1994ApJ...424L.107M

THE ASTROPHYSICAL JOURNAL, 424:L107–L110, 1994 April 1

SN 1992bc AND SN 1992bo: EVIDENCE FOR INTRINSIC DIFFERENCES IN TYPE Ia SUPERNOVA LUMINOSITIES

JOSÉ MAZA
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile;
jmaza@das.uchile.cl

AND

MARIO HAMUY, M. M. PHILLIPS, N. B. SUNTZEFF, AND R. AVILÉS
National Optical Astronomy Observatories,[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile;
mhamuy@noao.edu; mphillips@noao.edu; nsuntzeff@noao.edu; raviles@noao.edu
Received 1993 November 18; accepted 1993 December 28

ABSTRACT

Based on the two best-observed Type Ia supernovae found in the Calán/Tololo Supernova Search, in this *Letter* we present convincing evidence that Type Ia supernovae with a fast rate of decline in the B band are intrinsically subluminous with respect to those with a slower decline rate. The effect is greater in the B band than in the I band. Specifically, we show that the two Type Ia supernovae SN 1992bc and SN 1992bo differ by 0.80 ± 0.2 mag in their peak B absolute magnitudes, and by only 0.41 ± 0.2 mag in the I band. SN 1992bc occurred in a spiral galaxy, whereas SN 1992bo exploded very far from the nucleus of a lenticular galaxy. These findings suggest the possibility that these two Type Ia supernovae may have had progenitors with significant physical differences. Both objects are normal Type Ia supernovae from a photometric and spectroscopic point of view. Even though these objects confirm the dependence of the absolute B magnitude on the rate of decline, that relation could be less pronounced than suggested recently by Phillips (1993).

Subject headings: distance scale — supernovae: general — supernovae: individual (SN 1992bc, SN 1992bo)

1. INTRODUCTION

The very high intrinsic luminosity of supernovae (SNe) at maximum light makes them potentially powerful as extragalactic distance indicators. If it could be established that the intrinsic cosmic scatter of some type of SNe is low, they could then in principle be used to obtain both the Hubble constant H_0 and the deceleration parameter q_0 (see Branch & Tammann 1992 and references therein).

The first Hubble diagram for Type I supernovae (SNe I) was presented by Kowal (1968), who pointed out the potential of these objects as distance indicators. From photographic observations in blue light Kowal determined a dispersion of $\sigma = 0.6$ mag for the peak luminosity of a number of SNe I, implying that the intrinsic cosmic scatter should be smaller than this value. Later on, different types of SNe I were recognized, and the Hubble diagram was reanalyzed for SNe Ia (see, for example, Leibundgut 1991; Miller & Branch 1990), yielding an observed dispersion in the peak B magnitudes of 0.2–0.4 mag. Leibundgut & Tammann (1990) suggested that this scatter could be caused solely by observational errors, and the intrinsic magnitude scatter of SNe Ia could be "vanishingly small." However, recent examples like SN 1986G, SN 1991T, and SN 1991bg cast some doubts regarding the extreme homogeneity of SNe Ia (Phillips et al. 1987; Filippenko et al. 1992a; Phillips et al. 1992; Filippenko et al. 1992b; Leibundgut et al. 1993).

In mid-1990 a group of investigators from the University of Chile (Cerro Calán) and from Cerro Tololo Inter-American Observatory (CTIO) initiated a photographic search for SNe, with the aim of studying the suitability of these objects for cosmological tests (Hamuy et al. 1993, hereafter Paper I). So far, a total of 40 SNe in the redshift range $z = 0.01$–0.1 have been discovered in the Calán/Tololo survey. Paper I reports on the four discoveries made during 1990, and future papers will report on the progress of the survey. In this *Letter* we present a clear example of photometric inhomogeneities among the Type Ia class, supplied by the two best-observed SNe of the Calán/Tololo survey discovered in the course of 1992: SN 1992bc and SN 1992bo.

2. SN 1992bc AND SN 1992bo

SN 1992bc was found by R. Antezana on a plate taken on 1992 October 4.36 (UT) in the spiral galaxy ESO 300-G9 ($\alpha = 3^h03^m22^s$; $\delta = -39°45'15''$; equinox 1950.0) at an observed redshift of $z = 0.020$. A spectrogram obtained right after discovery revealed the characteristic Si II λ6355 feature of SNe Ia (Hamuy & Maza 1992). SN 1992bo was also discovered by R. Antezana on 1992 December 20.06 (UT) in the lenticular galaxy ESO 352-G57 ($\alpha = 1^h19^m44^s$; $\delta = -34°27'29''$; equinox 1950.0) at an observed redshift of $z = 0.019$. A spectrogram also revealed this object as a Type Ia supernova (Maza & Hamuy 1992; Hamuy 1993).

Immediately after discovery an intensive photometric follow-up of these objects was initiated at CTIO using a CCD camera in the $BV(RI)_{KC}$ system. A detailed report of these observations will be presented in a forthcoming paper. Figures 1 and 2 show the resulting light curves of SN 1992bc and SN 1992bo. It can be seen that both objects were discovered well before maximum light in all four bands. This fact, along with the excelling photometric quality of the data, produced the best light curves ever published for SNe Ia beyond the Virgo cluster. SN 1992bc reached maximum light in B on 1992 October 16.8 ± 0.5 (UT) with $B_{max} = 15.15 \pm 0.03$, and $V_{max} = 15.22 \pm 0.02$ about 0.5 days later. For SN 1992bo we estimate

---

[1] Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under cooperative agreement with the National Science Foundation.

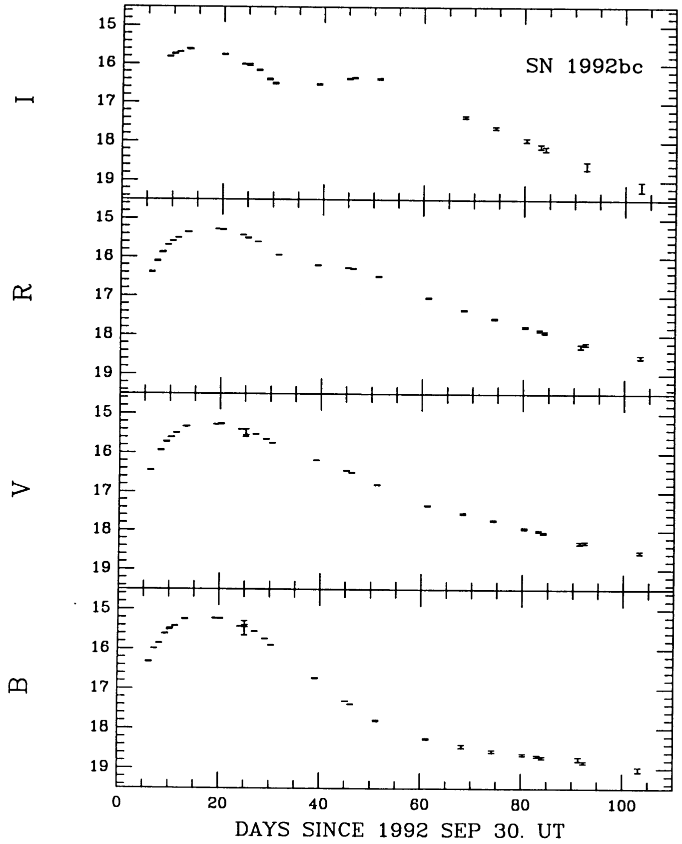

FIG. 1.—*B*, *V*, *R*, and *I* light curves of SN 1992bc

$B_{\rm max} = 15.84 \pm 0.02$ on 1992 December 29.7 ± 0.5 and $V_{\rm max} = 15.82 \pm 0.01$ two days later. Corrections to these magnitudes due to reddening in our Galaxy are not necessary, since foreground extinction is negligible in the direction of the parent galaxies (Burstein & Heiles 1982).

The above observations imply that SN 1992bc was 0.69 mag brighter in *B* than SN 1992bo. Correcting for their small difference in redshift, this discrepancy increases to 0.80 mag in absolute magnitude. Given that the precision of our data is ~0.02 mag, it is clear that the disparity observed in their absolute magnitudes is due to a source other than observational errors. Possible explanations for this striking difference are the following:

1. Extinction in host galaxies: Dust in the parent galaxies can in principle be an important mechanism contributing to explain the observed difference. There is, however, little evidence for significant reddening. First, the spectra show no signature of interstellar Na I D absorption at the redshifts of the host galaxies. Second, at a projected distance of ~70″ from the nucleus of the parent galaxy (~19 h^{-1} kpc, where $h = H_0/100$), extinction for SN 1992bo seems very unlikely. Although SN 1992bc lies at a much smaller projected distance to the center of its parent galaxy, any correction for reddening would make this object even more luminous than SN 1992bo.

2. Peculiar velocities of host galaxies: SN 1992bc lies ~3° from the center of the Abell cluster 3089, ~2° from Abell 3098, ~2°5 from Abell 3114, and ~2°5 from Abell S0316, which has a mean redshift $z = 0.0201$. On the other hand, SN 1992bo lies ~4° from Abell 2911 with a mean redshift $z = 0.0202$, and ~3° from cluster S0141 with a mean redshift $z = 0.0206$ (Abell, Corwin, & Olowin 1989). Hence SN 1992bc and SN 1992bo may lie in superclusters associated with these clusters. Thus there is a real possibility that their velocities are perturbed because of these structures. If we assign a possible peculiar velocity component of ± 600 km s^{-1} to each galaxy (R. Schommer, private communication), this results in a ±0.2 mag uncertainty in the supernova absolute relative magnitudes, several times smaller than the observed effect. Peculiar velocities of the order 2500 km s^{-1} (40%) are needed to explain the observed differences. We judge this to be very unlikely.

3. The observer's motion with respect to the cosmic background radiation (solar motion in our Galaxy, Virgo infall, etc.) could in principle, introduce peculiarities in the observed redshifts. Since these objects lie only ~21° apart, this possible source of confusion does not apply in this particular case.

4. An intrinsic dispersion in absolute magnitude: the last explanation that we consider is that there is an intrinsic difference between these two SNe. In the following discussion we strongly argue in favor of this alternative.

Figure 3 shows a superposition of the light curves of SN 1992bc and SN 1992bo as a function of time since $B_{\rm max}$. Magnitudes for SN 1992bo were made intentionally brighter by 0.69 *in all bands* in order to make the *B* maximum coincide with that of SN 1992bc. This comparison shows that the *shapes* of both light curves are significantly different. A serious discrepancy can be seen also with respect to the *B* and *V* template average curves for SNe Ia (Leibundgut 1988). SN 1992bc decayed more slowly than the *B* template, whereas SN 1992bo decayed significantly faster. These photometric differences

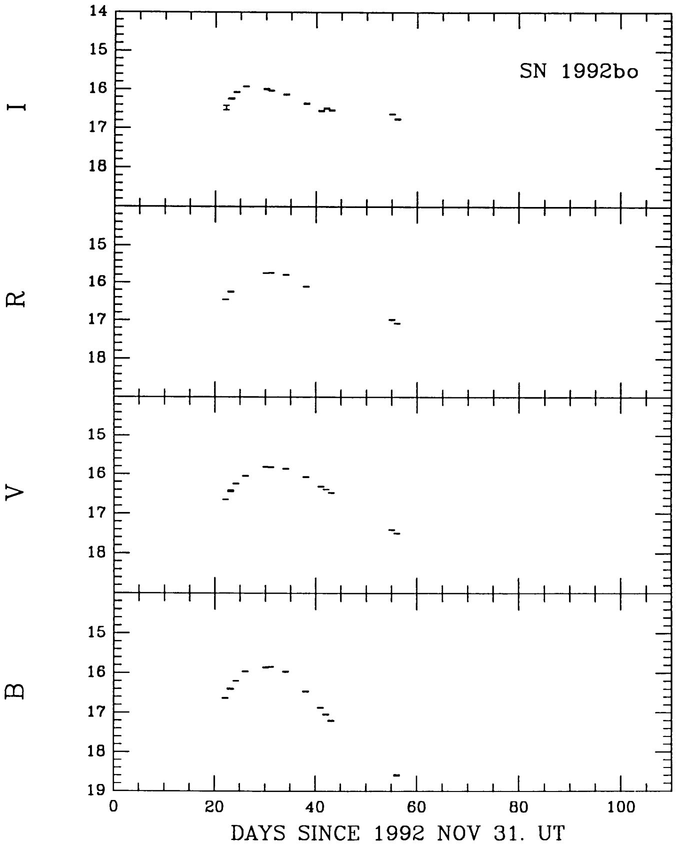

FIG. 2.—*B*, *V*, *R*, and *I* light curves of SN 1992bo

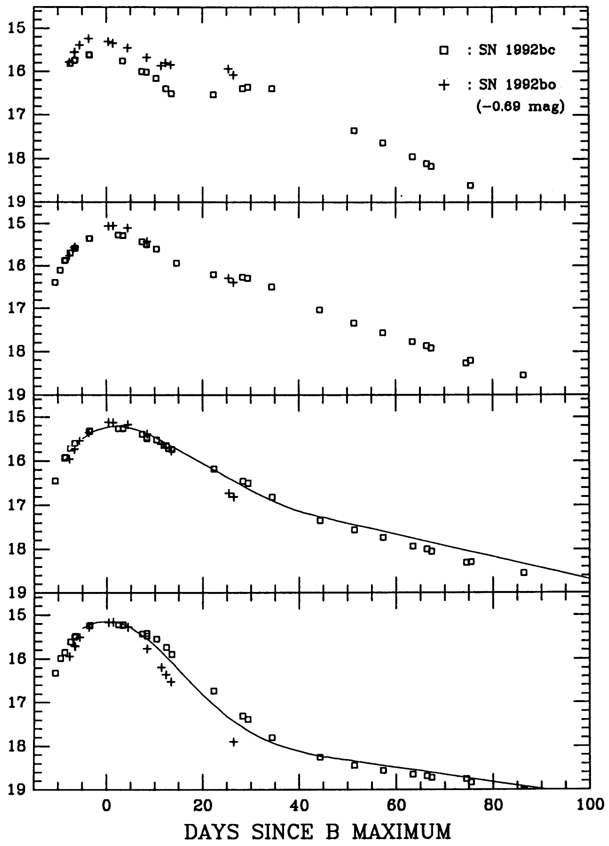

FIG. 3.—Light curves in *B*, *V*, *R*, and *I* for SN 1992bc and SN 1992bo. A shift of −0.69 mag was applied to all of the photometry of SN 1992bo to make the *B* maximum of both SNe coincide. The photometric uncertainty of each point is smaller than the size of the symbols used.

provide support to the recent findings of Phillips (1993), that fast-declining SNe Ia are intrinsically fainter than SNe Ia displaying a slow decline. SN 1992bc has a decline rate comparable to or even slower than that of SN 1991T (Filippenko et al. 1992a; Phillips et al. 1992). SN 1992bo, on the other hand, has a decline rate similar to that of SN 1992A (Suntzeff et al. 1994) but slower than those of SN 1986G and SN 1991bg (Phillips et al. 1987; Filippenko et al. 1992b; Leibundgut et al. 1993). Interestingly, SN 1992bo also rose to maximum faster than SN 1992bc; SN 1992bo took 19 days to go from 1 mag below the peak before maximum light to 1 mag below the peak after maximum light, whereas SN 1992bc took 27 days to do the same.

The *I*-band light curves of these SNe deserve a few words. The maximum magnitudes of both SNe differ by only 0.30 mag in *I*, instead of the 0.69 mag difference seen in $B_{\max}$. This is consistent with the conclusion of Phillips (1993) that the dispersion in SNe Ia absolute magnitudes in the *I* band is less than or equal to one-half of that observed in *B*. The shapes of the *I* light curves of both SNe are quite different, however. SN 1992bc reached maximum light in $I \sim 3$ days before $B_{\max}$ occurred, and a secondary maximum was observed some 30–35 days after $B_{\max}$. The *I* light curve of SN 1992bo seems to show such a secondary maximum, which, however, must have occurred significantly earlier than in SN 1992bc.

Figure 4 shows the $B-V$ color evolution for the two objects plotted as a function of time since $B_{\max}$. Plotted for comparison in the same figure is Leibundgut's template average curve normalized to an intrinsic color of $B-V=0$ at $B_{\max}$. There is convincing evidence that the intrinsic $B-V$ color of typical SNe Ia at maximum is ∼0.0 (Hamuy et al. 1991; Sandage & Tammann 1993; Maza et al. 1994). Evidently SN 1992bc displays a color behavior significantly different from the template. During the premaximum phase SN 1992bc shows no significant variation in color at $B-V \sim -0.11$. Then its $B-V$ color grew redder at a rate lower than that of the average curve. On the other hand, SN 1992bo displays a color $B-V \sim 0$ throughout the premaximum phase, getting redder for later epochs at a faster rate than the template. Evidently, the template average color curve is not a good representation for the color evolution of either SN 1992bc or SN 1992bo.

3. DISCUSSION

The suggestion made in the past that the maximum luminosity of SNe Ia, $B_{\max}$, is related to the initial rate of decline of the *B* light curve (Pskovskii 1967; Branch 1981; Phillips 1993) is clearly supported by our data for SN 1992bc and SN 1992bo. The former, with a slow decline rate, is shown to be 0.80 mag brighter in its absolute peak *B* magnitude with respect to the latter. This amount is almost certainly too large to be accounted for by anomalies in the Hubble flow. Although the faintest of the two objects proves to be the reddest, this fact may not be explainable in terms of extinction by dust in the parent galaxy but, more likely, by an inherent property of the objects. The parameter $\Delta m_{15}(B)$, defined by Phillips (1993) as the total decay in magnitudes in the *B* band after 15 days, amounts to 0.89 for SN 1992bc and to 1.61 for SN 1992bo; the difference in absolute *B* magnitude is 0.80 ± 0.2. These values produce a formal dependence of M_B on $\Delta m_{15}(B)$ less steep than the data analyzed by Phillips (1993), namely, $b = 1.11$ (instead of the value 2.70 found by Phillips). Obviously two SNe are not enough to determine this parameter *b*, but these objects, while supporting the relationship recently discussed by Phillips, suggest that it could be less pronounced. This has an important consequence for the quality of SNe Ia as standard candles. In the first place, these two SNe confirmed that they are not *perfect* standard candles. In addition, the absolute magnitude difference of these two SNe, which cover the whole range of decline rates observed for Type Ia's (excluding peculiar Type Ia

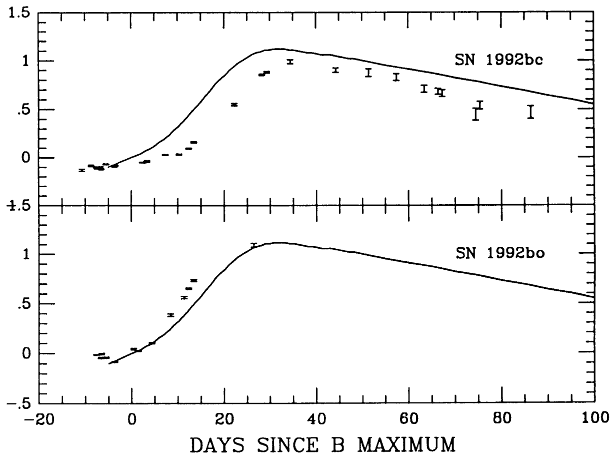

FIG. 4.—$B-V$ curves of SN 1992bc and SN 1992bo plotted as a function of time since *B* maximum, along with Leibundgut's (1988) template average curve.

events like SN 1991bg), suggests an intrinsic cosmic scatter for SNe Ia at maximum light $\sigma > 0.4$ in the B band.

Another evidence for an intrinsic difference between these two SNe Ia is provided by their different $B-V$ color evolution. The I-band light curves, on the other hand, differ by 0.30 mag at maximum light, meaning that the difference in absolute magnitude is only 0.41. More data are necessary in order to fully explore the potentials of I-band light curves of SNe Ia as standard candles. This will be a real challenge for SN surveys, because the I-band maximum occurs ~ 3 days before $B_{\max}$, making it then difficult to observe. In addition, I light curves are too different in shape to allow the I maximum to be reconstructed from later observations using a template curve.

Based on two well-observed SNe Ia, discovered in the course of the Calán/Tololo SN survey, we conclude that this class of objects does not prove as homogeneous as suggested in the past. The question naturally arises as to the cause for the inhomogeneities. Are the well-established photometric differences a hint that SNe Ia come from progenitors belonging to different stellar populations? Interestingly, SN 1992bc went off in a spiral galaxy, whereas SN 1992bo occurred far away from the center of a lenticular galaxy. These photometric differences could be complementary to a discrepancy in the blueshifts of the Si II feature ($\lambda 6355$) found by Branch & van den Bergh (1993) between SNe Ia in early- and late-type galaxies. We hope in the future, with the full sample of Calán/Tololo SNe Ia, to be able to examine such questions.

The Calán/Tololo Supernova Search is possible thanks to grant 92/0312 from the Fondo Nacional de Ciencias y Tecnología (FONDECYT-Chile). The support from CTIO and the University of Chile is also fully appreciated. We are deeply indebted to a large number of CTIO visiting astronomers who have generously gathered data for this program. We express our gratitude to R. Schommer for helpful discussions held throughout this work. One of us ((J. M.) thanks the Director and the staff of the Cerro Tololo Inter-American Observatory for their hospitality at La Serena during two weeks in 1993 January, when the first draft of this paper was written.

REFERENCES

Abell, G. O., Corwin, H. G., & Olowin, R. P. 1989, ApJS, 70, 1
Branch, D. 1981, ApJ, 248, 1076
Branch, D., & Tammann, G. A. 1992, ARA&A, 30, 359
Branch, D., & van den Bergh, S. 1993, AJ, 105, 2231
Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
Filippenko, A. V., et al. 1992a, ApJ, 384, L15
———. 1992b, AJ, 104, 1543
Hamuy, M. 1993, IAU Circ., No. 5687
Hamuy, M., & Maza, J. 1992, IAU Circ., No. 5630
Hamuy, M., Phillips, M. M., Maza, J., Wischnjewsky, M., Uomoto, A., Landolt, A. U., & Khatwani, R. 1991, AJ, 102, 208
Hamuy, M., et al. 1993, AJ, 106, 2392 (Paper I)
Kowal, C. T. 1968, AJ, 73, 1021
Leibundgut, B. 1988, Ph.D. thesis, Univ. Basel
———. 1991, in Supernovae, ed. S. E. Woosley (New York: Springer), 751
Leibundgut, B., & Tammann, G. A. 1990, A&A, 230, 81
Leibundgut, B., et al. 1993, AJ, 105, 301
Maza, J., & Hamuy, M. 1992, IAU Circ., No. 5682
Maza, J., et al. 1994, in preparation
Miller, D. L., & Branch, D. 1990, AJ, 100, 530
Phillips, M. M. 1993, ApJ, 413, L105
Phillips, M. M., et al. 1987, PASP, 99, 592
———. 1992, AJ, 103, 1632
Pskovskii, Yu. P. 1967, Astron. Zh., 44, 82 (Soviet Astron., 11, 63)
Sandage, A., & Tammann, G. A. 1993, ApJ, 415, 1
Suntzeff, N. B., et al. 1994, in preparation