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TYPE Ia SUPERNOVAE IN LATE TYPE GALAXIES: REDDENING CORRECTION, SCALE HEIGHT, AND ABSOLUTE MAXIMUM MAGNITUDE

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ABSTRACT

We have collected and analyzed the color excess data for the best photometrically studied type Ia supernovae (SNIa) which occurred in late type galaxies. From these data we find a ratio of the B band to selective extinction in the parent galaxies of $R_B = A_B/\mathrm{E}(B-V) = 3.35 \pm 0.25$ (1σ). This indicates that the extinction curves in late type galaxies have similar properties to that of our Galaxy. We obtain a new calibration for the absolute magnitude at maximum of SNIa in late type galaxies $\langle M_B \rangle = -19.24 \pm 0.18(1\sigma) + 5\log(H_0/75)$, which is marginally brighter than the recent determinations for type Ia supernovae observed in elliptical (dust-free) galaxies, and appears to confirm the potential of SNIa as standard candles for distance determinations. Studying the distribution of the extinction in the parent galaxies we find an average half-width of selective extinction of $\Delta[\mathrm{E}(B-V)] = 0.13 \pm 0.04$ and a dispersion of extinction to SNe of $\sigma[\mathrm{E}(B-V)] = 0.15 \pm 0.01$. Allowing for extinction biases, the total width of the dust disk turns out to be $2\tau_0 = 1.28 \pm 0.23$ mag. These results imply that SNIa have a considerably broader distribution than the dust disk and confirm that they are older than old disk population objects, i.e., age > 1–2 billion years. Also, we conclude that total extinction thickness of late type galaxies is very similar to that of the Milky Way.

1. INTRODUCTION

SNIa are generally regarded as reliable standard candles because they constitute a very homogeneous class of objects for their light curves and, more importantly, for their small magnitude dispersion near maximum light (Barbon *et al.* 1973a). Their absolute maximum magnitudes $M_B \sim -19$ (van den Bergh 1988; Leibundgut & Tammann 1990; Miller & Branch 1990) make them observable out to distances of cosmological interest ($cz > 5000$ km s^{-1}).

A proper calibration of their peak luminosity is, therefore, of paramount importance. There are a number of problems that make this task nontrivial, i.e., (a) the current uncertainty of ± 0.4 mag (Leibundgut & Tammann 1990; Jacoby *et al.* 1990) in the distance modulus of the Virgo Cluster, normally used to calibrate the absolute magnitude at maximum of SNIa (Capaccioli *et al.* 1990); (b) the lack of homogeneity in the photometric observations of SNe, which forces one to use approximate color equations (Arp 1961; Branch & Bettis 1978; Cadonau 1987; Tammann & Leibundgut 1990); (c) for SNe occurring in late type galaxies, the actual amount of reddening internal to the parent galaxies is generally not well determined.

About this last item we like to point out the following: While the shape of the template color curve [intrinsic $(B-V)_0$ versus time] is relatively well known (Barbon *et al.* 1973a; Leibundgut 1989), a large uncertainty affects the zero-point value, i.e., the value at maximum light, whose determinations range from $(B-V)_0^{\max} = -0.04$ (Capaccioli *et al.* 1990) through $(B-V)_0^{\max} = -0.15$ (Cappellaro 1982) to $(B-V)_0^{\max} = -0.20/-0.27$ (Pskovskii 1968; Cadonau *et al.* 1985). The effect of this uncertainty alone is to introduce a global error as large as $\sim 20\%$ into the distance determinations.

In the cases in which the color excess is available, the extinction can be calculated from the usual relation $A_B = R_B \times \mathrm{E}(B-V)$. However, there is no general consensus about the use of the canonical value $R_B \simeq 4$ which is determined for our Galaxy (e.g., Savage & Mathis 1979) and some authors propose much lower values. For example, Jõeever (1982) derives $R_B = 1.8$ from a statistical analysis of a sample of SNe-I; Cadonau *et al.* (1985) adopt $R_B \simeq 2$; Tammann (1987) reports unconventional values as small as $R_B \simeq 1$; Leibundgut (1989) confirms $R_B \simeq 1$ from the analysis of the $(B-H)$ vs $(B-V)$ color diagram of a sample of SNIa observed at maximum. Finally, Capaccioli *et al.* (1990) find $R_B \simeq 1.7$ (but with a quite large uncertainty of ± 1.4 as one can infer from their Fig. 7) from an analysis of the dispersion of $B_{\max}$ for SNIa in the Virgo Cluster.

Although one cannot exclude such low values *a priori*, it is clear that they would imply quite extreme properties for the dust population that is present in late type galaxies. For example, $R_B = 1$ would imply $A_V \equiv 0$ for *any* value of $\mathrm{E}(B-V)$, which is a little too extreme. Also, a value of $R_B = 1.7$ implies a λ^{-4} dependence for the distinction: this

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TABLE 1. Basic data for SNIa.

SN	*Type*	Galaxy	*Type*	$5logd-5$	B_{max}	$E(B-V)_{tot}$	N	$A_B(MW)$	Ref.
1954B	I	NGC 5668	S*d*	32.15	12.4	0.13	5	0.04	0
1959C	I	M+01 34 05	SB*c*	33.14	14.1	-0.13	6	0.02	1
1965I	Ia	NGC 4753	I0	30.89	12.5	-0.07	6	0.02	2
1967C	Ia	NGC 3389	S*c*	31.76	13.0	-0.11	11	0.06	3
1969C	Ia	NGC 3811	SB*cd*	33.23	14.4	0.27	5	0.01	4
1971G	I	NGC 4165	S*a*	32.20	13.7	0.15	17	0.05	5,7
1971I	Ia	NGC 5055	S*bc*	29.27	11.9	0.50	15	0.00	5,6
1972E	Ia	NGC 5253	I0*p*	27.53	8.4	0.02	14	0.19	8,9,10,11
1972J	I	NGC 7634	SB0	33.11	14.3	-0.12	6	0.12	12
1974G	Ia	NGC 4414	S*c*	29.93	12.4	0.34	8	0.02	12
1975N	Ia	NGC 7723	SB*b*	31.88	13.7	0.36	8	0.08	13,14
1975O	I	NGC 2487	SB*b*	34.08	15.2	-0.08	3	0.13	13
1976J	I	NGC 977	S:	33.78	15.1	-0.03	6	0.04	13,15
1979B	Ia	NGC 3913	S*d*	31.15	12.3	0.29	3	0.00	16
1980N	Ia	NGC 1316	S0*p*	31.14	12.5	0.30	8	0.00	17
1981B	Ia	NGC 4536	S*c*	30.62	12.0	0.19	28	0.00	18,19,20
1982B	Ia	NGC 2268	S*bc*	32.68	13.7	0.39	3	0.21	23,24,27
1983G	Ia	NGC 4753	I0	30.89	12.9	0.33	7	0.02	21,22
1983R	Ia	IC 1731	S*c*	33.42	14.4	0.20	4	0.19	25
1984A	Ia	NGC 4419	SB*a*	31.13	12.5	0.36	14	0.06	26
1986A	Ia	NGC 3367	SB*a*	33.20	14.4	-0.13	6	0.05	28
1986G	Ia	NGC 5128	S0*p*	28.45	12.5	1.24	18	0.49	29
1989B	Ia	NGC 3627	S*b*	29.09	12.55	0.70	5	0.05	30

0 Wild (1960), 1 Mihalas (1962), 2 Ciatti and Barbon (1971), 3 de Vaucouleurs et al. (1967), 4 Bertola and Ciatti (1971) 5 Barbon et al. (1973b), 6 Deming et al. (1973), 7 de Vaucouleurs et al. (1971), 8 Ardeberg and Grood (1973), 9 Jarret and Eksten (1973), 10 Cousin (1972), 11 Lee et al. (1972), 12 Ciatti and Rosino (1977), 13 Ciatti and Rosino (1978), 14 Wegner (1977), 15 Wegner (1979), 16 Barbon et al. (1982b), 17 Olzewski (1982), 18 Barbon et al. (1982a) 19 Tsvetkov (1982), 20 Buta and Turner (1983), 21 Harris et al.(1983), 22 Buta et al. (1984), 23 Cadonau and Trefzger (1983), 24 Tsvetkov (1983), 25 Barbon et al. (1989b), 26 Kimeridze and Tsvetkov 1986, 27 Ciatti et al. (1988), 28 Tsvetkov (1988), 29 Philips et al. (1987), 30 Barbon et al. (1990).

requires grains to be purely dielectric and very small so that the extinction would consist of pure scattering. All of this, although *physically* possible, is *astrophysically* very unlikely. After all, late type galaxies are known to be strong FIR sources and, therefore, their dust grains must be made of rather refractory materials, just as they are in our Galaxy.

The cosmological consequences of the uncertainty attached to R_B are dramatically illustrated by Capaccioli *et al.* (1990): they show (their Table 3) that M_B(SNIa) varies by $\sim$0.6 mag and H_0 by $\sim$30% if R_B is varied between 1 and 4.

These problems have motivated our study of the reddening to SNIa in late type galaxies, aiming at both determining the properties of their dust extinction and calibrating the magnitude at maximum of SNIa.

One of our conclusions is that the available evidence does not support values of R_B significantly smaller than 3 and, in fact, favors the hypothesis that the dust properties in late type galaxies are quite similar to those of dust grains in the Milky Way.

Also, we shall show that the absolute magnitudes of SNIa in late type galaxies are essentially identical to those of SNIa in ellipticals and, therefore, they constitute excellent standard candles indeed. Finally, we find that the z distribution of SNIa provides evidence that they are older than disk population objects.

2. BASIC DATA

Our selection of SNIa is based on an updated version of the *Asiago Supernova Catalogue* (ASC, Barbon *et al.*

TABLE 2. Regression data.

SN	M_B^*	$E(B-V)$	$\sigma_{E(B-V)}$	i
1954B	-19.75	0.12	0.06	21
1959C	-19.04	-0.14	0.11	81
1965I	-18.39	-0.07	0.06	–
1967C	-18.76	-0.13	0.07	56
1969C	-18.83	0.26	0.20	39
1971G	-18.50	0.04	0.14	44
1971I	-17.37	0.50	0.23	52
1972E	-19.13	-0.03	0.03	–
1972J	-18.81	-0.15	0.15	41
1974G	-17.53	0.34	0.14	53
1975N	-18.18	0.34	0.07	44
1975O	-18.88	-0.11	0.13	34
1976J	-18.68	-0.03	0.17	–
1979B	-18.85	0.29	0.23	17
1980N	-18.64	0.30	0.03	39
1981B	-18.62	0.19	0.07	62
1982B	-18.98	0.34	0.05	50
1983G	-17.99	0.33	0.04	–
1983R	-19.02	0.08	0.08	49
1984A	-18.63	0.35	0.09	68
1986A	-18.80	-0.14	0.11	24
1986G	-15.95	1.12	0.14	73
1989B	-16.54	0.70	0.06	60

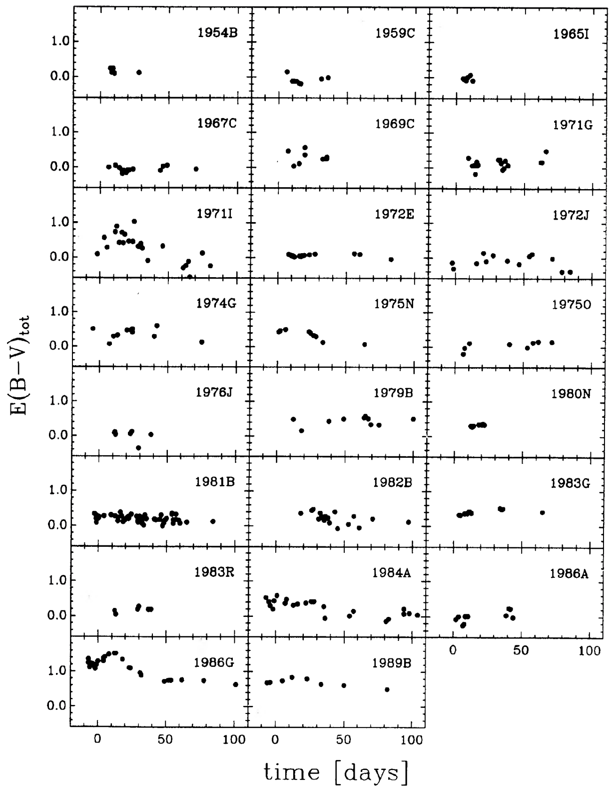

FIG. 1. The trend of $E(B-V)_{tot}$ vs time (days after the maximum). The data points have been derived by comparing the original $(B-V)$ observations to the intrinsic color curve given by Leibundgut (1989).

1989a). The individual observations have been collected from the original sources as available in the literature published by the end of 1990. We have kept only objects with published B and V photometry. Supernovae with insufficient or contradictory photometric information have been disregarded, as well as all observations in nonstandard systems.

The selected objects are listed in Table 1 which gives the SN designation (column 1) and type (column 2), the parent galaxy (column 3) and its Hubble type (column 4), as reported in ASC. The distance moduli (column 5) have been taken from the *Nearby Galaxies Catalog* (Tully 1988). We adopt these distances which are based on velocities corrected for velocity perturbations in the vicinity of the Virgo Cluster (Tully & Shaya 1984) because they are the best estimates of the distance to *individual* galaxies. The alternative of using group distances for nearby galaxies, although an apparently safer choice, relies too heavily on the assumption that proximity in the sky is a reliable criterion to assure closeness in distance. In any case, there are only two galaxies in our sample that belong to the same group and for which the redshift distances are significantly different from each other, namely SN 1972E in NGC 5253 and SN 1986G in NGC 5128. Their redshift distances are 4.9 and 3.2 Mpc, respectively. In the same scale the distance to the Centaurus Group is 4.3 Mpc, so that they seem to lie on opposite sides of the group center. On the other hand, the angular separation of NGC 5253 from NGC 5128 is 11.7° that, at a distance of 4.3 Mpc, corresponds to a linear separation, as projected on the plane of the sky, of 0.9 Mpc. This provides an approximate scale of the "acceptable" differences of distance of two galaxies within *that* cluster. Since the apparent difference in distance is comparable to the acceptable deviation within the cluster, we conclude that there is no tenable justification to force both galaxies to be exactly at the same distance and that their redshift distances are likely to be more correct.

The B_{max} values (column 6) are taken from the *Asiago Supernova Catalogue*. We see that 6 SNe out of the total of 23 objects do not have a specification of the subtype (i.e., whether Ia or Ib). This may introduce a contamination in the sample. On the other hand, on a simple statistical basis, no more than one out of the three "generic" type I SNe may be expected to be a SNIb (e.g., Panagia 1987), thus little affecting our analysis.

The evaluation of the total (i.e., including the effect of dust in both our Galaxy and the parent galaxy) color excess, $E(B-V)_{tot}$, for each SN (column 7) has been carried out by subtracting the original $(B-V)$ observations, at different epochs (references in column 10), of Leibundgut (1989) intrinsic color curve and adopting a zero point of $(B-V)_0^{max}=-0.16\pm0.05$. We adopted this value because it makes the negative $E(B-V)_{tot}$ values present in Table 2 statistically acceptable (from the present statistics of 23 objects, one may expect up to four values of $E(B-V)_{tot}$ more negative than 1σ of their own measurement). The resulting curves of $E(B-V)_{tot}$ as a function of time for all SNe are displayed in Fig. 1. An inspection to this figure reveals that for some SN, most noticeably SN 1986G and 1975N, the curve of $E(B-V)_{tot}$ versus time is not quite flat but rather it shows some systematic deviations. This indicates that the color evolution for all SNIa is not strictly equal. A systematic deviation from the average curve reduces the significance of an $E(B-V)_{tot}$ determination. On the other hand, just because of the systematic differences, the rms deviation of $E(B-V)_{tot}$ will be larger so that, at the end, a proper statistical weight will automatically be attributed to the $E(B-V)_{tot}$ determination of each color deviant SN.

The formal error attributed to $(B-V)_0^{max}$ is just an educated guess based on the average dispersion of good measurement sets. In determining the average $E(B-V)_{tot}$ value for each SN we included only data referring to epochs earlier than 30 days after maximum because this is the time interval over which a SNIa is brightest and, therefore, presumably best measured. The number of $(B-V)$ observations used to compute $E(B-V)_{tot}$ for each SN are given in column 8.

For six distant galaxies not included in the *Nearby Galaxies Catalog* (Tully 1988), the distance moduli are based on their average heliocentric velocities (Palumbo *et al.* 1983). To be consistent with the *Nearby Galaxies Catalog*, we assume the IAU standard correction to reduce the motion to the centroid of the Local Group (i.e., $\Delta V = 300 \cos b \sin l$), a Virgocentric infall velocity of 300 km s^{-1}, and $H_0 = 75$ km s^{-1} Mpc^{-1}. Column 9 gives the galactic contribution to the extinction for each parent galaxy as derived by Burstein & Heiles (1984).

In general, the absolute magnitude at maximum, corrected for Milky Way extinction M_B^* is related to the intrinsic absolute B magnitude at maximum, M_B^{max}, and to the color excess produced in the parent galaxy, $E(B-V)$, through the equation

$$B_{max} - (5 \log d - 5) - A_B(\text{MW}) = M_B^* = R_B \times E(B-V) + M_B^{max}. \tag{1}$$

Therefore, if we assume that (a) all SNIa have the same peak magnitude and (b) the extinction curve in all late type galaxies has the same R_B, by fitting the M_B^* and $E(B-V)$ data in terms of the above regression, we can simultaneously determine R_B and M_B^{max} and, from the derived rms dispersions, check the validity of these assumptions.

The regression data are listed in Table 2. The columns report, respectively, the SN designation (column 1), M_B^* (column 2), $E(B-V)$, which is the total value of Table 1 subtracted of our Galaxy contribution, and its standard deviation (column 4). Finally, column 5 gives the inclination of the parent galaxy disk, whenever available from the ASC. In the case of NGC 5128, however, we adopted an inclination $i = 73°$ which is the value appropriate for its dusty disk (e.g., Ebneter & Balick 1983) whereas the value of 37° given in ASC refers to the elliptical component of the galaxy.

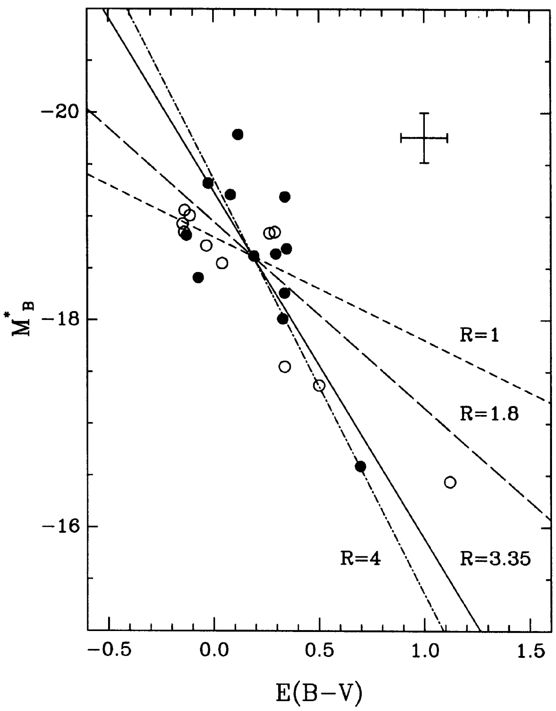

FIG. 2. The absolute magnitude at maximum, corrected only for Milky Way extinction, M_B^*, is plotted as a function of the color excess in the parent galaxy, $E(B-V)$, for 23 SNIa. Filled and open circles are points with $E(B-V)$ uncertainties lower and higher than 0.1, respectively. The cross represents the median uncertainties for both coordinates. The solid line shows the best fit of the data points corresponding to $R_B = 3.35$. Dashed lines show the traces for different values of R_B found in the literature $R_B = 1.8$ (Jõeever 1982, Capaccioli *et al.* 1990), $R_B = 1$ (Tammann 1987; Leibundgut 1989).

Since the robustness of the fit depends strongly on the very reddened SNe 1986G and 1989B, special care has been devoted to the estimate of their color excess. In both cases our estimates of the amount of the reddening due to internal absorption are confirmed by photometric CCD observations as well as spectroscopy (Philips *et al.* 1987; Barbon *et al.* 1990). In particular, for SN 1986G Philips *et al.* (1987) estimate a total color excess of 0.9 ± 0.1 whereas Rich (1987) suggests a total extinction $E(B-V) = 0.88$ (of which 0.12 due to Galactic contribution). Cristiani *et al.* (1991) rediscuss the previous determinations and add new independent estimates to obtain a value of the total color excess of 1.1 ± 0.1: this value is only marginally lower than our estimate of 1.24 ± 0.14.

For SN 1989B the apparent disagreement of ~ 0.1 mag with the value by Barbon *et al.* (1990) is entirely due to a different assumption of the $(B-V)_0^{max}$ value.

3. ANALYSIS AND RESULTS

Before proceeding with our analysis, we must consider the uncertainties in both $E(B-V)$ and M_B^*. While we can directly estimate the errors affecting E$(B-V)$ through its standard deviation $\sigma_{E(B-V)}$ (see Table 2), it is hard to do the same for M_B^*. This is mainly caused by the lack of homogeneous criteria to estimate the errors to each distance modulus. Therefore, we have assigned a conservative error of $\sim \pm 0.4$ (3σ) mag to every distance modulus (i.e., 20% uncertainty in the distances), which corresponds to the current uncertainty on the Virgo Cluster distance (see Introduction), combined with an average uncertainty of $\Delta m \simeq \pm 0.2$ mag in $B_{\max}$. Since both E$(B-V)$ and M_B^* are affected by appreciable uncertainties, one cannot use either of the two as the independent variable and fit the data points assuming that the error is predominantly in the other variable. Rather, we compute the best-fit regression by using a linear maximum likelihood algorithm, that takes into account the errors in both coordinates (Melnick 1988).

From the whole sample of 23 objects we obtain

$$M_B^* = 3.35 \pm 0.25(1\sigma) \times \mathrm{E}(B-V) - 19.24 \pm 0.08(1\sigma). \quad (2)$$

Let us first note that the resulting uncertainties on both R_B and M_B are rather small, thus, confirming our assumption that unique values of these quantities apply to supernovae in all late type galaxies. In particular, it is apparent that R_B is definitely higher than 3. In fact, including E$(B-V)$ data corresponding to epochs $t \geqslant 30^d$, we still obtain $M_B^* = 3.64 \pm 0.36(1\sigma) \times \mathrm{E}(B-V) - 19.15 \pm 0.08(1\sigma)$. Even excluding the two most reddened SNe, i.e., 1989B and 1986G, the regression yields quite similar fitting parameters, i.e., $R_B = 3.27 \pm 0.34$ and $M_B^{\max} = -19.2 \pm 0.1$. Similarly, excluding the SNe most deviant in color evolution, i.e., SN 1975N and 1986G, we obtain $R_B = 3.45 \pm 0.28$ and $M_B^{\max} = -19.18 \pm 0.08$. We also note that, had we decided to adopt the Centaurus Group distance for both SN 1972E and SN 1986G, the former would have a brighter magnitude while the latter would be fainter, and the derived slope would be slightly steeper.

The plot of M_B^* as a function of E$(B-V)$ (Fig. 2) illustrates quite clearly that values as small as $R_B \simeq 1$ must be excluded, and even intermediate values, falling close to 2 are not acceptable. Among others, shallow slopes were derived by Jöeever (1982) and Capaccioli *et al.* (1990) who analyzed SNIa data following methods very similar to ours. We identify the main cause of their exceedingly shallow slopes in their assumption of negligible errors in the abscissa while computing their best-fit parameters. In fact, if we compute an unweighted fit to Table 2 data, minimizing the rms deviations in the ordinate only, we would find a slope as shallow as ~ 2.2, which is close to Jöeever and Capaccioli *et al.* estimates. In addition, there is a number of other effects which all may lead to even more extreme underestimates of R_B: (a) the lack in some samples of highly reddened SNe, (b) the scatter of the relation coupled to the fact that the relation itself is not homogeneously populated along the entire range of M_B^* and E$(B-V)$, and (c) the contamination of early samples with SNIb.

The R_B value we find for late type galaxies is somewhat lower than the canonical Milky Way value of ~ 4.1 (e.g., Savage & Mathis 1979). The discrepancy appears to be significant and may be evidence that, on the average, grains in late type galaxies are somewhat smaller than those found in the solar neighborhood. Values of R_B smaller than the Galactic value have been found for the SMC (3.7 ± 0.2; Lequeux 1988, and references therein) and for the inner regions of M31 ($R_B = 3.8 \pm 0.3$, Walterbos 1986; $R_B \sim 3$ at $r = 5$ kpc, Searle & Thompson 1986) as well as in some early type galaxies (e.g., $R_B \sim 3.8$ in NGC 7625, Brosch & Loinger 1991). It is worth noting that, since the uncertainty of ± 0.05 mag in the zero point of $(B-V)_0^{\max}$ induces a shift along the E$(B-V)$ axis, it has no effect on the slope in Eq. (2), hence on R_B, but it may affect the calibration of the absolute magnitude at maximum of SNIa, introducing an additional uncertainty in $\langle M_B^{\max} \rangle$ of about ± 0.15 mag.

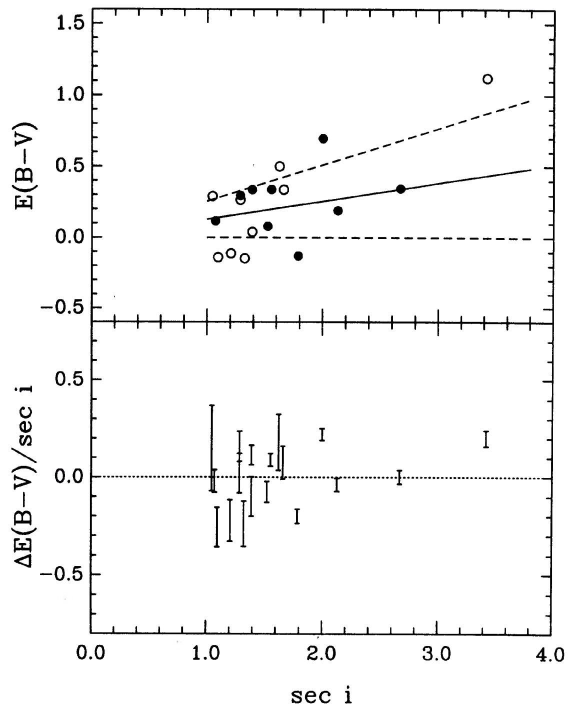

FIG. 3. Upper panel: E$(B-V)$ as a function of the secant of the inclination of the parent galaxy disk. Filled and open circles are points with E$(B-V)$ uncertainties lower and higher than 0.1, respectively. The solid line represents the best fit given in Eq. (5) and corresponds to a selective extinction half-width of 0.13 ± 0.04 mag. Lines corresponding to slopes 0 and twice the average are also shown. Lower panel: Residuals relative to the average as a function of sec *i*. The error bars denote the 1σ uncertainties of the individual points. The dispersion corresponds to rms$=0.15 \pm 0.01$.

Since the distance moduli of the parent galaxies are based on $H_0 = 75$ km s^{-1} Mpc^{-1}, from Eq. (2) we obtain

$$\langle M_B \rangle = -19.24 \pm 0.18(1\sigma) + 5 \log(H_0/75), \quad (3)$$

where the attached error includes the uncertainty on the zero point of the $(B-V)_0^{\max}$.

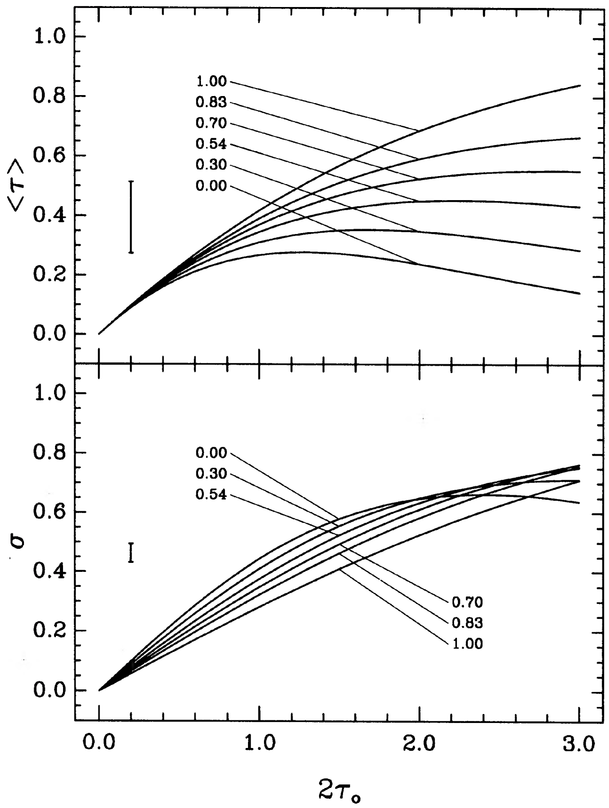

FIG. 4. The average optical depth $\langle\tau\rangle$ and the rms deviation σ as a function of the total dust disk width $2\tau_0$ [Eqs. (8), (9), and (10)]. Curves are shown for a number of z_d/z_{SN} ratios. The average SNIa values are shown as errorbars of length corresponding to their standard deviations.

This calibration is in good agreement with $\langle M_B\rangle = -18.45\pm0.23+5\log(H_0/100)$ obtained by van den Bergh (1988) for a sample of 13 SNIa occurred in Shapley–Ames galaxies, and within the errors, with the estimates by Leibundgut & Tammann (1990).

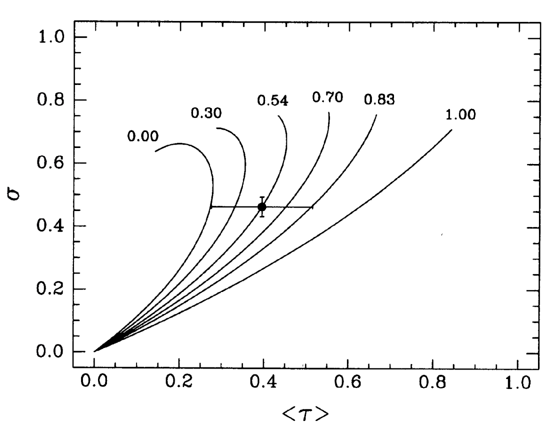

FIG. 5. The rms deviation σ as a function of the average optical depth $\langle\tau\rangle$. The SNIa values are shown together with their uncertainties.

Also, we find good agreement with Miller & Branch's (1990) calibration (H_0=75 km s^{-1} Mpc^{-1})

$$\langle M_B\rangle = -18.95\pm0.11(1\sigma) \tag{4}$$

for SNIa occurred in *elliptical* (i.e., essentially dust-free) galaxies. This indicates that we have made proper allowance for the absorption, lends support to our choice of $(B-V)_0^{\max}=-0.16$ and confirms our determination of R_B =3.35. We see that SNIa in elliptical and spiral galaxies have similar magnitudes at maximum and, therefore, they appear to be good candidates for standard candles. On the other hand, we note that our average M_B is 0.29 brighter than Miller and Branch's value: this difference is marginally significant, at a $\sim 2\sigma$ level. If confirmed, this result would indicate that some systematic difference exists in the photometric behaviors of SNIa occurring in early and late type galaxies as suggested by Filippenko (1989).

Another aspect that we wish to investigate is the dependence of the SN extinction produced in the parent galaxies on the galaxy inclination. Intuitively, one expects the extinction to increase for high inclinations. At the same time, one can expect quite some dispersion around an average relationship due to the fact that individual SNe are embedded at different depths into the disks of their parent galaxies. Figure 3(a) displays the plot of E$(B-V)$ as a function of sec i for all SNe occurred in disk galaxies. A positive trend is clearly apparent. The best-fit in terms of a relationship E$(B-V)$=const$\times$sec i yields

$$E(B-V) = (0.13\pm0.04)\sec i. \tag{5}$$

Since this is the average relationship, the slope represents a measure of the half-width of the extinction in the galactic disks of parent galaxies. Note that within the errors all E$(B-V)$ values are confined between zero and twice the average line (dashed lines in Fig. 3). This is just what one would expect for objects distributed with a scale height equal or greater than that of dust and suggests that the estimated total width of the dust disk is a realistic value.

The dispersion around the average relationship is significantly larger than the average uncertainties and, therefore, can provide an estimate of the distribution of intrinsic extinction to individual SNe. In fact, assuming all galactic disks to be similar to each other, such dispersion provides a direct measurement of the z dispersion of SNIa progenitors in late type galaxies. Figure 3(b) displays the deviation of the ratio E$(B-V)$/sec i from the average: this quantity represents the projection of the optical depth toward a SN in the z direction of the parent galaxy. We derive an intrinsic [i.e., after allowance for uncertainties on individual values of E$(B-V)$] dispersion of σ[E$(B-V)$] =0.15±0.01. This value is higher than the extinction half-thickness of galactic disks which indicates that the scale height of SNIa is appreciably higher than that of extinction and that extinction in the disk may affect the SN statistics. In order to put the argument in more quantitative terms, let us consider a simplified model in which SNIa and dust are assumed to be evenly distributed within slabs with common median plane and widths z_{SN} and z_d, respectively.

Denoting with τ_0 the half-width of the dust layer and *neglecting* any bias introduced by extinction, the average observed width is

$$\langle\tau\rangle=\tau_0 \tag{6}$$

and the rms deviation from the average

$$\sigma=\tau_0\sqrt{1-2z_d/3z_{\rm SN}}. \tag{7}$$

According to these equations in all cases one finds $\sigma\leqslant\langle\tau\rangle$, the equality being approached when $z_d\ll z_{\rm SN}$. Then, the observed ratio $\sigma/\langle\tau\rangle=1.17\pm0.35$ would imply $z_d/z_{\rm SN}\leqslant0.49$ with the lowest values being strongly favored.

A more refined analysis can be performed by taking into account that the detectability of a SN is reduced by a factor $\exp(-\tau)$ because of extinction. In this case, one obtains somewhat more complicated formulas,

$$\langle\tau\rangle=\frac{(\rho/\tau_0)[1-(1+2\tau_0)e^{-2\tau_0}]+2\tau_0e^{-2\tau_0}(1-\rho)}{(1-\rho)(1+e^{-2\tau_0})+2(\rho/\tau_0)(1-e^{-2\tau_0})}, \tag{8}$$

$$\langle\tau^2\rangle=\frac{(\rho/\tau_0)[2-(4\tau_0^2+4\tau_0+2)e^{-2\tau_0}]+4\tau_0^2e^{-2\tau_0}(1-\rho)}{(1-\rho)(1+e^{-2\tau_0})+2(\rho/\tau_0)(1-e^{-2\tau_0})}, \tag{9}$$

$$\sigma=\sqrt{\langle\tau^2\rangle-\langle\tau\rangle^2}, \tag{10}$$

where, for the sake of convenience, we have defined

$$\rho=z_d/z_{\rm SN}. \tag{11}$$

The curves of $\langle\tau\rangle$ and σ as a function of the total width $2\tau_0$ are displayed in Fig. 4. We see that for high values of $2\tau_0$, the average optical depth becomes smaller than the half width of the disk and that this effect is more conspicuous for low values of the $z_d/z_{\rm SN}$ ratio. The rms deviation, on the other hand, is only mildly affected by extinction and does not depend on the $z_d/z_{\rm SN}$ ratio either.

In these graphs, the experimental values of $\langle\tau\rangle=0.40\pm0.12$ mag and $\sigma(\tau)=0.46\pm0.02$ are indicated as error bars whose sizes correspond to their respective uncertainties. A more clear view of the allowed parameter space can be taken looking at Fig. 5 which displays σ as a function of $\langle\tau\rangle$. It is apparent that, because of the large uncertainty on $\langle\tau\rangle$, we cannot bracket the $z_d/z_{\rm SN}$ range very well. The central value is $z_d/z_{\rm SN}=0.54$ which corresponds to SNIa having a scale height about twice as high as that of dust; however, any value in the interval 0 and 0.83 is statistically acceptable to within one standard deviation. On the other hand, the total dust disk width is much better defined and turns out to be $2\tau_0=1.28\pm0.23$ mag. This value is comparable to the width of our Galaxy in the solar neighborhood $2\tau_0(\mathrm{MW})=0.94$ mag (Allen 1973). The close similarity in both R_B and $2\tau_0$ values indicates that the general distribution and properties of dust grains in late type galaxies is rather similar to those of the dust population in the Milky Way.

As for the z distribution of SNIa in late type galaxies, our analysis shows that they are likely to have a scale height twice as high as that of the dust and possibly higher. Taken at face value and considering that the scale height of extinction in our Galaxy is $\beta=140$ pc (Allen 1973), this result suggests a SNIa scale height greater than ~300 pc which is comparable to that of old disk population stars. Therefore, SNIa in late type galaxies must have an age in excess of 1–2 billion years, i.e., they are at least as old as old disk populations.

4. CONCLUSIONS

We have critically reviewed the $(B-V)$ observations of the best investigated SNIa occurring in late type galaxies in order to derive homogeneously their color excesses and to study their dependence on the internal absorption A_B. The main results of our analysis can be summarized as follows:

(a) We find a ratio of B band to selective absorption of $R_B=A_B/\mathrm{E}(B-V)=3.35\pm0.25$ (1σ). This figure is somewhat lower than the mean Galactic value $R_B\simeq4$, and is significantly higher than the values $R_B=1-2$ determined by other authors.

Also, this result provides clear evidence that, to an accuracy of 10%, R_B is a constant, and can confidently be used in the computation of the extinction affecting SNIa occurring in different Hubble type galaxies.

(b) We have obtained a new calibration of the absolute magnitude at maximum of SNIa in late type galaxies:

$$\langle M_B\rangle=-19.24\pm0.18(1\sigma)+5\log(H_0/75). \tag{12}$$

The good agreement with Miller & Branch's (1990) calibration ($H_0=75$ km s^{-1} Mpc^{-1})

$$\langle M_B\rangle=-18.95\pm0.11(1\sigma) \tag{13}$$

for SNIa occurred in *elliptical* (i.e., essentially dust-free) galaxies indicates that SNIa have similar magnitudes at maximum in all types of galaxies, although there is marginal evidence for SNIa in spiral galaxies to be somewhat brighter than those in ellipticals.

(c) We find that the extinction thickness of late type galaxies is comparable to that of the Milky Way and that the z dispersion of SNIa relative to the plane of their parent galaxies is appreciably higher than that of dust extinction. We conclude that SNIa progenitors in late type galaxies are older than old disk population objects, i.e., older than 1–2 billion years.

(d) Late type galaxies have been found to have $R_B=3.35\pm0.25$ and $2\tau_0=1.28\pm0.23$ mag which are close to the Milky Way values, 4.10–4.15 (Savage & Mathis, 1979) and 0.94 (Allen 1973), respectively. Such a close similarity in both quantities indicates that the general distribution and properties of dust grains in late type galaxies are rather similar to those of the dust population in the Milky Way.

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