SN 1992K: A TWIN TO THE SUBLUMINOUS TYPE Ia SN 1991bg

MARIO HAMUY AND M. M. PHILLIPS
National Optical Astronomy Observatories,[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

JOSÉ MAZA
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

NICHOLAS B. SUNTZEFF
National Optical Astronomy Observatories,[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

MASSIMO DELLA VALLE
La Silla Observatory, European Southern Observatory, Vitacura, Casilla 19001, Santiago, Chile

J. DANZIGER
European Southern Observatory, K. Schwarzschild-Strasse 2, D/W-8046 Garching bei München, Germany

R. ANTEZANA AND M. WISCHNJWESKY
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

ROBERTO AVILÉS AND ROBERT A. SCHOMMER
National Optical Astronomy Observatories,[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

Y.-C. KIM
Department of Astronomy, Yale University, P.O. Box 6666, New Haven, Connecticut 06511

LISA A. WELLS
National Optical Astronomy Observatories,[1] Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile

MARÍA TERESA RUIZ
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

CHARLES F. PROSSER
Harvard-Smithsonian Center for Astrophysics, 60 Garden St., MS-66, Cambridge, Massachusetts 02138

W. KRZEMINSKI
Las Campanas Observatory, Carnegie Institute of Washington, Casilla 601, La Serena, Chile

CHARLES D. BAYLIN
Department of Astronomy, Yale University, P.O. Box 6666, New Haven, Connecticut 06511

PATRICK HARTIGAN AND JOANNE HUGHES
Department of Astronomy, University of Massachusetts, Amherst, Massachusetts 01003
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ABSTRACT

We present spectroscopic and photometric data for SN 1992K, a Type Ia event found in the course of the Calán/Tololo supernova survey. These data show an impressive similarity with the spectra and light curves of the atypical Type Ia SN 1991bg. In particular, the remarkably red color and low luminosity of SN 1991bg are closely mimicked by SN 1992K. The discovery of SN 1992K confirms that the family of Type Ia supernovae covers a range of a factor of 5 or more in peak bolometric luminosity. Given their fast-declining light curves and considerably lower luminosity, SN 1991bg-like events are very likely selected against in traditional flux-limited supernova searches; nevertheless these objects could be quite common in a volume-limited sample.

1. INTRODUCTION

Because of their high intrinsic luminosities, Type Ia supernovae (SNe Ia, hereafter) offer an attractive potential as extragalactic distance indicators. The standard model of a SN Ia consists of an evolved C+O white dwarf which accretes matter from a companion star until reaching the Chandrasekhar mass (1.39 $\mathscr{M}_\odot$), at which point carbon is ignited near the center yielding a violent explosion which completely disrupts the white dwarf. Since the observable light curve in this model is powered entirely by the subsequent radioactive decay of ^{56}Ni and its daughter product ^{56}Co, the single most important parameter that determines the peak luminosity of a SN Ia is the total mass of ^{56}Ni produced in the explosion (see Leibundgut & Pinto 1992, and references therein). It has been often argued (e.g., Branch 1992) that the nickel mass is fairly tightly constrained to a value of $\mathscr{M}_{\rm Ni}\approx0.6\mathscr{M}_\odot$, leading to a corresponding small dispersion in the bolometric luminosities of SNe Ia. However, recent attempts to model SNe Ia progenitors as sub-Chandrasekhar mass white dwarfs would allow a much larger (factor of 4) range of peak luminosities (Woosley & Weaver 1994).

Up to a few years ago the available spectroscopic and photometric data on SNe Ia were basically consistent with the standard model prediction of a uniform luminosity, leading some astronomers to believe that these objects were even *perfect standard candles*. However, the appearance of SN 1986G revealed the existence of a Type Ia event with spectroscopic peculiarities and unusual light curves (Phillips *et al.* 1987), casting legitimate doubts regarding the extreme homogeneity of these objects. Unfortunately, due to the location of this object in a region of particularly high obscuration in NGC 5128 (Centaurus A), it was not possible to clearly establish whether the anomalies displayed by SN 1986G were related or not to an abnormal luminosity. More recently, the Type Ia SN 1991bg in the elliptical galaxy NGC 4374 of the Virgo cluster provided much clearer evidence for both spectroscopic and photometric peculiarities among the Type Ia class (Filippenko *et al.* 1992; Leibundgut *et al.* 1993). When compared to the Type Ia SN 1957B which occurred in the same galaxy, SN 1991bg proved to be 2.5 mag fainter at B maximum, revealing thus a wide range of luminosities within the Type Ia class.

Since its discovery, SN 1991bg has tended to be viewed as an exceptional object. This impression was reinforced recently by Branch *et al.* (1993), who identified only two possible additional 1991bg-like events out of a total sample of 84 historical SNe Ia with existing spectroscopic observations. Nevertheless, as these same authors admit, such low-luminosity events could be much more common in a volume-limited sample (see, also, van den Bergh 1993). In this paper, we report the discovery of SN 1992K, a new SN 1991bg-like object found during the course of the Calán/Tololo supernova search program. In Sec. 2 we describe our observations and reductions; in Sec. 3 we present and discuss our results and a comparison between SNe 1992K and 1991bg; finally, in Sec. 4 we summarize our conclusions.

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2. OBSERVATIONS AND REDUCTIONS

SN 1992K was discovered by R. Antezana on a photographic plate taken on 1992 March 3.32 (UT) (Hamuy & Maza 1992) in the course of the Calán/Tololo SN search, a collaborative effort between the University of Chile and the Cerro Tololo Inter-American Observatory (CTIO) (Hamuy *et al.* 1993a, hereafter referred to as Paper I). SN 1992K occurred in the SBb galaxy ESO 269–G57 ($\alpha_{1950}=13^{\rm h}07^{\rm m}10^{\rm s}$; $\delta_{1950}=-46°10'12''$) at a redshift of $cz=2908$ km s^{-1} measured in the Galactic Standard of Rest (RC3, de Vaucouleurs *et al.* 1991). The object exploded at a relatively small projected distance (2 arcsec west and 14 arcsec south) from the center of the host galaxy (2.3 kpc for $H_0=85$ km s^{-1} Mpc^{-1}), between the bulge and a spiral arm. Figure 1 (Plate 82) shows the location of SN 1992K on a V band CCD image taken with the CTIO 4 m telescope on 1992 March 6. Unfortunately, the last search plate of the field of ESO 269–G57 *not* showing the supernova was obtained ~6 months before the discovery plate, and so does not help to constrain the date of explosion.

The first spectrum of SN 1992K was secured promptly after discovery, on March 6, with the CTIO 1.5 m telescope and a GEC CCD in the wavelength range 3500–7600 Å at a resolution of 16 Å. A second spectrum was obtained on April 4 with the CTIO 4 m telescope and a Reticon CCD in the wavelength range 3300–7500 Å at a resolution of 7 Å. The wavelength calibration was accomplished via observations of a He–Ar lamp taken at the position of the SN, and the flux calibration was performed using nightly sensitivity curves determined from the observation of southern flux standards chosen from the list of Hamuy *et al.* (1992).

SN 1992K was monitored photometrically in the $BV(I)_{\rm KC}$ system starting on March 6 for a period of five months using the 0.9 m, 1.5 m, and 4 m telescopes at CTIO. Further data were gathered with the NTT, 3.6 m and 2.2 m telescopes at the European Southern Observatory (ESO). Additional digital images of the host galaxy, ESO 269–G57, were obtained in 1993 after the SN had faded from sight. Table 1 gives a journal of the photometric and spectroscopic observations, listing the UT date, the telescopes used, the observatory, the type of CCD employed, a note about the type of data obtained, and the name of the observer.

The extraction of the SN magnitude from a CCD frame is generally hampered by the uneven background upon which the object is projected. Although SN 1992K was not located in a particularly complicated area, we developed a general technique (based on IRAF[2] tasks) with the aim of subtracting the parent galaxy from the SN frames. To avoid introducing noise into the data, this technique requires the best possible image of the galaxy which we generally secure by collecting several (4–5) deep images of the SN field once the SN has faded beyond detection. Having several images of the galaxy

[2]IRAF (Image Reduction and Analysis Facility).

TABLE 1. Journal of the observations.

UT DATE		TEL	OBSERVAT	CCD	PHOT/SPEC	OBSERVERS(S)
1992	Mar 06	1.5-m	CTIO	GEC10	SPEC	M. Phillips
	Mar 06	4.0-m	CTIO	TEK2	PHOT	N. Suntzeff
	Mar 10	0.9-m	CTIO	TEK4	PHOT	M. Hamuy
	Mar 10	NTT	ESO	THOM18	PHOT	J. Danziger
	Mar 13	0.9-m	CTIO	TEK2	PHOT	C. Prosser
	Mar 19	1.0-m	LCO	TEK	PHOT	W. Krzeminski
	Mar 19	0.9-m	CTIO	TEK4	PHOT	P. Hartigan/ J. Hughes
	Mar 29	1.5-m	CTIO	TEK2	PHOT	M. Ruiz
	Apr 04	4.0-m	CTIO	Reticon	SPEC	M. Hamuy/ J. Maza
	Apr 05	0.9-m	CTIO	TEK2	PHOT	C. Bailyn/ Y.-C. Kim
	Apr 07	2.2-m	ESO	THOM19	PHOT	M. Della Valle
	Apr 12	0.9-m	CTIO	TEK2	PHOT	Y.-C. Kim
	Apr 16	0.9-m	CTIO	TEK1	PHOT	L. Wells
	Apr 19	0.9-m	CTIO	TEK1	PHOT	R. Schommer
	Apr 20	0.9-m	CTIO	TEK1	PHOT	R. Schommer
	May 11	NTT	ESO	THOM18	PHOT	M. Della Valle
	May 25	0.9-m	CTIO	TEK1	PHOT	M. Hamuy/ R. Avilés
	Jul 03	3.6-m	ESO	TEK26	PHOT	M. Della Valle
	Aug 01	2.2-m	ESO	THOM19	PHOT	M. Della Valle
1993	Mar 17	0.9-m	CTIO	TEK3	PHOT	R. Avilés
	May 17	0.9-m	CTIO	TEK3	PHOT	R. Avilés
	May 19	0.9-m	CTIO	TEK3	PHOT	R. Avilés
	May 28	0.9-m	CTIO	TEK1	PHOT	R. Avilés
	Jun 16	0.9-m	CTIO	TEK1	PHOT	R. Avilés
	Jun 24	4.0-m	CTIO	TEK3	PHOT	N. Suntzeff

has the advantage of allowing the removal of cosmic rays, but the complication of possible misalignments among the various frames. To get around this problem, we use several (~10) field stars in order to map the geometrical transformation among the final images. In doing so, we employ the *geomap* task which solves for three parameters for each axis; namely, the rotation angle, the scale factor due to possible changes in pixel sizes, and the shift in the new origin. The mapping of the geometrical transformation is generally very accurate, with residuals smaller than 0.5 pixels. Next, we use the *geotran* task which makes use of the $x-y$ mappings to perform the actual geometrical transformation required to register all of the final images. Once the various frames are properly aligned, we coadd them in order to produce a deep (*master*) image of the host galaxy.

The subtraction of the galaxy from the frames containing the SN requires matching the flux scales of both images. In general, we perform this step with bright field stars or the core of the galaxy itself. In the case of SN 1992K we used a large circular aperture (10 arcsec in diameter) centered on the host galaxy. Even on short exposures this aperture contained enough counts such that the scaling factor had a typical accuracy of 1%–3%. Figure 2 (left) shows an example of a V image of the SN 1992K field taken one month after discovery. The SN had a V magnitude of 18 and cannot be seen at all due to the low contrast with respect to the bright background of the host galaxy. The picture on the right side shows the result of subtracting the core of the galaxy using the transformed galaxy image; the SN is now clearly visible.

TABLE 2. Photometric sequence around SN 1992K.

Star	B	V	I
1	16.437(18)	15.753(10)	14.944(15)
2	17.639(08)	16.990(07)	16.229(07)
3	18.122(10)	17.467(04)	16.704(10)
4	17.798(10)	17.134(02)	16.368(01)
5	17.643(12)	16.667(03)	15.598(07)
6	17.139(10)	16.490(02)	15.738(11)

Once the galaxy was subtracted from the frames containing the SN, instrumental magnitudes were calculated via a point spread function (PSF) fitting to the images of the SN and a number of field local standard stars. The PSF was determined with DAOPHOT using the brightest stars of the field, independently for each image. The instrumental magnitudes were then transformed to the standard system through the use of a photometric sequence around SN 1992K, which was determined on four photometric nights. For more details concerning our photometric reductions, the reader can refer to Paper I. All of the comparison stars are identified in Fig. 1, and Table 2 lists their magnitudes (errors are given in brackets in units of mmag).

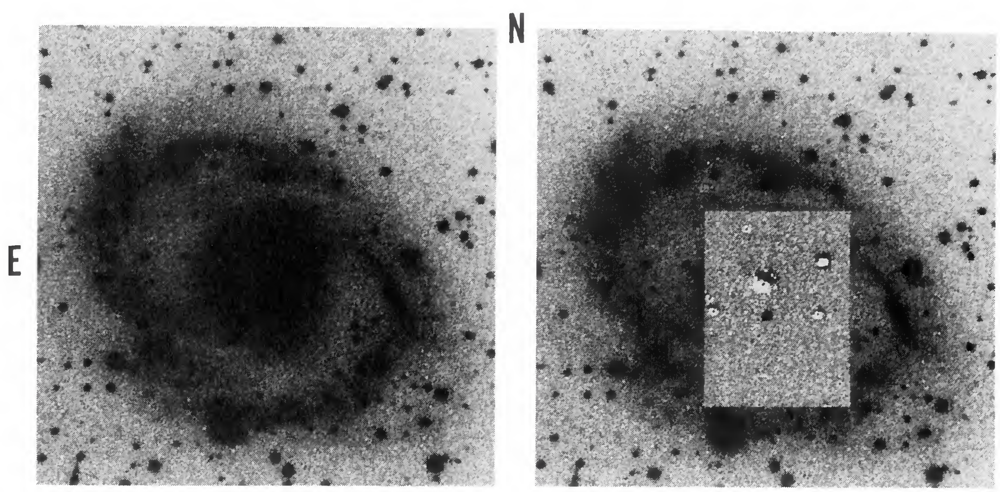

FIG. 2. (left) V image of the SN 1992K field taken one month after discovery. The SN had a V magnitude of 18 and cannot be seen at all due to the low contrast with respect to the bright background of the host galaxy. (right) Same image shown on the left after subtracting the core of the galaxy using the transformed galaxy image; the SN is now clearly visible.

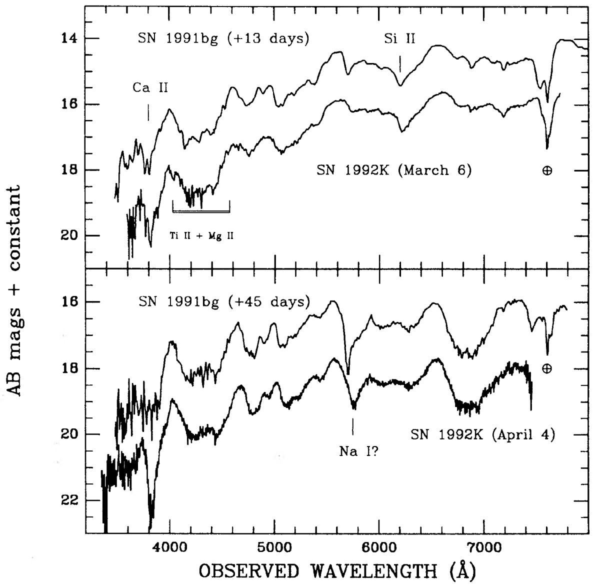

FIG. 3. Comparison of the spectra of SN 1992K with similar epoch spectra of the subluminous SN 1991bg. The spectra are plotted on a AB magnitude scale ($AB=-2.5\ \log[f_\nu]$ + constant). Note that the strong blended absorption feature at ~7600 Å observed in both SNe is due to a combination of telluric (the atmospheric A band) and intrinsic (probably O I λ7774) absorption.

3. RESULTS AND DISCUSSION

Figure 3 shows the two spectra obtained for SN 1992K. The lack of any signature of hydrogen and the fairly strong absorption feature at 6210 Å in the first (March 6) spectrum of SN 1992K (attributed to the Si II λ6355 line with an expansion velocity of ~9085 km s^{-1}) clearly defines this object as a Type Ia SN. However, this spectrum showed a number of unusual characteristics. SN 1992K displayed a remarkably red continuum (characterized by a $B-V$ color of 1.6). Although reddening by dust is potentially important in spiral galaxies, this alternative seems unlikely in the case of SN 1992K because of the absence of strong interstellar absorption lines in the spectrum.[3] Another unusual feature was the broad absorption spanning from 4000 to 4600 Å which contrasts with the blend of Si, Mg, and Fe lines observed at early epochs in typical SNe Ia (e.g., see Kirshner *et al.* 1993). These unusual characteristics of SN 1992K are reminiscent of the features displayed by the *sui generis* Type Ia SN 1991bg in the elliptical galaxy NGC 4374. The top panel of Fig. 3 shows a comparison of the first spectrum of SN 1992K with a spectrum of SN 1991bg taken 13 days after the maximum light in V, revealing a striking similarity between both objects. In particular, the absorption feature between 4000–4600 Å in SN 1991bg—presumably due to Ti II and Mg II (Filippenko *et al.* 1992)—provides an impressive match to the spectrum of SN 1992K. Note also the close similitude in the color of both spectra. To continue with this comparison, in the bottom panel of Fig. 3 we show the second spectrum of SN 1992K along with a spectrum of SN 1991bg taken 45 days after V maximum. Although the spectra had evolved considerably by that epoch, the close resemblance between both objects remains. Note that the λ6355 Si II absorption in both spectra has been replaced by a strong absorption feature near 5750 Å [possibly associated with Na I; see Filippenko *et al.* (1992), Leibundgut *et al.* (1993)]. At this epoch the color of both objects had grown significantly bluer ($B-V=1.0$).

Table 3 summarizes the final photometry obtained for SN 1992K (errors are given in brackets in units of mmag), and Fig. 4 shows the light curves. Overall, the B and V light curves are very well defined, showing a fast-decline phase

[3]The higher resolution of our two spectra (April 4) shows evidence for weak (0.8±0.4 Å equivalent width) interstellar Na I D absorption at zero redshift, consistent with the expected amount of Galactic extinction of E $(B-V)$ =0.12 (Burstein & Heiles 1982); Na I D absorption at the redshift of the host galaxy, ESO 269–G57, is *not* detected in this spectrum to a limiting equivalent width of 0.5 Å.

TABLE 3. Photometry for SN 1992K.

JD − 2448681.5 (Feb. 29)	B	V	I
6.252	18.017(010)	16.410(003)	...
10.191	18.284(005)	16.806(002)	15.780(005)
13.338	18.501(023)	17.045(007)	...
19.152	18.704(033)	17.351(012)	16.505(014)
29.312	18.939(022)	17.842(015)	...
36.265	19.170(026)	18.089(010)	...
38.245	19.114(020)	18.156(010)	17.496(015)
43.056	19.273(041)	18.307(015)	...
47.190	19.317(141)	18.401(054)	17.708(090)
50.051	19.349(016)	18.590(038)	...
51.327	19.476(041)	18.571(030)	...
72.246	...	19.268(035)	...
86.020	20.433(258)	19.820(219)	19.446(208)
125.093	20.988(083)	20.936(066)	...
154.072	...	21.544(035)	...

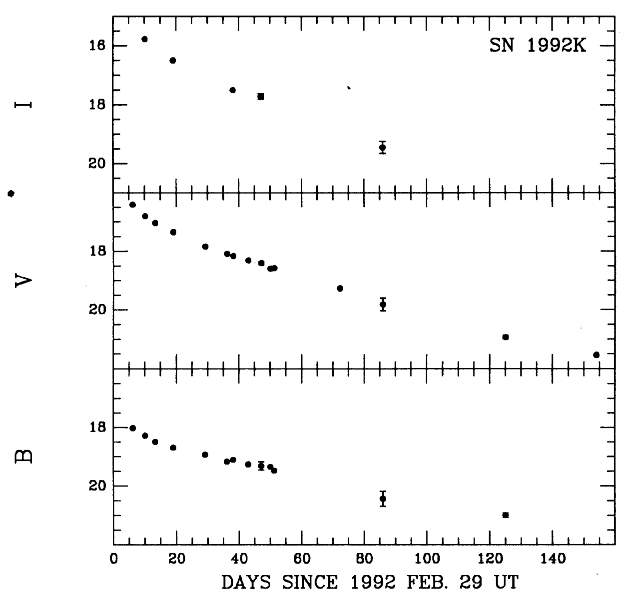

FIG. 4. B, V, and I light curves of SN 1992K.

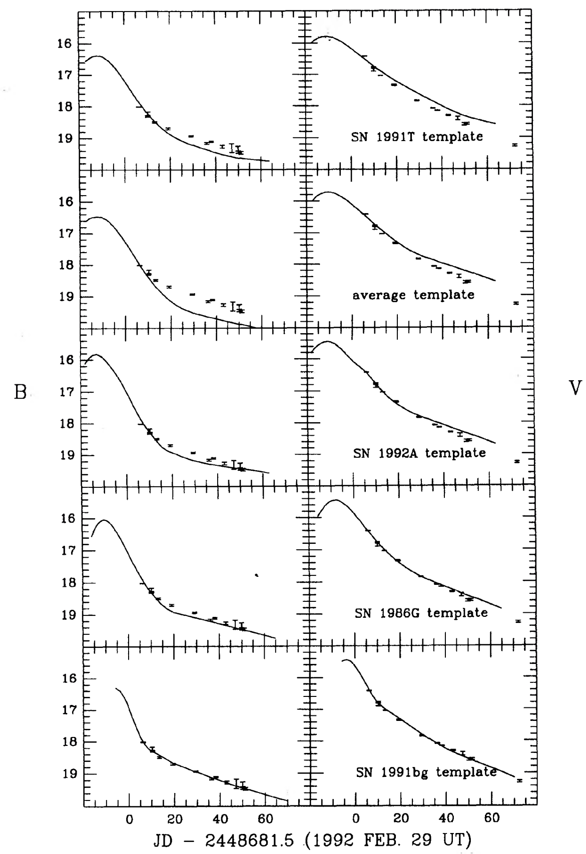

FIG. 5. The B and V light curves of SN 1992K are compared to five template light curves selected by their different post-maximum decline rates. All of the templates were properly modified by the K-terms calculated by Hamuy *et al.* (1993b) and time dilatation.

until approximately March 13 followed by a slower (linear) decay in magnitude. Evidently, SN 1992K was caught after maximum light. Figure 5 compares these light curves with five different templates, selected with the aim of representing the wide range of light curve morphologies displayed by SNe Ia. Specifically, the templates include (in order of increasingly faster initial decline rate) 1991T, Leibundgut's (1988) average curves for SNe Ia, 1992A, 1986G, and 1991bg. Although SN 1992K was at a relatively small redshift, all these

TABLE 4. Maximum magnitudes for SN 1992K.

TEMPLATE	T^V_{MAX}	B_{MAX}	V_{MAX}	χ^2_{RED}
SN 1991T	1992 Feb. 17.2 ±0.2	16.38 ±0.02	15.79 ±0.01	161.9
Leibundgut	1992 Feb. 18.5 ±0.3	16.27 ±0.03	15.72 ±0.02	148.6
SN 1992A	1992 Feb. 18.1 ±0.1	15.82 ±0.01	15.44 ±0.01	40.2
SN 1986G	1992 Feb. 20.7 ±0.2	16.05 ±0.02	15.45 ±0.01	20.0
SN 1991bg	1992 Feb. 25.1 ±0.1	16.31 ±0.01	15.45 ±0.01	4.3

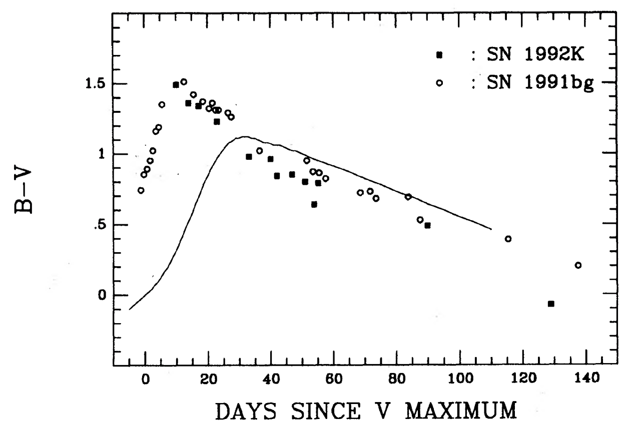

FIG. 6. The $B-V$ color evolution of SNe 1992K and 1991bg along with the average color template curve calculated by Leibundgut (1988). The data for SN 1992K have been corrected for an assumed Galactic reddening of $E(B-V)=0.12$.

templates were modified according to the K terms calculated by Hamuy *et al.* (1993b) for SNe Ia, and stretched to account for time dilatation. The templates were then fitted to the observed points using a χ^2 minimizing procedure, solving simultaneously for the time of V maximum, and the peak magnitudes B_{MAX} and V_{MAX}. In Table 4 we summarize the parameters for the five fits along with 2σ variance uncertainties and the value of the reduced χ^2. Clearly, the best representation of the SN 1992K light curves is obtained with the templates of the fast-decliner SN 1991bg, which can be also visually judged in Fig. 5. With this technique we can estimate the peak magnitudes of the SN from the best fit obtained, and their uncertainties by comparing such values with the peak magnitudes derived from the SN 1986G templates (the next best fit). This technique yields $B_{MAX}=16.31\pm0.20$ and $V_{MAX}=15.45\pm0.20$. According to the best fit, the time of V maximum occurred on Feb. 25.1, implying that our two spectra of SN 1992K were obtained ~10 and ~39 days after V maximum. Note that this result is in very good agreement with the dating yielded by the spectroscopic comparison with SN 1991bg (cf. Fig. 3).[4]

The $B-V$ color evolution of SN 1991bg was peculiar in a number of respects (Leibundgut *et al.* 1993). At maximum light SN 1991bg had an unusually red $B-V$ color of 0.7. As the SN evolved, its color grew still redder, reaching a maximum on day 12 at $(B-V)=1.5$, as opposed to most SNe Ia which reach this maximum on day 30 at $(B-V)=1$. From day 12 onward SN 1991bg grew bluer again at a fast rate. Figure 6 shows a comparison of the $B-V$ color evolution of SNe 1991bg and 1992K along with the $B-V$ template average curve calculated by Leibundgut (1988). Note that the data for SN 1992K have been corrected for an assumed Galactic reddening of $E(B-V)=0.12$ (see next paragraph). Al-

[4]The low Si II λ6355 expansion velocity of 9085 km s^{-1} determined for SN 1992K from the April 4 spectrum, which is similar to the value observed for SN 1991bg at a comparable epoch, stands as a counterexample to the trend noted by Filippenko (1989) and Branch & van den Bergh (1993) that SNe Ia in early-type galaxies (E, S0, Sa) have lower expansion velocities than SNe Ia in late-type spirals and irregular galaxies.

though SN 1992K was not discovered soon enough to observe the early evolution in the color curve, the available data closely mimic the unusual behavior displayed by SN 1991bg between days 10–30. This resemblance in the $B-V$ color evolution remained over a period of ~100 days.

As mentioned earlier, one of the most remarkable features of SN 1991bg was the low luminosity observed at maximum light. Based on a distance modulus of 31.08±0.08 derived from surface brightness fluctuations (SBF) measurements of its host galaxy (Tonry *et al.* 1990; Tonry 1991), Phillips (1993) finds $M_B=-16.38\pm0.15$ and $M_V=-17.13\pm0.10$ for SN 1991bg. In order to compare the luminosity of SN 1991bg with SN 1992K it becomes necessary to adopt a value for the Hubble constant. To be consistent with the zero point of the SBF method hereafter we adopt H_0=85 km s^{-1} Mpc^{-1} (Jacoby *et al.* 1992). The redshift of the parent galaxy then yields a distance modulus for SN 1992K of 32.67 mag with an uncertainty of ±0.45 mag if we assume a typical peculiar velocity of 600 km s^{-1} in the observed redshift with respect to the general Hubble flow. Combining this distance modulus with the observed magnitudes, we get $M_B=-16.36\pm0.49$ and $M_V=-17.22\pm0.49$ for SN 1992K. An additional correction must be applied to these magnitudes due to foreground extinction in the direction of the parent galaxy of SN 1992K, which we take to be $E(B-V)=0.12\pm0.03$ (Burstein & Heiles 1982), yielding $(M_B)_0=-16.84\pm0.50$ and $(M_V)_0=-17.58\pm0.50$. These estimates reveal that SN 1992K was significantly fainter than most of the SNe Ia in the sample of well observed events recently studied by Phillips (1993), and only comparable in brightness to SN 1991bg. In terms of the bolometric luminosity, events like SNe 1991bg and 1992K are probably more than a factor of 5 times dimmer at maximum than the most luminous SNe Ia (Suntzeff 1994).

At first glance, the frequency of subluminous SNe Ia would appear to be quite low; e.g., SN 1992K was the only 1991bg-like event to be discovered out of the total of 30 SNe Ia found during the course of the Calán/Tololo SN survey. However, as pointed out by Branch *et al.* (1993) and van den Bergh (1993), traditional magnitude-limited searches like the Calán/Tololo survey are relatively insensitive to 1991bg-like events. This is illustrated in Fig. 7, which summarizes results from a Monte Carlo simulation of a twice-monthly supernova search with parameters representative of the Calán/Tololo survey. The line labeled "parent pop." shows the redshift distribution of the 10,000 SN events included in the simulation which were assumed to occur at random times and positions within a volume bound by $z\leqslant0.1$. A Hubble constant of 85 km s^{-1} Mpc^{-1} was adopted along with a limiting discovery magnitude of $B=19$. The SNe were assumed to occur in "idealized" host galaxies consisting of smooth exponential disks with a scale length of 4 kpc, with the radial distribution of the SN events following that of the host galaxy light. The galaxies were also assigned random orientations with respect to the observer. Successful "discovery" of a SN event was defined to require not only an apparent magnitude brighter than the limiting magnitude, but also a minimum projected separation between the SN and parent galaxy nucleus of 2 arcsec (cf. Shaw 1979). Three different cases

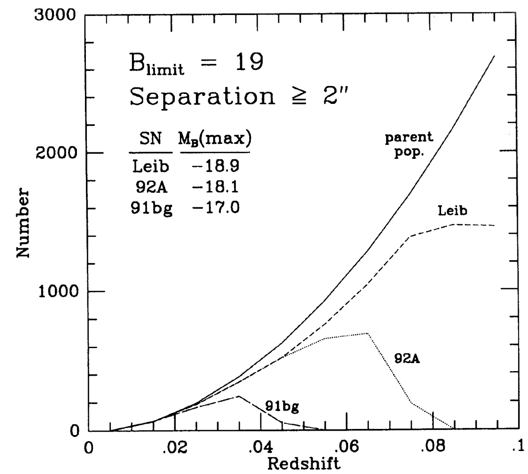

FIG. 7. Results of Monte Carlo simulation of a SN search program with parameters similar to those of the Calán/Tololo survey. The solid curve shows the redshift distribution of SN events generated for the simulation, while the three lower curves correspond to the actual "discoveries" assuming three different light curve shapes and peak luminosities. See text for further details.

were then considered: In the first, all of the SNe were assumed to have B light curves identical to the Leibundgut (1988) template with a peak absolute magnitude of $M_B^{\max}=-18.9$. In the second, each event was taken to have a B light curve like SN 1992A (Suntzeff 1994) with a peak magnitude of $M_B^{\max}=-18.1$, while in the third case, all of the SNe were assumed to resemble 1991bg with an absolute magnitude of $M_B^{\max}=-17.0$ at maximum.

The three curves in Fig. 7 marked "Leib," "92A," and "91bg" shows the redshift distributions of the number of SNe "discovered" in the simulation for each of the above three cases. Not surprisingly, the success rate is seen to depend strongly on peak luminosity. The luminous "Leib" SNe are predicted to be visible over the entire redshift range, whereas events like SN 1991bg become undetectable at redshifts beyond 0.045 due to their intrinsic faintness. These results suggest that, were these three subtypes of SNe Ia equally common, only ~1–2 91bg-like events should have been discovered during the course of the Calán/Tololo survey. Of course, the detection probability of a SN depends on other factors such as the proximity to local brightness contributions (e.g., spiral arms and H II regions) which are neglected in this particular simulation. Moreover, SNe Ia occur in galaxies with a variety of morphologies. Bearing in mind these oversimplifications, it is nevertheless reasonable to conclude that the results of the Calán/Tololo survey are consistent with the possibility that 91bg-like events comprise as many as 1/4 to 1/2 of all SNe Ia in a volume-limited sample. Hence, these SNe may play an, until now, unappreciated role in the chemical enrichment and evolution of galaxies.

4. CONCLUSIONS

(1) We have obtained spectroscopic and photometric data for SN 1992K found in the course of the Calán/Tololo SN

survey, which reveal that this object was a twin to the subluminous Type Ia SN 1991bg.

(2) The discovery of SN 1992K confirms that SNe Ia can display a large (⩾ a factor of 5) range in peak luminosities.

(3) Although the observed frequency of occurrence of subluminous SNe Ia appears to be low, traditional magnitude-limited SN searches like the Calán/Tololo survey are likely to be insensitive to the discovery of such events. A simple attempt to model the selection effects of the Calán/Tololo survey suggests that 1991bg-like events could be as common as other more typical SNe Ia.

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REFERENCES

Branch, D. 1992, ApJ, 392, 35
Branch, D., Fisher, A., & Nugent, P. 1993, AJ, 106, 2383
Branch, D., & van den Bergh, S. 1993, AJ, 105, 2231
Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Buta, R. J., Paturel, G., & Fouqué, P. 1991, Third Reference Catalogue of Bright Galaxies (Springer, Berlin)
Filippenko, A. V. 1989, PASP, 101, 588
Filippenko, A. V., *et al.* 1992, AJ, 104, 1543
Hamuy, M., & Maza, J. 1992, IAU Circ., No. 5468
Hamuy, M., Walker, A. R., Suntzeff, N. B., Gigoux, P., Heathcote, S. R., & Phillips, M. M. 1992, PASP, 104, 533
Hamuy, M., *et al.* 1993a, AJ, 106, 2392 (Paper I)
Hamuy, M., Phillips, M. M., Wells, L. A., & Maza, J. 1993b, PASP, 105, 787
Jacoby, G. H., *et al.* 1992, PASP, 104, 599
Kirshner, R. P., *et al.* 1993, ApJ, 415, 589
Leibundgut, B. 1988, PhD. thesis, University of Basel
Leibundgut, B., & Pinto, P. A. 1992, ApJ, 401, 49
Leibundgut, B., *et al.* 1993, AJ, 105, 301
Phillips, M. M., *et al.* 1987, PASP, 99, 592
Phillips, M. M. 1993, ApJ, 413, L105
Shaw, R. L. 1979, A&A, 76, 188
Suntzeff, N. B. 1994, in Supernovae and Supernovae Remnants, IAU Colloquium No. 145, edited by R. McCray (Cambridge University Press, Cambridge) (in press)
Tonry, J. L., Ajhar, E. A., & Luppino, G. A. 1990, AJ, 100, 1416
Tonry, J. L. 1991, ApJ, 373, L1
van den Bergh, S. 1993, RMexA&A, 26, 73
Woosley, S. E., & Weaver, T. A. 1994, ApJ, 423, 371

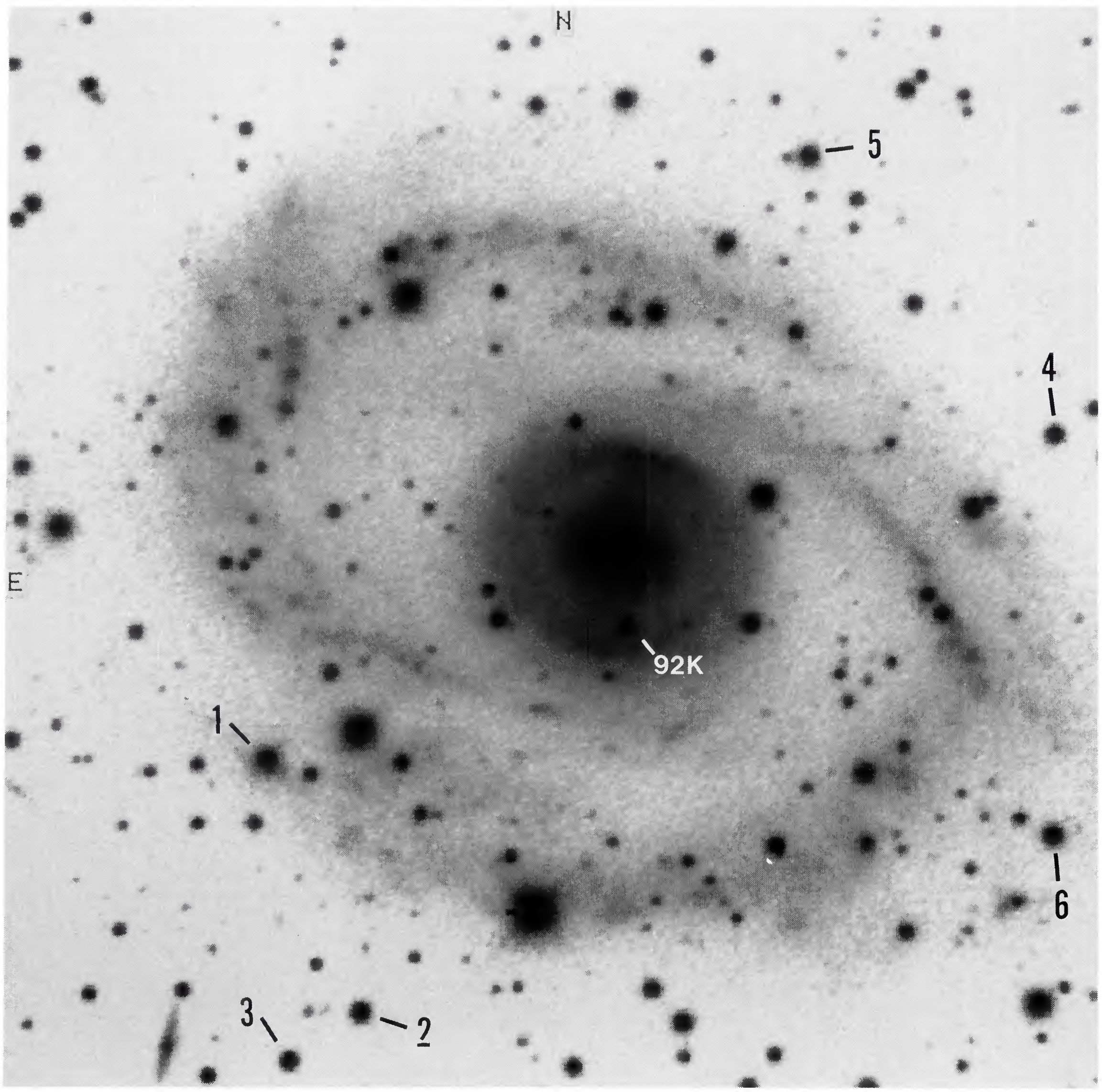

FIG. 1. *V* band image taken with a CCD on the 4 m telescope on 1992 March 6 showing SN 1992K along with the stars of the photometric sequence.

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