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X-RAY OBSERVATIONS OF TYPE Ia SUPERNOVAE WITH *SWIFT*: EVIDENCE OF CIRCUMSTELLAR INTERACTION FOR SN 2005ke

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ABSTRACT

We present a study of the early (days to weeks) X-ray and UV properties of eight Type Ia supernovae (SNe Ia) that have been extensively observed with the X-Ray Telescope (XRT) and UV/Optical Telescope (UVOT) on board *Swift*, ranging from 5 to 132 days after the outburst. SN 2005ke is tentatively detected (at a 3–3.6 σ level of significance) in X-rays based on deep monitoring with the XRT ranging from 8 to 120 days after the outburst. The inferred X-ray luminosity [$L_{0.3-2} = (2 \pm 1) \times 10^{38}$ ergs s^{-1}; 0.3–2 keV band] is likely caused by interaction of the SN shock with circumstellar material (CSM) deposited by a stellar wind from the progenitor's companion star with a mass-loss rate of $\dot{M} \approx 3 \times 10^{-6}\ M_{\odot}$ yr^{-1} (v_w/10 km s^{-1}). Evidence of CSM interaction in X-rays is independently confirmed by an excess of UV emission, as observed with the UVOT on board *Swift*, starting around 35 days after the explosion. The nondetection of SN 2005ke with *Chandra* 105 days after the outburst implies a rate of decline steeper than $L_{\rm X} \propto t^{-0.75}$, consistent with the decline expected from the interaction of the SN shock with a spherically symmetric CSM (t^{-1}). None of the other seven SNe Ia is detected in X-rays or shows a UV excess, which allows us to put tight constraints on the mass-loss rates of the progenitor systems.

Subject headings: circumstellar matter — supernovae: individual (SN 2005ke) — ultraviolet: ISM — X-rays: individual (SN 2005ke) — X-rays: ISM

Online material: color figures

1. INTRODUCTION

Type Ia supernovae (SNe Ia) are a subclass of exploding stars defined observationally by the absence of hydrogen lines in their optical spectra and the presence of lines from elements such as silicon and sulfur (Leibundgut 2000). There is consensus that SNe Ia are explosions of white dwarfs that occur when accretion from a companion star drives the white dwarf mass close to the Chandrasekhar limit (Woosley & Weaver 1986; Nomoto et al. 2003). However, the details of the system are not fully understood, especially with regard to the type of companion (a main-sequence star, a red giant). A useful indicator of the properties of the companion is through its mass loss, which depends strongly on the stellar type. The X-rays and the radio regimes are especially well suited to study the interaction of the SN ejecta with the surrounding CSM, which should be dominated by the companion's wind. However, no SN Ia has ever been detected in either regime.

In this Letter, we present X-ray and UV data for a sample of eight SNe Ia observed with *Swift* between 5 and 132 days after outburst. The dates of outburst were estimated to be 18 ± 2 days before the peak in the *B* band. The highlight of this study is the tentative detection of SN 2005ke in X-rays with *Swift*, which was discovered on 2005 November 13.33 UT with the Katzman Automatic Imaging Telescope (KAIT; Puckett et al. 2005) and later classified as an underluminous SN Ia from the presence of the characteristic 420 nm Ti ii and 635 nm Si ii lines (Patat & Baade 2005).

2. OBSERVATIONS AND DATA REDUCTION

A sample of eight SNe Ia was observed with the XRT (Burrows et al. 2005) and UVOT (Roming et al. 2005) instruments on board the *Swift* Observatory (Gehrels et al. 2004), ranging from days to weeks after the outburst. Multiple exposures were obtained in the *V*, *B*, *U*, UVW1 (181–321 nm), UVM2 (166–268 nm), and UVW2 (112–264 nm) UVOT filters and with the XRT (0.2–10 keV band) in photon-counting (PC) mode.

The *Swift* data were analyzed using the HEASOFT[14] (ver. 6.04) and *Swift* Software (ver. 2.3, build 17) tools and latest calibration products. X-ray counts were extracted from a circular region with an aperture of 10″ radius centered at the optical positions of the SNe. The background was extracted locally from two neighboring circular regions of 10″ radius located at the same distances from the nuclei of the host galaxies to account for residual diffuse emission from the galaxies.

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[14] See http://heasarc.gsfc.nasa.gov/docs/software/lheasoft.

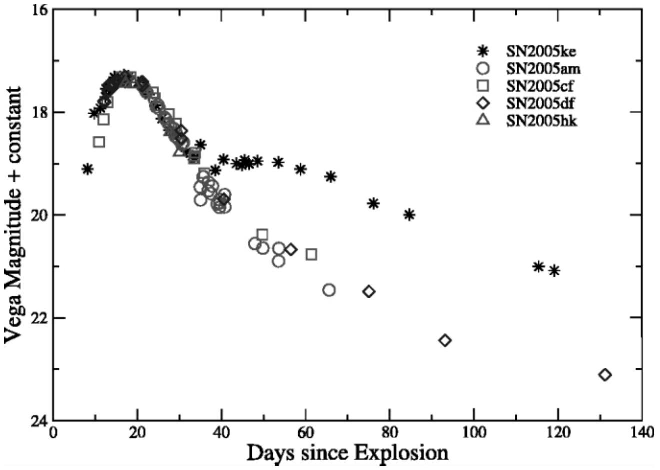

FIG. 1.—Comparison of the UVW1 magnitudes of SNe Ia observed with *Swift*. The light curves of SNe 2005am, 2005cf, 2005df, and 2005hk are shifted vertically to align them with the SN 2005ke template near maximum. The time is given in days after the outburst. The excess in the UV emission of SN 2005ke starting around day 35 after the outburst is likely caused by CSM interaction. [*See the electronic edition of the Journal for a color version of this figure.*]

(DDT) observation of SN 2005ke was obtained on 2006 February 19 (sequence 500693), corresponding to day 105 after the outburst. The data were analyzed with CIAO[15] (ver. 3.3.0.1) and the latest calibration products.

3. PROPERTIES OF THE SAMPLE

This *Swift* data set on SNe Ia is unique as it represents the best sample of any SNe Ia observed in the UV. While the UV light curves are strikingly similar (see Fig. 1), SN 2005ke shows a significant UV excess starting around day 35 after the outburst. A detailed analysis of the UV light curves will be presented in P. Milne et al. (2006, in preparation).

The upper limits to the X-ray luminosities of SNe 2005am, 2005cf, 2005df, 2005hk, 2006E, and 2006X are a few times 10^{39} ergs s^{-1}, implying mass-loss rates lower than a few times 10^{-5} $M_\odot$ yr^{-1} for thermal emission (see Table 1). The mass-loss rate of SN 2005gj is not well constrained owing to the relatively short XRT exposure time (5 ks) and the large distance to the SN (265 Mpc). While the above upper limits are consistent with the X-ray luminosity of SN 2005ke, the SN is peculiar as it is the only SN Ia of our sample showing excess UV emission after peak.

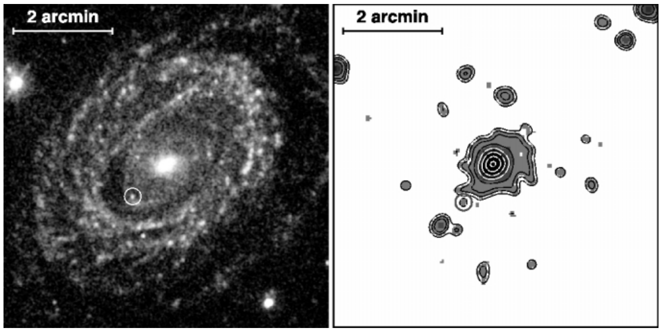

FIG. 2.—*Swift* UV and X-ray image of SN 2005ke and its host galaxy NGC 1371. *Left*: The UV image was constructed from the UVOT UVW1 (750 s exposure time), UVW2 (1966 s) and UVM2 (1123 s) filters obtained on 2005 November 14.67 UT and slightly smoothed with a gaussian filter of 1.5 pixel (FWHM). The position of SN 2005ke is indicated by a white circle of 10″ radius. *Right*: The (0.2–10 keV) X-ray image was constructed from the merged 268 ks XRT data and is slightly smoothed with a gaussian filter of 1.5 pixels (FWHM). The position of SN 2005ke is indicated by a red circle of 10″ radius. Contour levels are 0.3, 0.6, 0.9, 1.5, 3, 6, 12, and 20 counts pixel^{-1}. Same scale as the UV image. [*See the electronic edition of the Journal for a color version of this figure.*]

4. SUPERNOVA 2005ke

Forty-three individual exposures of SN 2005ke were obtained between 8 and 120 days after the explosion (2005 November 06 ± 2 days). X-ray and UV images of SN 2005ke and its host galaxy NGC 1371 are shown in Figure 2.

An excess of X-ray counts is detected from the position of SN 2005ke (3–3.6 σ level of significance depending on the location of the background extraction regions) in the merged XRT data ranging from day 1 to 54 after the outburst, with a point-spread function, sampling deadtime, and vignetting-corrected net count rate of $(2.2 \pm 0.6) \times 10^{-4}$ counts s^{-1}. Adopting a thermal plasma spectrum with a temperature of $kT = 10$ keV (see Fransson et al. 1996 and references therein) and assuming a Galactic foreground column density with no intrinsic absorption ($N_H = 6.16 \times 10^{20}$ cm^{-2}; Dickey & Lockman 1990), we obtain a 0.3–2 keV X-ray band flux and lu-

TABLE 1

SWIFT X-RAY TELESCOPE OBSERVATIONS OF TYPE Ia SUPERNOVAE

SN (1)	Galaxy (2)	Start (MJD) (3)	Stop (MJD) (4)	Distance (5)	N_H (6)	Exposure (7)	Rate (8)	f_X (9)	L_X (10)	$\dot{M}$ (11)
2005am	NGC 2811	53433.94	53507.14	33.6	4.5	62.6	<6.2	<3.6	<4.9	<1.7
2005cf	MCG −01-39-3	53525.04	53574.67	27.4	7.0	53.8	<3.5	<2.2	<1.9	<1.0
2005df	NGC 1559	53592.11	53711.25	18.4	2.7	25.8	<9.8	<5.4	<2.2	<1.4
2005ke	NGC 1371	53688.68	53799.72	20.7	1.4	267.8	2.2 ± 0.6	0.4 ± 0.1	0.2 ± 0.1	0.3 ± 0.1
2005gj	Anonymous	53698.13	53698.33	264.5	7.1	5.0	<35.0	<21.3	<1790	<37
2005hk	UGC 272	53677.75	53744.66	55.6	2.8	45.1	<4.1	<2.2	<8.3	<1.7
2006E	NGC 5338	53748.83	53763.23	11.5	2.1	10.1	<13.8	<7.4	<1.2	<0.8
2006X	NGC 4321	53774.34	53806.77	17.1	2.4	25.3	<7.8	<4.3	<1.5	<0.7

NOTES.—(1) Name of the SN; (2) host galaxy; (3) start of the observation in modified Julian days; (4) end of the observation in modified Julian days;
(5) distance in units of megaparsecs, using the NED redshifts of the host galaxies and assuming $H_0 = 71$ km s^{-1} Mpc^{-1}, $\Omega_\Lambda = \frac{2}{3}$, and $\Omega_M = \frac{1}{3}$; (6) Galactic foreground column density in units of 10^{20} cm^{-2} (Dickey & Lockman 1990); (7) *Swift* XRT exposure time in units of kiloseconds; (8) 3 σ upper limit to the 0.2–10 keV count rate in units of 10^{-4} counts s^{-1}; (9) 3 σ upper limit to the 0.2–10 keV X-ray band flux in units of 10^{-14} ergs cm^{-2} s^{-1}; (10) 3 σ upper limit to the 0.2–10 keV X-ray band luminosity in units of 10^{39} ergs s^{-1}; (11) mass-loss rate of the progenitor systems in units of 10^{-5} $M_\odot$ yr^{-1}.

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[15] See http://cxc.harvard.edu/ciao.

minosity of $f_{0.3-2} = (4 \pm 1) \times 10^{-15}$ ergs cm^{-2} s^{-1} and $L_{0.3-2} = (2 \pm 1) \times 10^{38}$ ergs s^{-1}, respectively, for a distance of 20.7 Mpc ($z = 0.00488$, $H_0 = 71$ km s^{-1} Mpc $^{-1}$, $\Omega_\Lambda = \frac{2}{3}$, $\Omega_M = \frac{1}{3}$; Koribalski et al. 2004). The chance probability of a background active galactic nucleus at the measured flux being within a radius of 10″ of the position of SN 2005ke is estimated to be $\lesssim 10^{-3}$ (Hasinger et al. 2001).

No X-ray source is visible at the position of SN 2005ke in the *Chandra* observation. The inferred 3 σ upper limit to the X-ray count rate of $<3.5 \times 10^{-4}$ counts s^{-1} corresponds to a flux and luminosity of $f_{0.3-2} < 2.3 \times 10^{-15}$ ergs cm^{-2} s^{-1} and $L_{0.3-2} < 1.2 \times 10^{38}$ ergs s^{-1}, respectively, using the same spectral template above.

The *Swift* XRT X-ray luminosity inferred for SN 2005ke is lower than the lowest published upper limit of the early X-ray emission of SNe Ia (e.g., 5×10^{38} ergs s^{-1} for SN 1992A on day 16; Schlegel & Petre 1993). This improvement in the sensitivity of our measurement allows us to place significant constraints on SN Ia models. The SN, however, is not detected at late times (day 105) with *Chandra*. If the X-ray source detected with *Swift* is indeed the SN, a rate of decline of $L_X \propto t^n$ with index $n < -0.75$ (3 σ) is inferred. This is consistent with the X-ray rate of decline expected from the interaction of the SN shock with a spherically symmetric CSM (t^{-1} for thermal emission), as well as observations of X-ray–emitting core-collapse SNe (see Immler & Lewin 2003 and references therein). No other X-ray source or enhancements of the diffuse emission within the host galaxy is visible in the high-resolution ($\lesssim 1''$ FWHM) *Chandra* images within the XRT counts extraction aperture (10″ radius), which excludes the possibility that an X-ray binary or clumps in the diffuse emission in NGC 1371 might have caused the excess emission observed with the *Swift* XRT. Each of the other >3 σ enhancements in the XRT image, however, have matching *Chandra* X-rays sources.

In the following we therefore assume that the *Swift* detection of SN 2005ke in X-rays is real, but even if it is only an upper limit, our analyses hold true. Our detection implies either X-ray emission from Compton-scattered γ-rays of the radioactive decay products of the SN ejecta or an interaction of the SN shock with a sufficiently dense CSM. For comparison of the observed X-ray luminosity (or upper limit) with the expected X-ray luminosity from SN Ia models, we calculated the emergent hard X-ray spectrum of model W7 (Nomoto et al. 1994) using a Monte Carlo γ-ray transport code to simulate the propagation of photons produced by the radioactive-decay of ^{56}Ni and ^{56}Co and experiencing Compton scattering, photoelectric absorption, and pair production processes (Burrows & The 1990). Bremsstrahlung emission is expected to dominate the radiation in the 0.3–2.0 keV band (Clayton & The 1991). We calculate the bremsstrahlung emergent spectrum of model W7 (as in Clayton & The 1991) but with much improved statistics. The bremsstrahlung component extends to ≈ 0.2 keV at $t = 12$ days and lower at later times. The total luminosities in the energy range of 0.3–2.0 keV are 9.2×10^{33}, 1.0×10^{34}, and 1.6×10^{34} ergs s^{-1} at $t = 26$, 38, and 46 days, respectively. Clearly, the bremsstrahlung emission from SN Ia models is far below the observed luminosity from SN 2005ke.

A more likely source of the X-ray emission is circumstellar interaction, probably with mass lost by the companion. The reported velocity of the Si II 6, 355 Å absorption-line minimum (13,300 km s^{-1}; Patat & Baade 2005) provides a lower limit to the shock velocity of the interaction. Models of hydrodynamic interaction for a typical SN Ia density structure show that the forward shock velocity may be $v_s \gtrsim 40{,}000$ km s^{-1} (R. A. Chevalier & C. Fransson 2006, in preparation). Assuming a constant mass-loss rate $\dot{M}$ and wind velocity v_w from the progenitor's companion, the thermal X-ray luminosity of the forward shock region is $L_X = 1/(\pi m^2)\Lambda(T)(\dot{M}/v_w)^2(v_s t)^{-1}$ (Immler et al. 2002),[16] where m is the mean mass per particle (2.1×10^{-24} g for a H+He plasma) and $\Lambda(T)$ the cooling function of the heated plasma at temperature T. Because of the higher density at the reverse shock, it is likely for the reverse shock component to dominate the luminosity by a factor of 10–100 (Chevalier 1982). Adopting $L_{\text{reverse}} = 30 L_{\text{forward}}$, an effective cooling function of $\Lambda_{0.3-2} = 3 \times 10^{-23}$ ergs cm^3 s^{-1} for an optically thin thermal plasma with temperature of $T = 10^9$ K for the forward shock (Fransson et al. 1996; Raymond et al. 1976), and $v_s = 40{,}000$ km s^{-1}, a mass-loss rate of

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[16] Note the missing factor of 4 as a correction to Immler et al. (2002).

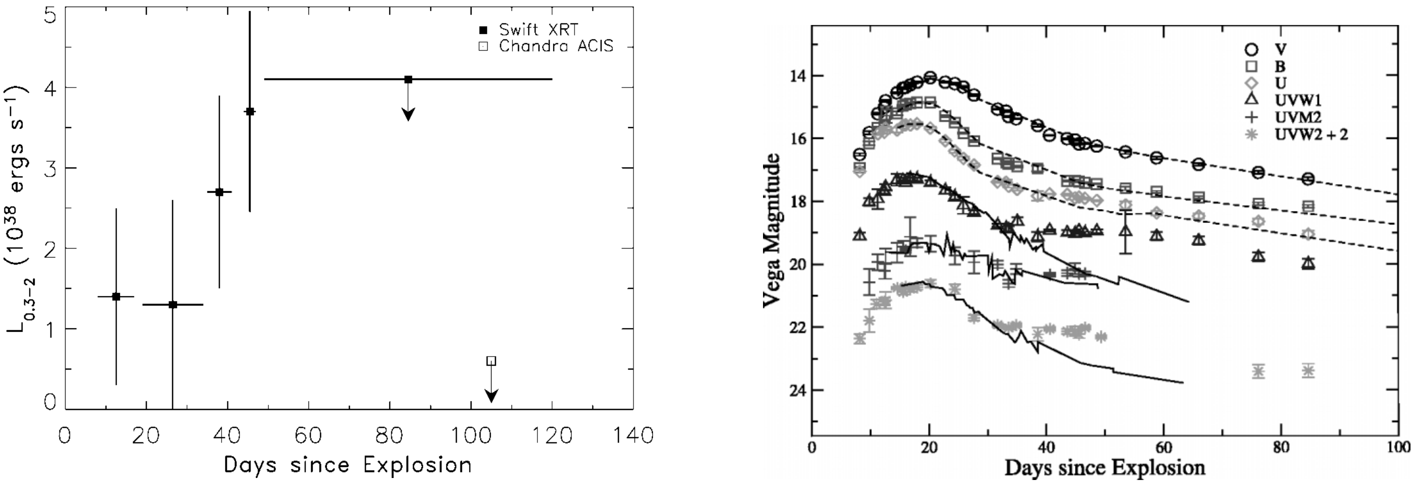

Fig. 3.—*Left*: Soft (0.3–2 keV) X-ray band light curve of SN 2005ke as observed with the *Swift* XRT. The time is given in days after the outburst (2005 November 06). The average X-ray luminosity over the observed period of 8–120 days after the explosion is $L_{0.3-2} = (2.0 \pm 0.5) \times 10^{38}$ ergs s^{-1}. Vertical error bars are statistical 1 σ errors; horizontal error bars indicate the periods covered by the observations (which are not contiguous). The upper limit is at a 3 σ level of confidence. *Right*: Optical/UV light curves of SN 2005ke in all six UVOT filters. For comparison, the *V*, *B*, and *U* light curves of the SN Ia 1999by (Garnavich et al. 2004) and the UV (UVW1, UVM2, UVW2) light curves of SN 2005am (Brown et al. 2005) are drawn as lines shifted vertically to match the SN 2005ke light curves near maximum. [*See the electronic edition of the Journal for a color version of this figure.*]

$\dot{M} \approx 3 \times 10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}\ (v_w/10\ \mathrm{km\ s}^{-1})$ with an uncertainty of a factor of 2–3 is inferred. Assuming different plasma temperatures in the range 10^6–10^9 K would lead to changes in the emission measure of $\lesssim$40%.

The mass-loss rate is one of the lowest reported for any SN progenitor system detected in either X-rays (Immler & Lewin 2003) or the radio (Weiler et al. 2002). However, Panagia et al. (2006) have recently presented upper limits on the radio emission from a number of SNe Ia that are interpreted as setting upper limits on $\dot{M}$ as low as $\sim 3 \times 10^{-8}\ M_{\odot}\ \mathrm{yr}^{-1}\ (v_w/10\ \mathrm{km\ s}^{-1})$. In addition, Soderberg (2006) reports the nondetection of SN 2005ke at 8.46 GHz, although flux limits are not given.

X-ray emission from SNe is usually interpreted as thermal radiation. At low circumstellar densities, nonthermal mechanisms may dominate and $\dot{M}$ could be as low as $10^{-7}\ M_{\odot}\ \mathrm{yr}^{-1}$ for $v_w = 10\ \mathrm{km\ s}^{-1}$ in SN 2005ke (R. A. Chevalier & C. Fransson 2006, in preparation). However, the nondetection of radio emission could limit the applicability of these mechanisms.

We rebinned 268 ks of XRT data of SN 2005ke into five consecutive time bins with similar exposure times (47, 47, 62, 56, and 55 ks) to further study the temporal behavior of the X-ray emission (see Fig. 3, *left*). Although the X-ray light curve is consistent with a constant X-ray luminosity during the period monitored, we find marginal evidence that the X-ray luminosity might have increased during the early observations. The X-ray rise could be due to decreasing absorption by material along the line of sight to the hot gas as the expanding shell becomes optically thin, although we do not expect local absorption to be important for our deduced parameters.

Significant excess in the UV output of SN 2005ke starts around day 35 after the explosion, especially in the UVW1 and UVW2 filters (see Fig. 3, *right*). No such excess is observed in the optical band light curves. Possible effects of CSM interaction on UV emission are inverse Compton scattering of photospheric photons by hot electrons or a reduction of UV line blanketing due to heating and ionization by circumstellar radiation. The luminosity of the UV excess dropped by a factor of >4 between days 45 and 105, as estimated from comparisons with the other SN Ia light curves. If the X-ray luminosity experienced a similar drop during that time period, the *Chandra* upper limit may not be in conflict with the XRT detection.

Evidence for CSM interaction has only been reported for a few SNe Ia (e.g., SNe 1999ee, Mazzali et al. 2005; 2002ic, Hamuy et al. 2003, Chugai et al. 2004, Kotak et al. 2004, Deng et al. 2004, Nomoto et al. 2005; 2003du, Gerardy et al. 2004; 2005cg, Quimby et al. 2006; and 2005gj, Prieto et al. 2005) based on optical spectroscopy. Our detection of CSM interaction in X-rays is independently confirmed by the excess of UV emission after maximum. The most plausible explanation for the presence of dense CSM is that a more massive companion star ($\lesssim 10\ M_{\odot}$) blew off its outer layers via stellar winds or Roche lobe overflow over the last few 10,000 years before the accreted mass from the companion star pushed the progenitor close to the Chandrasekhar limit, resulting in an SN Ia explosion.

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REFERENCES

Brown, P. J., et al. 2005, ApJ, 635, 1192
Burrows, A., & The, L.-S. 1990, ApJ, 360, 626
Burrows, D. N., et al. 2005, Space Sci. Rev., 120, 165
Chevalier, R. A. 1982, ApJ, 259, 302
Chugai, N. N., Chevalier, R. A., & Lundqvist, P. 2004, MNRAS, 355, 627
Clayton, D. D., & The, L.-S. 1991, ApJ, 375, 221
Deng, J., et al. 2004, ApJ, 605, L37
Dickey, J. M., & Lockman, F. J. 1990, A&A Rev., 28, 215
Fransson, C., Lundqvist, P., & Chevalier, R. A. 1996, ApJ, 461, 993
Garnavich, P. M., et al. 2004, ApJ, 613, 1120
Gehrels, N., et al. 2004, ApJ, 611, 1005
Gerardy, G. L., et al. 2004, ApJ, 607, 391
Hamuy, M., et al. 2003, Nature, 424, 651
Hasinger, G., et al. 2001, A&A, 365, L45
Immler, S., & Lewin, W. 2003, in Supernovae and Gamma-Ray Bursters, ed. K. Weiler (Berlin: Springer), 91
Immler, S., Wilson, A. S., & Terashima, Y. 2002, ApJ, 573, L27
Koribalski, B. S., et al. 2004, AJ, 128, 16
Kotak, R., Meikle, W. P. S., Adamson, A., & Leggett, S. 2004, MNRAS, 354, L13
Leibundgut, B. 2000, A&A Rev., 10, 179
Mazzali, P. A., et al. 2005, MNRAS, 357, 200
Nomoto, K., Suzuki, T., Deng, J., Uenishi, T., & Hachisu, I. 2005, in ASP Conf. Ser. 342, 1604–2004: Supernovae as Cosmological Lighthouses, ed. M. Turatto et al. (San Francisco: ASP), 105
Nomoto, K., Thielemann, F.-K., & Yokoi, K. 1984, ApJ, 286, 644
Nomoto, K., Uenishi, T., Kobayashi, C., Umeda, H., Ohkubo, T., Hachisu, I., & Kato, M. 2003, in From Twilight to Highlight: The Physics of Supernovae, ed. W. Hillebrandt & B. Leibundgut (Berlin: Springer), 115
Panagia, N., Van Dyk, S. D., Weiler, K. W., Sramek, R. A., Stockdale, C. J., & Murata, K. P. 2006, ApJ, 646, 369
Patat, F., Baade, D., Wang, L., Taubenberger, S., & Wheeler, J. C. 2005, IAU Circ. 8631
Prieto, J., Garnavich, P., Depoy, D., Marshall, J., Eastman, J., & Frank, S. 2005, IAU Circ. 8633
Puckett, T., Pelloni, A., Baek, M., Prasad, R. R., & Li, W. 2005, IAU Circ. 8630
Quimby, R., et al. 2006, ApJ, 636, 400
Raymond, J. C., Cox, D. P., & Smith, B. W. 1976, ApJ, 204, 290
Roming, P. W. A., et al. 2005, Space Sci. Rev., 120, 95
Schlegel, E. M., & Petre, R. 1993, ApJ, 412, L29
Soderberg, A. M. 2006, Astron. Tel., 722, 1
Weiler, K. W., Panagia, N., Montes, M. J., & Sramek, R. A. 2002, ARA&A, 40, 387
Woosley, S. E., Weaver, Th. A. 1986, ARA&A, 24, 205