PRE-DISCOVERY AND FOLLOW-UP OBSERVATIONS OF THE NEARBY SN 2009nr: IMPLICATIONS FOR PROMPT TYPE Ia SUPERNOVAE

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ABSTRACT

We present photometric and spectroscopic observations of the Type Ia supernova SN 2009nr in UGC 8255 (z = 0.0122). Following the discovery announcement at which turned out to be 10 days after peak, we detected it at V ≃ 15.7 mag in data collected by the All-Sky Automated Survey (ASAS) North telescope 2 weeks prior to the peak, and then followed it up with telescopes ranging in aperture from 10 cm to 6.5 m. Using early photometric data available only from ASAS, we find that the supernova is similar to the overluminous Type Ia SN 1991T, with a peak at M_V ≃ −19.6 mag, and a slow decline rate of ΔM_V(B) ≃ 0.95 mag. The early post-maximum spectra closely resemble those of SN 1991T, while the late-time spectra are more similar to those of normal Type Ia supernovae (SNe Ia). Interestingly, SN 2009nr has a projected distance of 13.0 kpc (∼4.3 disk scale lengths) from the nucleus of the small star-forming host galaxy UGC 8255. This indicates that the progenitor of SN 2009nr is not associated with a young stellar population, calling into question the conventional association of luminous SNe Ia with the “prompt” component directly correlated with current star formation. The pre-discovery observation of SN 2009nr using ASAS demonstrates the science utility of high-cadence all sky surveys conducted using small telescopes for the discovery of nearby (d ≲ 50 Mpc) supernovae.

Key words: galaxies: individual (UGC 8255) – supernovae: general – supernovae: individual (SN 2009nr)

Online-only material: color figures

1. INTRODUCTION

The absence of hydrogen and the abundant presence of Si II close to maximum light distinguish Type Ia supernovae (SNe Ia) from other types of SNe (e.g., Filippenko 1997). They are astrophysically significant for several reasons. SNe Ia are reliable cosmological distance indicators because their intrinsic luminosity can be well calibrated, and were used to discover the acceleration of the universe and to characterize the dark energy models (e.g., Riess et al. 1998; Perlmutter et al. 1999; Astier et al. 2006; Wood-Vasey et al. 2007; Kessler et al. 2009). The heavy elements (mostly Fe group) produced by their explosions play a pivotal role in the chemical evolution of galaxies (e.g., Kobayashi & Nomoto 2009). Well-observed SNe Ia let us investigate the nature of their progenitors and study their explosion mechanism.

The nature of the progenitors of SNe Ia is still being debated. In the single degenerate model, a carbon/oxygen white dwarf (CO WD) in a close binary system accretes matter from a stellar companion (Whelan & Iben 1973). As its mass approaches or exceeds the Chandrasekhar limit, it is unable to support itself through electron degeneracy pressure. The resulting thermonuclear explosions are expected to release similar amounts of energy, as they all burn the same amount of fuel ignited through the same mechanism (e.g., Hillebrandt & Niemeyer 2000). In the double-degenerate model, Type Ia supernovae (SN Ia) results from the merger of two degenerate compact objects, igniting the potentially super-Chandrasekhar mass progenitor (e.g., Iben & Tutukov 1984; Webbink 1984). Recent studies have argued that the double-degenerate scenario is the dominant mechanism (e.g., Pritch et al. 2008; Ruiter et al. 2009; Mennekens et al. 2010).

Early discovery of SNe enables us to study their photometric evolution, and identify spectroscopic features that are difficult to detect in post-maximum spectra dominated by Fe group elements. Moreover, well-sampled photometric data around the peak are crucial for the light curve fits needed to calibrate the luminosity. These provide valuable information regarding the nature of the progenitor and the explosion itself. The All-Sky Automated Survey (ASAS) for variable stars has two small telescopes with wide-field cameras, at sites in Chile and Hawaii, and is obtaining images of the entire sky every 3 days down to V ≃ 15 mag (Pojmanski 1997, 2002; Szczygiel et al. 2010). The high cadence, large area, and magnitude limit of this survey are optimal for making early discoveries of bright SNe in nearby galaxies.

SN 2009nr (R.A. = 13°10′58″59′, decl. = +11°29′29″73′; J2000.0), in the Scd galaxy UGC 8255 (z = 0.0122), was...
detected in an unfiltered image taken at Blagoveschensk, Russia on 2009 December 22.901 UT, and the discovery was announced on 2010 January 6 UT by the Master Robotic Telescope Network (Balanutsa & Lipunov 2010). It was also independently found by the Lick Observatory Supernova Survey (LOSS) in an unfiltered image taken with the 0.76 m Katzman Automated Imaging Telescope (KAIT) on 2010 January 6.53 (Li et al. 2009). It was spectroscopically confirmed as a 1991T-like Type Ia by the CfA Supernova Program using spectra taken on 2010 January 7 UT using the Whipple Observatory 1.5 m telescope (Foley & Esquerdo, 2010). Following the discovery announcement, we detected the SN in archival data collected by the ASAS North telescope on 2009 December 13 UT, and then followed it up with telescopes ranging in aperture from 10 cm to 6.5 m. Figure 1 shows the Sloan Digital Sky Survey (SDSS) g-band image of the SN 2009nr host galaxy UGC 8255, and ASAS V-band images of the same field taken prior to and after the explosion.

Our analysis shows that the earliest ASAS observation of SN 2009nr was obtained 14 days prior to maximum light (2455193.16 ± 0.3; 2009 December 27 UT) and 24 days prior to the discovery announcement. Our spectroscopic and photometric follow-up observations of the SN and its host galaxy lasted until 110 days after the peak. In what follows, Section 2 describes the photometric and spectroscopic observations, data reduction, and calibration methods. Section 3 presents the optical light curves, spectral evolution, and host galaxy properties of SN 2009nr. Section 4 discusses the implications of our observations for conventional understandings of the nature of prompt SNe Ia, and the utility of ASAS for studying nearby SNe. Section 5 presents our conclusions.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Photometric Data

The photometric data were collected using the 10 cm ASAS North telescope in Hawaii (Pojmanski 2002; Pigulski et al. 2009), the 50 cm Dedicated Monitor of Exotransit (DEMONEX) telescope located at the Winer Observatory (Eastman et al. 2009), the 2.4 m Hiltner telescope at the MDM Observatory, and the 2.5 m du Pont telescope at the Las Campanas Observatory. Table 1 has the calibrated BVRI magnitudes of SN 2009nr from the telescopes and instruments we used.

The data reduction and photometry from the ASAS North telescope images were obtained through a custom-made, well-tested data reduction pipeline described in detail in Pojmanski (1998, 2002). The V and I magnitudes form ASAS were tied to the Johnson V and Cousins I scales using Tycho (Hog et al. 2000) and Landolt (Landolt 1983) stars.

The images from DEMONEX, the Ohio State Multi-Object Spectrograph (OSMOS; Stoll et al. 2010; Martini et al. 2010) on the MDM 2.4 m telescope, and the Wide-Field CCD (WFCCD) on the du Pont telescope were reduced (bias subtraction, cosmic ray (CR) rejection, and flat-fielding) using standard techniques in IRAF. Relative photometry of the supernova (SN) with respect to several local standards (σ ≳ 4) was obtained with PHOT in IRAF using an aperture comparable to the FWHM of the stars in the image, and a background estimated in an annulus around the object. Since the SN is well isolated and far from the host galaxy, aperture photometry was the technique of choice. We did not apply any fringing correction to the late-time I-band images (both from DEMONEX).

We calibrated the relative photometry in the BVRI system using zero-point offsets estimated with respect to the magnitudes of the local standards from the SDSS-DR7 release (Abazajian et al. 2009), which were transformed from the SDSS filter system to the standard Bessell/Kron–Cousins magnitudes using the transformations in the SDSS-DR7 Web site. The uncertainties quoted in Table 1 include the standard errors and the rms of the zero-point transformation from the local standards.

2.2. Spectroscopic Data

We obtained nine post-maximum optical spectra of SN 2009nr using the Boller and Chivens CCD Spectrograph (CCDS), WFCCD on the 2.5 m du Pont telescope at the Las Campanas Observatory, the Dual Imaging Spectrograph (DIS) on the 3.5 m Astrophysical Research Consortium (ARC) telescope at the Apache Point Observatory, and the Inamori-Magellan Areal Camera & Spectrograph (IMACS; Dressler et al. 2006) on the 6.5 m Magellan I (Baade) telescope at Las Campanas Observatory. Table 2 shows the journal of spectroscopic observations of SN 2009nr, with details of the epochs and different spectrographs used.

The spectroscopic data were reduced using standard techniques in IRAF, which included the basic data reductions (bias subtraction, CR rejection, and flat-fielding), one-dimensional spectrum extraction, wavelength calibration with HeNeAr (WFCCD, DIS, and IMACS) and Xe (CCDS) arc-lamps obtained at the same position as observations, and flux calibration using a spectroscopic standard observed the same night as the calibration.
3. ANALYSIS

3.1. Light Curve

Figure 2 shows the $V$- and $I$-band light curves of SN 2009nr. An SN Ia light curve template fit to the ASAS $V$- and $I$-band data was performed using the template fitting method described in Prieto et al. (2006). The results of the fit are presented in Table 3.

Table 1

| Parameter | Result | Note |
|-----------|--------|------|
| $\chi^2$ ($v = 25$) | 1.1 | Chi-square of fit |
| $t_{\text{max}}(B)$ | 2455193.2 ± 0.3 | HJD of $B$-band maximum |
| $\Delta m_{15}(B)$ | 0.93 ± 0.02 mag | $B$-band decline rate |
| $E(B - V)_{\text{host}}$ | 0.00 ± 0.01 mag | Host color excess |
| $\mu$ | 33.27 ± 0.15 mag | Distance modulus |

The derived epoch of $B$-band peak magnitude, $t_{\text{max}}(B)$, implies that the earliest ASAS measurement was obtained 14 days before $B$-band maximum. The $B$-band magnitude decline in the first 15 days after maximum light ($\Delta m_{15}(B) \approx 0.93$ mag) confirms that SN 2009nr is more luminous than normal SNe Ia, which usually have $\Delta m_{15}(B) = 1.1$ mag.
(Phillips 1993). The host galaxy reddening, $E(B-V)_{\text{host}}$, estimate is consistent with zero, as expected given the distance of the SN from the host (13.0 kpc, ~4.3 disk scale lengths).

The light curve fits imply peak apparent magnitudes of $m_V = 13.8$ mag and $m_I = 14.0$ mag. This indicates a peak absolute magnitude of $M_V \simeq -19.6$ mag and a distance modulus of $\mu \simeq 33.3$ mag ($d = 45.1$ Mpc), based on the derived host galaxy reddening of zero, Galactic foreground extinction of $A_V \simeq 0.1$ mag, and Hubble constant $H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$. This is brighter than most normal SNe Ia, and is consistent with that of overluminous ones (e.g., Benetti et al. 2005).

Figures 3–5 compare the $V$- and $I$-band light curves and the color evolution of SN 2009nr to those of the overluminous Type Ia SN 1991T ($M_V \simeq -19.6$; Filippenko et al. 1992), the normal Type Ia SN 2003du ($M_V = -19.2$; Stanishev et al. 2007), and the possibly super-Chandrasekhar mass Type Ia SN 2009dc (Silverman et al. 2010). The light curves are corrected to the cosmic microwave background (CMB) rest frame and K-corrections are applied. The colors are corrected for Galactic foreground extinction, host galaxy reddening, and K-corrections. We only used the Bessell filters for K-corrections and did not apply S-corrections.

The SN 2009nr light curve is consistent with SN 1991T. It is clearly different from SN 2009dc, which has a much slower decline rate ($\Delta m_{15}(B) = 0.72 \pm 0.03$ mag; Silverman et al. 2010), and has a very similar decline rate to SN 1991T ($\Delta m_{15}(B) = 0.95 \pm 0.05$ mag; Phillips et al. 1992). The $B-V$ color of SN 2009nr is consistent with the other SNe, while the $V-R$ color is redder than the others between ~50 and ~100 days but becomes bluer around ~100 days. The $R-I$ color is slightly bluer than the other SNe between ~50 and ~100 days while the $V-I$ color is consistent with the others.

A simple fit to the two earliest $V$-band data points (in flux scale) with assumed light curve rise going as $(t - t_{\text{exp}})^2$ (Arnett 1982; Hayden et al. 2010b) implies $t_{\text{exp}} \simeq 17.7$ days before $B$-band maximum. Since our light curve fits show that the $V$-band peak occurred at $t \simeq 2$ days after $B$-band maximum, this indicates a rise time of $t_r = 19.7$ days. Using the equation in Section 6.6 of Hayden et al. (2010b) with peak $M_V = -19.6$ mag and $t_r = 19.7$ days gives a total $^{56}$Ni yield of $\sim 0.9 M_\odot$, which is consistent with similar estimates for bright and slow SNe Ia (e.g., Stritzinger et al. 2006; Hayden et al. 2010b).

### 3.2. Spectra

The nine post-maximum optical spectra of SN 2009nr span +12 to +103 days relative to the epoch of $B$-band maximum light. Figure 6 shows the temporal evolution of SN 2009nr spectra. Figure 7 compares the earliest SN 2009nr spectrum with an SN 1991T-like SN and a normal SN Ia template. Figure 8 compares the SN 2009nr spectra with other SNe that are determined

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**Figure 2.** $V$- and $I$-band light curves of SN 2009nr. The horizontal axis is in days from the date of maximum brightness in the $B$ band. The two solid lines are SN Ia light curve template fits to the ASAS data points only. The dotted line shows the epoch of the discovery announcement (~10 days after $B_{\text{max}}$). The $V$-band light curve is shifted by +1 mag for clarity.

(A color version of this figure is available in the online journal.)

**Figure 3.** Comparison of $V$-band light curve of SN 2009nr with those of the overluminous Type Ia SN 1991T (Lira et al. 1998), the normal Type Ia SN 2003du (Stanishev et al. 2007), and the possibly super-Chandrasekhar mass Type Ia SN 2009dc (Silverman et al. 2010). The black solid line is the SN Ia light curve template fit to the ASAS data points only. The light curves of the comparison SNe are shifted so that their peaks approximately match that of SN 2009nr.

(A color version of this figure is available in the online journal.)

**Figure 4.** Same as Figure 3, but for $I$ band.

(A color version of this figure is available in the online journal.)
Figure 5. Color evolution of SN 2009nr (black data points) compared to those of the overluminous Type Ia SN 1991T (red; Lira et al. 1998), the normal Type Ia SN 2003du (blue; Stanishev et al. 2007), and the possibly super-Chandrasekhar Type Ia SN 2009dc (green; Silverman et al. 2010). The horizontal axis is same as in Figure 2. The continuous lines are connected color evolution data points of the respective SNe.

(A color version of this figure is available in the online journal.)

Figure 6. Spectral evolution of SN 2009nr. Epochs are in days since the date of maximum brightness in the B band. The vertical displacements are arbitrary. The telluric lines at 6800 Å, 7200 Å, and 7600 Å are labeled.

to be spectroscopically similar at the relevant phase by SNID (Blondin & Tonry 2007). Important spectral features have been identified using Li et al. (1999), Pastorello et al. (2007), Branch et al. (2008), and Wang et al. (2009).

SNID identifies the earliest SN 2009nr spectra collected 12 days after the date of maximum brightness in the B band

Figure 7. Comparison of the earliest SN 2009nr spectrum (black continuous line) and the spectrum of SN 1991T like supernova SN 1997br (red long dashed line, dereddened by $E(B-V) = 0.35$ mag; Li et al. 1999), both collected 12 days after the date of maximum brightness in the B band, with a normal SN Ia spectrum template for the same post-maximum epoch (green short-dashed line; Hsiao et al. 2007). All the spectra are corrected to the rest frame and shifted so that their flux approximately match at 5500 Å.

(A color version of this figure is available in the online journal.)

Figure 8. Spectral evolution of SN 2009nr as compared to spectroscopically similar SNe at the relevant phase as determined by SNID (Blondin & Tonry 2007). Important features are labeled along with the telluric lines (6800 Å, 7200 Å, and 7600 Å). The data for SN 1991T, SN 1998aq, and SN 2003du are from Mazzali et al. (1995), Branch et al. (2003), and Stanishev et al. (2007), respectively. All the spectra are corrected to the rest frame using the redshifts ($z_{\text{helio}}$) of the hosts. The SN 1991T spectra is dereddened by $E(B-V) = 0.13$ mag (Li et al. 1999; Saha et al. 2001). Host extinction for SN 1998aq (Reindl et al. 2005), SN 2003du (Stanishev et al. 2007), and SN 2009nr (Section 3.1) are consistent with zero.

(A color version of this figure is available in the online journal.)
as spectroscopically most similar to an SN 1991T spectrum collected 16 days after maximum, while two SN 1991T like SNe, SN 1997br and SN 1999aa (spectra collected 12 and 15 days after peak, respectively), are identified as the second and third most similar spectra. In Figure 7, we compare the earliest SN 2009nr spectrum and the spectrum of SN 1997br (Li et al. 1999) since both were collected 12 days after maximum. We also show a normal SN Ia template for the same post-maximum epoch (Hsiao et al. 2007). While many features of the earliest SN 2009nr spectrum are present in both the comparison spectra in Figure 7, we specifically note some important features that are very similar in the SN 1997br and SN 2009nr spectra and differs from the normal SN Ia template.

The Co II λ4302 and Fe II λλ6238, 6248 lines are clearly present in both the SNe spectra but in the normal SN Ia template they are completely absent. Also, the Si II λ6355 line of the two SNe spectra, which is a characteristic feature of SNe Ia, is more consistent with each other than the normal SN Ia template. As noted by Li et al. (1999) in case of SN 1997br, the red wing of the Si II λ6355 line of the SN 2009nr spectrum is also contaminated by the Fe II λλ6456, 6518 line, unlike the normal SN Ia template where the Si II line is much stronger. The Co II λ4152, Fe II λ4555, Fe II λ4924, and Fe II λ5018 lines of the two SNe spectra appear stronger, while the Si II λ4550, Si II λ5051, and Si II λλ5612, 5654 lines are more prominent in the normal SN Ia template.

Based on the SNID comparison and the better match of spectral features in the earliest spectra (as well as the B-band decline rate and peak magnitude), we conclude that SN 2009nr is most likely an SN 1991T like object.

Although at early times SN 2009nr is spectroscopically most similar to the overluminous Type Ia SN 1991T, at later times it becomes more similar to the normal Type Ia SN 1998aq and SN 2003du. This is consistent with the observed characteristics of 1991T-like SNe (not very strong Si II, different ionization state of some dominant features because of higher temperature, etc.) that are strongest before and around maximum light, but later on dilute to become similar to normal SNe Ia. The earliest spectrum at \( t = +12 \) days shows singly ionized lines of intermediate mass elements (Si, S, and Na), as well as various Fe II lines. The Si II λ6355 line is clearly visible at \( t = +12 \) days, and is identifiable at \( t = +19 \) days as well, but not at \( t = +54 \) days. The Cr II line is visible at \( t = +12 \) days, and becomes more prominent at \( t = +19 \) days, but is no longer identifiable in the iron group element dominated latter spectra.

We examined the blueshifted Si II λ6355 and Fe II λ4555 absorption features in the earliest spectra (\( t = +12 \) days) to determine the photospheric expansion velocity of SN 2009nr. The Si II line is observed at redshift corrected λ6150 implying an expansion velocity of \( \sim 9700 \) km s\(^{-1}\), and the Fe II line is observed at redshift corrected λ4400 implying an expansion velocity of \( \sim 10,000 \) km s\(^{-1}\), which are consistent with the velocities of normal and overluminous SNe Ia (e.g., Benetti et al. 2005) at similar epochs.

### 3.3. Host Galaxy Properties

Table 4 summarizes the basic parameters of the host galaxy of SN 2009nr, UGC 8255. We derived total magnitudes of UGC 8255 from SDSS in the ugriz bands using Sextractor (Bertin & Arnouts 1996). The total SDSS gr magnitudes were used to infer the absolute magnitude in B, correcting for Galactic extinction (Schlegel et al. 1998), and K-corrections (Blanton & Roweis 2007), and using the distance modulus derived from the light curve fits (see Table 3). The derived absolute magnitude in B and the rest-frame B – V color of UGC 8255 are shown in Table 4.

We used the total magnitudes of UGC 8255 in the SDSS bands and GALEX UV photometry (FUV and NUV), estimated from aperture photometry, to fit stellar population synthesis (SPS) models with the FAST code (Kriek et al. 2009). The results for the total stellar mass, age, and star formation rate derived from the SPS fits with FAST are also presented in Table 4. Within FAST we used the Bruzual & Charlot (2003) SPS models, a Salpeter initial mass function, and assumed solar metallicity based on abundance estimates we discuss shortly.

Figure 9 shows the SDSS r-band image of the SN 2009nr host galaxy UGC 8255, and the residual after subtracting a GALFIT (Pen g et al. 2002) model that includes an exponential disk and a Sersic profile for the bulge. The results are also presented in Table 4.

We took a spectrum of the host galaxy using IMACS on the Baade 6.5 m Telescope at the Las Campanas Observatory, running the slit across the SN and the center of the host. Figure 10 shows the radial metallicity dependence of the SN 2009nr host galaxy, UGC 8255, along the slit. Oxygen abundances of the nucleus and six off-center H II regions were estimated using the \([\text{N} II]/\text{H} \alpha\) calibration described in Denicoló et al. (2002). The linear fit to the oxygen abundance measurements has a gradient of \( \sim 0.06 \) dex kpc\(^{-1}\), which is consistent with other observations for similar galaxy type (Zaritsky et al. 1994).

## 4. DISCUSSION

### 4.1. SN 2009nr Properties

SN 2009nr has a projected distance of 13.0 kpc or \( \sim 4.3 \) disk scale lengths from the nucleus of its metal-rich star-forming Scd host galaxy UGC 8255. This is a lower limit on its physical distance, since we do not know if the object is located on the same plane as the disk. The derived physical parameters of the galaxy, the radial metallicity gradient, and the projected distance of the SN from its host nucleus all indicate that SN 2009nr is located in the halo of UGC 8255 rather than in an extended disk. Given that the metallicity of Milky Way halo stars is \( \sim 1 \) dex lower than the disk stars (e.g., Ivezić et al. 2008), and the radial
metallicity gradient of UGC 8255 (Figure 10), it is apparent that SN 2009nr exploded in a low-metallicity region.

The spectroscopic identification, B-band decline rate, and absolute magnitude all indicate that SN 2009nr is an SN 1991T like event. Significantly more luminous than normal SNe Ia, SN 1991T is thought to be the result of the delayed detonation of a CO WD, or the double detonation of a WD initiated at the boundary layer between the CO core and the He envelope (Filippenko et al. 1992). More recently, it has been proposed that the SN 1991T like SNe progenitor population may emerge from WD+MS systems (Kasen et al. 2004), and that these events may not have any special physical properties except for the viewing angle of the observer (Meng & Yang 2010).

If the SN 2009nr progenitor formed in the central region of the host and lived few × 100 Myr, then it would need to have a rather implausible radial velocity of 120 km s$^{-1}$ to travel 13.0 kpc in its lifetime. If it traveled that far from the host at a much slower speed, then the progenitor must be an old star. Alternatively, the progenitor formed in the metal poor environment of the halo, but then it cannot be related to the young population located in the host galaxy’s central region. While we cannot tell if the progenitor formed in the disk and moved out or it formed in the halo long ago, it would be old in either case. Therefore, we cannot make any statement regarding the stellar population from which the progenitor emerged, based on the recent star formation rate or environment of the host.

### 4.2. Implication for Prompt Type Ia SNe

Studies of the host metallicities of nearby SNe Ia (Hamuy et al. 2000; Gallagher et al. 2005) have claimed that the primary factor regulating SN Ia peak luminosities is the age of the stellar population rather than metallicity. A two-component progenitor distribution has been proposed, each associated with a distinct evolutionary timescale (e.g., Mannucci et al. 2005; Scannapieco & Bildsten 2005;Neill et al. 2006; Maoz et al. 2010a). The “prompt” component is thought to be correlated with the recent star formation rate of the host, and the SN explodes ∼ 100 Myr after star formation. This leads to the high SNe Ia rates in actively star-forming galaxies (late type spirals and irregulars). The “delayed” component tracks the underlying stellar population, scales with stellar mass, and explodes ≳ 1 Gyr after star formation, usually in old, quiescent, elliptical galaxies. The delayed component can be much older, as noted in recent delay time distribution studies (e.g., Maoz et al. 2010b; Horiuchi & Beacom 2010).

Luminous SNe Ia are conventionally associated with the prompt component, supposedly emerging from young stellar populations (Hamuy et al. 2000; Cooper et al. 2009; Sullivan et al. 2010), and the brightest events explode mainly in star-forming galaxies (Hamuy et al. 1996; van den Bergh et al. 2005). However, given its location, SN 2009nr has to be coming from an old population, and is clearly unrelated to the host’s recent star formation history. In fact, SNe Ia that are distant from their host nucleus are not rare. Figure 21 of Hicken et al. (2009) shows that a significant fraction (roughly, a third) of SNe Ia are more than 10 kpc away from their star-forming hosts. This is true both for SNe located in spirals or irregular galaxies and similar to SN 2009nr (the brightest, bluest, slowest ones; the blue points in that figure), and also for those in the broader host population with more normal luminosities (the green points in that figure).

Prieto et al. (2008) discusses some extreme and interesting SN-host pairs, such as the metal-poor (1/4 solar) host of SN 2007bk, where the 1991T-like overluminous SN was found ∼ 9 kpc away from its dwarf host galaxy’s center. Badenes et al. (2009) demonstrates that three of the four young SN Ia remnants in the LMC are associated with old, metal-poor stellar populations. For example, SNR 0509−67.5 is known...
to have been originated by an extremely bright Type Ia event but is located in a population with a mean age of 7.9 Gyr, far away from any sites of recent star formation. Moreover, three of the four claimed Super-Chandrasekhar SN Ia events detected in recent years, all extremely bright Type Ia events, are located far away from their star-forming hosts. Of these, SN 2003fg ($M_V = -20.0$; Howell et al. 2006) is located 0.9 kpc away from its small low-mass star-forming host, SN 2006gz ($M_V = -19.2$; Hicken et al. 2007) is located 14.4 kpc away from its Scd host, and SN 2009dc ($M_V = -19.8$; Silverman et al. 2010) is located $\sim 12$ kpc (5.7 Petrosian Radii) away from its S0 host. Besides, SBS 1150 + 599A, a close binary system hosted by the planetary nebula PNG 135.9 + 55.9 located in the Galactic halo (Tovmassian et al. 2010), is an excellent example of a possible SN Ia progenitor candidate in a very low metallicity environment of a star-forming host (Milky Way, in this case) that is unrelated to recent star formation.

Given the location of the progenitors and properties of their hosts, it appears to us that the higher SN luminosities are likely related to the low-metallicity local environments of these SN Ia progenitor systems rather than just the age of the stellar population (see Prieto et al. 2008 for related discussion). This motivates us to rethink the conventional association of luminous SN Ia with the “prompt” component directly correlated with recent star formation.

4.3. Utility of ASAS for Studying Nearby SNe

Clearly, the conventionally accepted understanding of luminous Ia SNe being directly related to the recent star-forming environment of their hosts needs to be reconsidered. If many of the luminous Ia like SNe are indeed physically separated from the central star-forming regions of their hosts, efforts to establish causal links between SNe Ia and their host environments become more challenging. For example, Brandt et al. (2010) discusses the host properties of SNe Ia discovered by SDSS, but SN 2009nr is an obvious example in which the SN would be outside the SDSS fiber, and we cannot learn anything about the progenitor environment (age and metallicity) from the SDSS spectrum. Similarly, Gallagher et al. (2005), Howell et al. (2009), andNeill et al. (2009) discuss relationships between SNe Ia and their star-forming host metallicity in the context of “global” measurements of oxygen abundance based on the mass of the galaxy or luminosity-weighted oxygen abundances. These may not be very good approximations for SNe located in parts of their hosts that have significantly different metallicity and star-forming history than what is inferred from such global estimates (e.g., Badenes et al. 2009).

Although there is general agreement that SNe Ia are thermonuclear explosions of WDs, whether it involves only one degenerate object stripping mass off its hydrogen-rich binary companion until it explodes upon reaching Chandrasekhar Mass, or two WDs merging into a super-Chandrasekhar mass object which then explodes, is less certain. Conceivably, either of these mechanisms can be involved, although it has been proposed that only one of them might dominate (Di Stefano 2010a, 2010b; Gilfanov & Bogdán 2010; Hayden et al. 2010a).

Pritchett et al. (2008) demonstrates that SNe Ia explosions are about 1% of the stellar death rate independent of star formation history, and proposes that some progenitor scenario other than the single-degenerate channel alone must be invoked to explain SNe Ia. Ruiter et al. (2009) finds strong indication that the double degenerates form the dominant channel generating SNe Ia in spiral galaxies. Mennekens et al. (2010) concludes that while the double degenerate delay time distribution, possibly combined with the single degenerate one, agrees with observation, the single degenerate scenario alone cannot reproduce the observed distribution. Detection of a greater number of, if not all, nearby ($d \lesssim 50$ Mpc) SNe, for which it is possible to obtain very late-time spectra, can help refine our current interpretation of what physical phenomenon may be contributing to the prompt and delayed SN Ia population (e.g., Leonard 2007).

While surveys targeting large and bright galaxies lead to a higher SN detection rate per observed galaxy, the low-metallicity, low-luminosity galaxies have hosted some of the most interesting SNe of all types (for example, SN 1999aw (Strolger et al. 2002), SN 2005cg (Quimby et al. 2006), SN 2005ej (Prieto et al. 2007), SN 2007bk (Prieto et al. 2008), SDWFS-MT-1 (Kozłowski et al. 2010) etc.). To identify and analyze the most unusual and potentially most informative SNe, we need galaxy-impartial surveys. High-cadence all sky surveys conducted using small telescopes such as ASAS give us the opportunity to build a galaxy independent SN sample, even if only for the very local universe. As illustrated in Figure 11, although the SN Ia detection rate has risen significantly in recent years, incompleteness continues to be a very real concern even in the immediate neighborhood ($d \lesssim 50$ Mpc).

The observation of SN 2009nr at $d \simeq 45$ Mpc two weeks prior to peak luminosity demonstrates the potential capability of ASAS, and similar high-cadence all sky surveys conducted using small telescopes, to meaningfully address this incompleteness issue. Moreover, early detection and well-sampled photometric data around the peak will enable us to accurately reconstruct the light curves and determine the peak luminosity, which can potentially address the theoretical uncertainty over SN Ia progenitor mass in the double degenerate scenario.
Discovery of most nearby SNe Ia for which we may obtain very late time spectroscopic data, which is not possible to do for distant SNe, can also help us better understand the progenitor systems.

5. CONCLUSIONS

SN 2009nr is an SN 1991T like SN that is more luminous and has a slower initial decline rate than normal SNe Ia. Located ∼4.3 disk scale lengths away from the nucleus of its star-forming host, it either formed in the halo or wandered out over a long time. Evidently, it is not associated with the young stellar population and central star-forming environment of its host.

In fact, many bright and slow SNe Ia occurring in star-forming hosts are not associated with young stellar populations, and thus should not be considered a part of the prompt Ia population by default. SNe Ia that are located far from their host galaxy nucleus probably have no association with the recent star-forming history of that galaxy. This may affect attempts to explore causal connections between SNe Ia and their host properties.

Scientifically interesting SNe, of both Type I and II, have often been discovered in low-metallicity, low-luminosity galaxies that are usually not targeted in SN surveys. Galaxy-impartial high-cadence all sky searches conducted using small telescopes such as ASAS can produce a galaxy independent SN sample and lead to pre-maximum detection of many local (d ≲ 50 Mpc) SNe.

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