting uncertainties. From this Table, SNe 1968E, 1973B and 1983U have been excluded owing to the poor accuracy of the fits to the template. Finally, in the last column we report the color shift between the old \( (B - V)_{\text{max}} \) from Leibundgut et al. (1991), adding the galactic reddening, and the revised values.

---

| SN     | \( B_{\text{max}} \) | \( (B - V)_{\text{max}} \) | \( \Delta(B - V)_{\text{max}} \) |
|--------|----------------|----------------|-----------------|
| this work |                  |                 |                 |
| 1957B  | 12.20           | —               | —               |
| 1960F  | 11.34           | —               | —               |
| 1960R  | 11.60           | —               | —               |
| 1965I  | 12.41 +0.19 ± 0.30 | —             | —               |
| 1970J  | 15.00 +0.12 ± 0.05 | —             | —               |
| 1971G  | 13.90 —0.10 ± 0.30 | +0.10         | —               |
| 1972J  | 14.76 +0.11 ± 0.05 | —             | —               |
| 1975N  | 14.00 +0.30 ± 0.30 | —             | —               |
| 1975O  | 15.30 +0.14 ± 0.30 | —             | —               |
| 1976B  | 15.10 +1.24 ± 0.30 | —             | —               |
| 1976J  | 14.28 0.00 ± 0.20 | —             | —               |
| 1977F  | 15.80           | —               | —               |
| 1981B  | 11.74 +0.06 ± 0.05 | —             | —               |

Tsvetkov’s re-calibration

| SN     | \( B_{\text{max}} \) | \( (B - V)_{\text{max}} \) | \( \Delta(B - V)_{\text{max}} \) |
|--------|----------------|----------------|-----------------|
| 1969C  | 13.79 +0.05 ± 0.20 | +0.07         | —               |
| 1971L  | 13.00 +0.25 ± 0.30 | +0.23         | —               |
| 1972H  | 14.40 +0.15 ± 0.30 | —             | —               |
| 1972R  | 12.85 +0.05 ± 0.30 | —             | —               |
| 1973N  | 14.91 —0.04 ± 0.30 | +0.43         | —               |
| 1974G  | 12.28 +0.30 ± 0.20 | —             | —               |
| 1974J  | 15.60 —0.40 ± 0.30 | +0.18         | —               |
| 1975G  | 14.44 —0.15 ± 0.30 | +0.15         | —               |
| 1975P  | 14.44 +0.26 ± 0.40 | —             | —               |
5. Absolute magnitude and color distributions

From the data of Tab. \ref{tab:distance_moduli} we can derive revised estimates of the absolute magnitudes and corrected colors to be compared with previous estimates for the same SNe and with other SN Ia samples. To this purpose we used distance moduli $\mu$ from Vaughan et al. (1995) or, if not available, from Tully (1988) or LEDA \footnote{The Lyon–Meudon Extragalactic Database (LEDA) is supplied by the LEDA team at the CRAL–Observatoire de Lyon (France)} normalized to $H_0 = 85$ km s$^{-1}$ Mpc$^{-1}$ for consistence with Vaughan et al. (1995). The galactic reddening $A_B$ was taken from Burstein & Heiles (1978). Instead, no correction has been applied for the possible reddening within the parent galaxies. SNe 1957B, 1960F and 1960R were excluded because the original plates were taken in the $m_{pg}$ system and because no color is available.

The resulting $M_B$ absolute magnitudes and the $(B-V)_0^{\text{max}}$ colors are reported in Tab. \ref{tab:distance_moduli} and compared to the previous estimates. These latters have been derived from the peak magnitudes reported by Leibundgut et al. (1991) and using the distance moduli listed in Table 7.

The effect of the color curve re-calibration on the distribution of the $(B-V)_0^{\text{max}}$ colors is illustrated in the upper two panels of Fig. \ref{fig:color_distribution}. Excluding SN 1976B, which most likely is a SNIb (Sandler & Chugai 1986), the mean color $<(B-V)_0^{\text{max}}>$ shifts from $-0.02$ to $+0.04$ and the dispersion decreases from $0.23$ to $0.20$ mag. The re-calibrated distribution compares very well with that of the SN sample by Hamuy et al. 1993 (Fig. \ref{fig:color_distribution}, bottom panel), which however has a redder average color: $<(B-V)_0^{\text{max}}>$ = +0.13 and $\sigma(B-V)_0^{\text{max}}$ = 0.22, due to the presence of two red SN Ia, 1990Y with $(B-V)_0^{\text{max}}$ = +0.39 and 1992K with $(B-V)_0^{\text{max}}$ = 0.74.

We can now turn to the use of SN Ia as distance indicators. Let us assume that there are no intrinsic differences among SN Ia and that the observed differences are only due to photometric errors and reddening. We therefore expect that in the $M_B$ vs. $(B-V)_0^{\text{max}}$ diagram the observed points distribute around the line with slope $R = \frac{A_B}{E(B-V)} = 4$, with a dispersion due to the photometric errors. This is shown in Fig. \ref{fig:color_distribution}.

In order to derive the intrinsic luminosity of SN Ia, assuming we know the distances, we need to identify a sub-sample of SNe for which we can measure, or estimate, the reddening. This is not trivial, especially for small SN samples affected by significant photometric errors, and it explains the large dispersion in the intrinsic color adopted by different authors, from $-0.27$ (Cadonau et al. 1983) to $+0.09$ (Sandage & Tammann 1993).

On the other hand, if our aim is to use SN Ia as distance indicators, we could calibrate the $M_B$ vs. $(B-V)_0^{\text{max}}$ relation. Since the slope of the relation is fixed, we can refer for convenience to $M_B^{(B-V)=0}$, the absolute magnitude corresponding to $(B-V)_0 = 0$, without knowing the intrinsic luminosity and color of SN Ia. Then, in order to derive the distance modulus of a new type Ia SN, we need only the difference between the observed apparent magnitude at maximum and the expected absolute magnitude corresponding to the observed SN color. The use of a larger SN sample in calibrating the $M_B$ vs. $(B-V)_0^{\text{max}}$ relation strongly reduces the influence of random photometric errors but, of course, it cannot help if systematic errors are present.

For the re-calibrated SN sample of Asiago we compute $M_B^{(B-V)=0} = -18.67$. This is in fair agreement with the value $M_B^{(B-V)=0} = -18.80$ derived from the SN sample of Hamuy et al. (1995) after excluding SN 1992K which was recognized to be intrinsically different from “normal” SN Ia (Hamuy et al.1994). The residual variance of the Asiago re-calibrated estimates and of the data of Hamuy et al. (1995) around the regression lines drawn in Fig. 6 is 0.21 and 0.07, respectively.

The difference of calibrations between the two SN samples corresponds to only 6% error in the distance calibration and the larger dispersion of the Asiago re-calibrated sample has to be attributed to the larger errors of the photometric photometry. Instead, if we had used the original Asiago data, we should have derived $M_B^{(B-V)=0} = -18.39$
which, taking the data of Hamuy et al. (1995) as reference, implies a 14% error in the distance scale.

It should be stressed that a much larger error would result if, as sometimes done in the past, the calibration is based only on the bluest objects of the sample. In this case the result would be dominated by photometric errors.

The above considerations are valid in the hypothesis that SN Ia have intrinsically the same absolute magnitude and color at maximum. For many years this assumption was made on the basis of both observational and theoretical evidence. However, it is now accepted that SN Ia are not exactly alike. A few SN Ia have shown strong photometric and spectroscopic peculiarities, in particular the bright SN 1991T (Ruiz-Lapuente et al. 1992, Phillips 1992, Filippenko et al. 1992a) and the faint SN 1991bg (Filippenko et al. 1992b, Leibundgut et al. 1993, Turatto et al. 1996). If these SNe are eliminated from the sample, the dispersion of the SN absolute magnitude distribution strongly decreases but the residual dispersion is not entirely due to photometric errors or different reddening.

The two recent SNe 1992A and 1994D for which accurate photometry is available, shows definite intrinsic differences (Patat et al. 1996). We also note that recently Höflich & Khokhlov (1995) have suggested, on the basis of theoretical modeling, the existence of a relation between $M_B$ and $(B-V)_0^{max}$ which mimics the reddening law (van den Bergh 1993). If this is the case, there is no need to exclude extreme SN Ia when calibrating the mentioned relation.

Therefore, the intrinsic differences of SNIa do not seem a severe threat to the use of SN Ia as distance indicators. From the dispersion of the points of the Hamuy et al.‘s SN sample in the $M_B$ vs $(B-V)_0^{max}$ diagram (which includes the photometric errors), it can be estimated that the distance of a SNIa with accurate photometry can be derived with a relative error of only 5%.

### 6. Conclusion

In this paper we have presented and discussed new CCD observations of several sequences of comparison stars used to calibrate the photographic photometry of SNe observed in the past at the Asiago Observatory. With these data, we have re-calibrated the light and color curves of a sample of SN Ia. This work was motivated by the claims of several authors (e.g. Sandage & Tamman 1993, Branch & Miller 1993, Vaughan et al. 1993) that systematic errors affected the photometry of some SN Ia observed at Asiago in the seventies.

Indeed we have found that, in most cases, the random errors affecting the zero point calibration of the comparison stars were consistent with the uncertainties quoted by the authors of the original papers (cfr. Tables 4 and...
Fig. 6. $M_B$ vs. $(B-V)_0$ for the Asiago SNe whose sequences have been re-calibrated in this work (filled circles), by Tsvetkov (empty circles) and by Hamuy et al. (1995) (starred symbols). The continuous line is the fitting of the re-calibrated Asiago data, the dashed line shows the fitting of the estimates based on the original Asiago photometry (not shown) and the dotted line is the fitting on the Hamuy et al. sample.

5). These errors (0.1 - 0.2 mag) were due to the observing technique employed and which was based on photographic transfers. We have however no explanation for the large errors found for the sequence used to calibrate SNe 1970J and 1972J, whereas the sequence of SN 1976J, the other object with a large correction, was reported as preliminary just in the original paper.

With the new sequences we have derived new light curves for the SNe determining new $B$ magnitude and $(B - V)$ color at maximum (see Tab. 6). Large differences of these values from those ones of Leibundgut et al. (1991) are found in several cases also because of different technique of fitting. As an effect of the re-calibration, the $(B - V)_0$ distribution becomes slightly sharper and moves to the red by 0.06 mag and it result in good agreement with that one of the SN sample of Hamuy et al.(1995). Only one case, i.e. SN 1974J, of very blue supernovae still remains which, as we said earlier, should need further investigation.

Finally, we stress that, as far as the use of SN Ia as distance indicators is concerned, the best approach is to calibrate the relation between $M_B$ and $(B - V)_0$ using all "bona fide" SN Ia. By using this approach, we cannot determine the intrinsic absolute magnitude and color of the individual objects, but we eliminate the problem of dealing with the unknown reddening in the parent galaxy and strongly reduce the influence of random photometric errors.

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