Discovery and Early Multi-Wavelength Measurements of the Energetic Type Ic Supernova PTF12gzk: A Massive-Star Explosion in a Dwarf Host Galaxy

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ABSTRACT

We present the discovery and extensive early-time observations of the Type Ic supernova (SN) PTF12gzk. Our light curves show a rise of 0.8 mag within 2.5 hr. Power-law fits [$f(t) \propto (t - t_0)^n$] to these data constrain the explosion date to within one day. We cannot rule out a quadratic fireball model, but higher values of n are possible as well for larger areas in the fit parameter space. Our bolometric light curve and a dense spectral sequence are used to estimate the physical parameters of the exploding star and of the explosion. We show that the photometric evolution of PTF12gzk is slower than that of most SNe Ic. The high ejecta expansion velocities we measure ($\sim 30,000\,\mathrm{km\,s^{-1}}$ derived from line minima four days after explosion) are similar to the observed velocities of broad-lined SNe Ic associated with gamma-ray bursts (GRBs) rather than to normal SN Ic velocities. Yet, this SN does not show the persistent broad lines that are typical of broad-lined SNe Ic. The host-galaxy characteristics are also consistent with GRB-SN hosts, and not with normal SN Ic hosts. By comparison with the spectroscopically similar SN 2004aw, we suggest that the observed properties of PTF12gzk indicate an initial progenitor mass of 25–35 $\mathrm{M}_\odot$ and a large [(5–10) $\times 10^{51}$ erg] kinetic energy, the later being close to the regime of GRB-SN properties.

1. Introduction

A core-collapse supernova (CCSN) occurs when a star having an initial mass $M \geq 8\,\mathrm{M}_\odot$ ends its life in a catastrophic explosion. Observationally, CCSNe are divided into three groups based on their observed spectra: SNe II show large amounts of hydrogen, SNe Ib

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exhibit helium but little or no hydrogen, and SNe Ic do not show significant amounts of hydrogen or helium (for a review, see Filippenko 1997).

SNe Ic are heterogeneous. Their luminosity, ejected mass, and kinetic energy span over an order of magnitude, from the subluminous SN 2004aw to the overluminous SN 1998bw (Mazzali et al. 2009; Drout et al. 2011). The light-curve shapes of different events are also quite diverse. A subclass of SNe Ic whose spectra are characterized by broad lines (Type Ic-BL; prototype SN 1998bw) is the only one for which clear evidence of an association with gamma-ray bursts (GRBs) exists (GRB-SNe; see Woosley & Bloom 2006 for a review). Superluminous SNe (SLSNe) of Type Ic are even more powerful (Gal-Yam 2012, and references therein), but these probably result from a different physical mechanism. While SNe Ic are common in the center of high-metallicity galaxies (Anderson et al. 2012), SLSNe-I and broad-lined GRB-SNe tend to be found in dwarf hosts (e.g., Stanek et al. 2006; Modjaz et al. 2008; Arcavi et al. 2010), giving untargeted sky surveys an advantage over targeted surveys in detecting these types of cosmic explosions.

The Palomar Transient Factory (PTF; Law et al. 2009; Rau et al. 2009) is a wide-field untargeted sky survey which explores the transient optical sky. It uses the PTF CFH12k camera mounted on the Palomar 48-inch telescope (P48). PTF's short observing cadence and real-time capability (e.g., Gal-Yam et al. 2011) enables the discovery and study of SNe at early stages of the explosion. In this *Letter* we report the discovery and study of PTF12gzk, a peculiar SN Ic in a dwarf star-forming galaxy located at redshift $z = 0.0137$ (distance 57.8 Mpc, distance modulus 33.8 mag, assuming $H_0 = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$).

2. Discovery

PTF12gzk was discovered on 2012 July 24.3 (UT dates are used herein) at $\alpha(\mathrm{J2000}) = 22^{\mathrm{h}}12^{\mathrm{m}}41.53^{\mathrm{s}}$ and $\delta(\mathrm{J2000}) = +00°30'43.1''$, in the dwarf galaxy SDSS J221241.53+003042.7 (within the SDSS Stripe 82 footprint), as part of a coordinated PTF-JVLA[1] survey[2]. The discovery magnitude was 20.66 in the r band[3], and it was not detected down to mag 21.6 (3σ) in previous PTF images obtained on July 19 (Ben-Ami et al. 2012).

[1]The Jansky Very Large Array is operated by the National Radio Astronomy Observatory (NRAO), which is a facility of the National Science Foundation (NSF), operated under cooperative agreement by Associated Universities, Inc. (AUI).

[2]It was also independently discovered by the La-Silla Quest (LSQ) and Pan-Starrs1 (PS1) surveys, and designated LSQ 2012dwl and PS1-12baa, respectively.

[3]PTF magnitudes are given in the PTF natural-magnitude system (Ofek et al. 2012), with respect to the SDSS r-band magnitudes.

Shortly after discovery, we initiated an extensive follow-up campaign, including our *Hubble Space Telescope (HST)* Target-of-Opportunity (ToO) program for STIS ultraviolet (UV) spectroscopy of a stripped-envelope SN (Cycle 19, GO-12530; PI Filippenko) and *Swift* X-ray and UV photometry (Cycle 8, PID 8110099; PI Kasliwal), the results of which are presented herein (see Figures 1 and 2 for photometry and spectroscopy, respectively). We also triggered radio and millimeter observations using the JVLA (program 12A-363; PI Horesh) and the Combined Array for Research in Millimeter-wave Astronomy (program 12A-c0945; PI Horesh); see Horesh et al. (in preparation).

3. Observations

3.1. Photometry

Optical photometry of PTF12gzk was obtained using multiple telescopes (Table 1). All data were calibrated with respect to the SDSS catalog. Light curves of PTF12gzk are shown in Figure 1.

Date (MJD)	Instrument	Filter	Apparent Magnitude	1σ Uncertainty
2456132.763	P48+CFH12k	R	20.66	0.12
2456132.779	P48+CFH12k	R	20.24	0.15
2456132.808	P48+CFH12k	R	20.13	0.08
2456132.809	P48+CFH12k	R	20.11	0.12
2456132.848	P48+CFH12k	R	20.02	0.07

Table 1: PTF12gzk photometry. Data were obtained using the P48+PTF camera, the Palomar 60-inch telescope + GRB camera, the Fairchild camera on the 40-inch telescope at Mt. Laguna Observatory (MLO), FS01 on the 2-m Faulkes Telescope South (FTS), the IO:O camera on the Liverpool telescope (LT), the PI camera on the Wise 1-m telescope, the Weizmann Institute Kraar 16-inch telescope, and the 0.76-m Katzman Automatic Imaging Telescope (KAIT; Filippenko et al. 2001). The full set of photometric data is available in the electronic version of this paper, as well as from WISeREP, http://www.weizmann.ac.il/astrophysics/wiserep/; Yaron & Gal-Yam (2012).

The optical data were reduced using standard IRAF procedures for aperture photometry (FTS data were reduced using point-spread-function photometry via DoPHOT). We subtract reference templates from the P48 and P60 data to remove contamination from the host[4]. Pre-explosion templates were not used for other data, but the contribution from the underlying galaxy ($g, r, z = 19.05$, 19.03, 18.75 mag from SDSS) is negligible, as was also demonstrated by reducing P60 data both with and without template subtraction. The data were calibrated

[4]SDSS images were used as reference images for the P60 data.

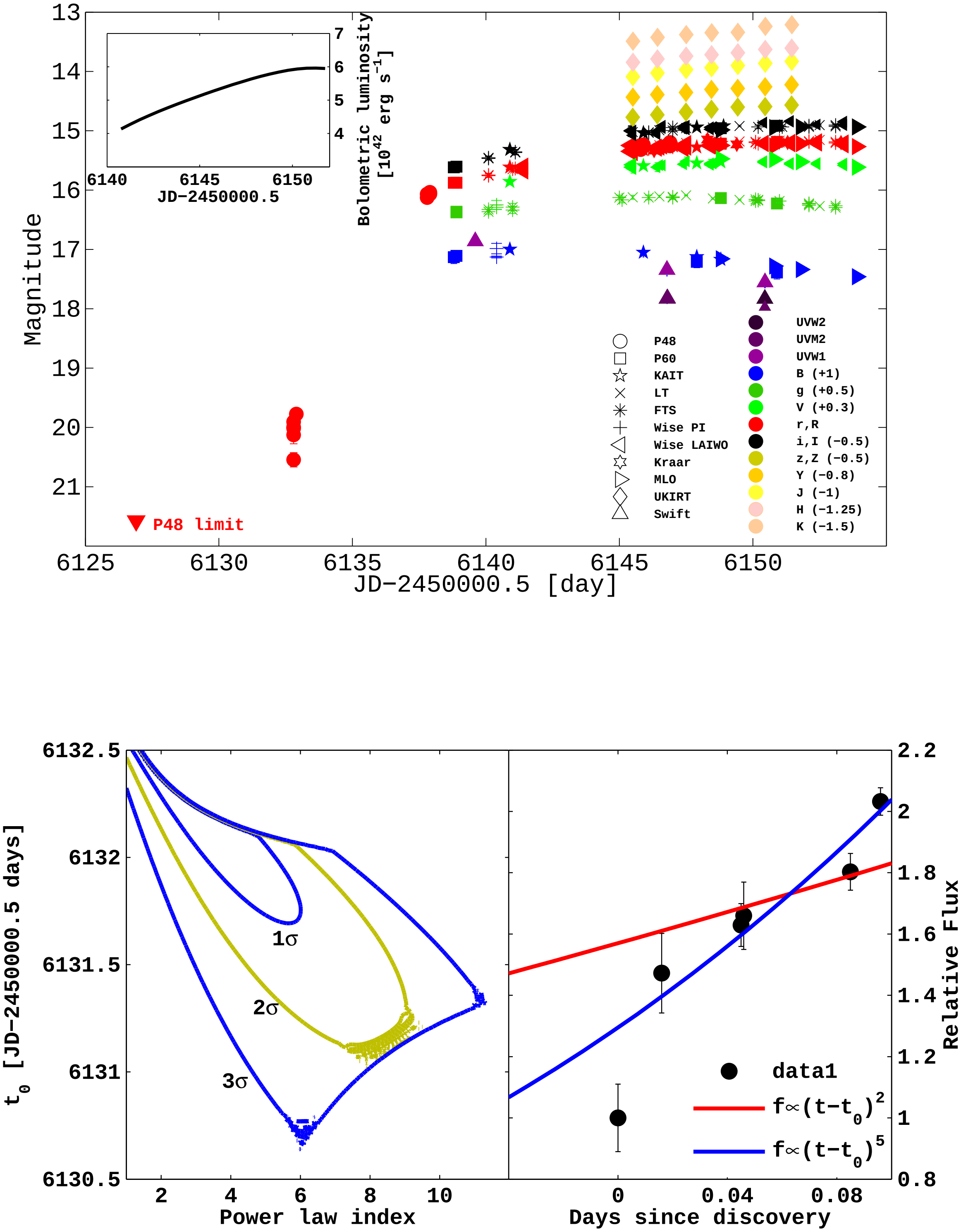


Fig. 1.— PTF12gzk photometry. **Top:** The long rise time and the large delay in peak magnitudes between the B and r bands is evident in the light curve. **Inset:** A bolometric light curve derived from a fourth-degree polynomial fit to our UV-optical-IR data. **Bottom left:** A χ^2 probability-density-function contour plot comparing power-law models with the first 2.5 hr of observations (see text). The value of the index n is not well constrained. Discontinuities in the contour curves are caused by finite sampling of the parameter space, and have no statistical significance. **Bottom right:** Early photometry. The flux is scaled with respect to the first data point. Fits of the scaled flux to $f \propto (t-t_0)^2$ (red) and $f \propto (t-t_0)^5$ (blue) are also shown. Considering the flux normalization as an additional parameter, there is no significant difference between the two fits.

to SDSS stars in the field, using the transformation equations given by Jordi et al. (2006) to place the local standards on the Johnson-Cousins system[5].

Infrared (IR) photometry of PTF12gzk (Table 1) was obtained using the Wide Field Camera mounted on the United Kingdom Infrared Telescope (UKIRT-WFCAM) using SExtractor, and calibrated with respect to the 2MASS catalog (magnitude errors $< 0.07\,\mathrm{mag}$) using the relation of Hodgkin et al. (2009).

Based on the absence of strong Na I D lines (see section 4), as well as the blue early-time spectrum (see below), we take a conservative approach assuming negligible extinction by the host galaxy at the SN location.

During the first night of observation, PTF12gzk brightened by $\sim 0.8\,\mathrm{mag}$ in less than $2.5\,\mathrm{hr}$ to $19.85\,\mathrm{mag}$ in r; we thus obtained remarkably early coverage of a SN Ic. We find that the SN peaked at $r = 15.2$ mag on August 14, $g = 15.55$ on August 8, and $B = 16$ on August 4. On August 15, PTF12gzk peaked in the i band.

PTF12gzk was observed with the X-Ray Telescope (XRT) and the Ultraviolet/Optical Telescope (UVOT) onboard the *Swift* satellite. XRT measurements, beginning at 13:39 on July 31, detected no source at the location of PTF12gzk; we estimate a dead-time-corrected limit on the XRT count rate of $< 2 \times 10^{-3}\,\mathrm{cps}$. Assuming a power-law spectrum with a photon index of 2, this corresponds to a limit on the X-ray flux of $< 7 \times 10^{-14}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. UVOT data were reduced using a $5''$ aperture to measure the counts for the coincidence-loss correction, a $3''$ or $5''$ source aperture (based on the signal-to-noise ratio) for the aperture photometry, and applying an aperture correction as appropriate. We used zeropoints from Breeveld et al. (2011), including a time-dependent sensitivity loss to put the magnitudes on the UVOT photometric system. Results are given in figure 1.

We have calculated a bolometric light curve by integrating the flux in the $UVW2$, $UVM2$, $UVW1$, B, g, V, r, R, i, I, J, H, K filters and fitting a fourth-degree polynomial to the obtained data points. When lacking IR photometry, we assume a constant fraction of IR flux, found to be $\sim 18\%$ from synthetic photometry using TSPEC IR spectra (see § 4.2). We estimate that the lack of IR (UV) coverage prior to August 7 introduces an uncertainty of $\sim 10\%$ from the small variation seen in the IR contribution ($< 5\%$ with respect to the overall flux) between August 4 (the first TSPEC IR spectrum) and August 12. Uncertainties introduced by the lack of UV photometry are $\sim 5\%$ from the even smaller variation in the

[5]We tested our cross-calibration among different telescopes by calculating low-order polynomial fits to the combined dataset in each filter and searching for systematic offsets of particular datasets from the combined fit. We found that two datasets (KAIT I and LT g) had to be corrected by 0.06 mag.

UV contribution ($< 2\%$ relative to the overall flux). The bolometric light curve is given in Figure 1 and shows a rise time of 18 ± 1 day, similar to that in the r band.

3.2. Spectroscopy

Extensive spectroscopy of PTF12gzk was performed, and detailed analysis will be presented in a future paper. A selection of optical spectra is shown in Figure 2.[6]

The first spectrum was obtained on July 27, revealing the object to be a peculiar SN I with a blue continuum, reminiscent of the blue continuum observed in the early-time spectra of SN 2006aj (Mazzali et al. 2006b). Initially it was difficult to classify the spectrum securely, but later optical spectra resemble those of SNe Ic, with an absence of prominent He I lines (Ben-Ami et al. 2012).

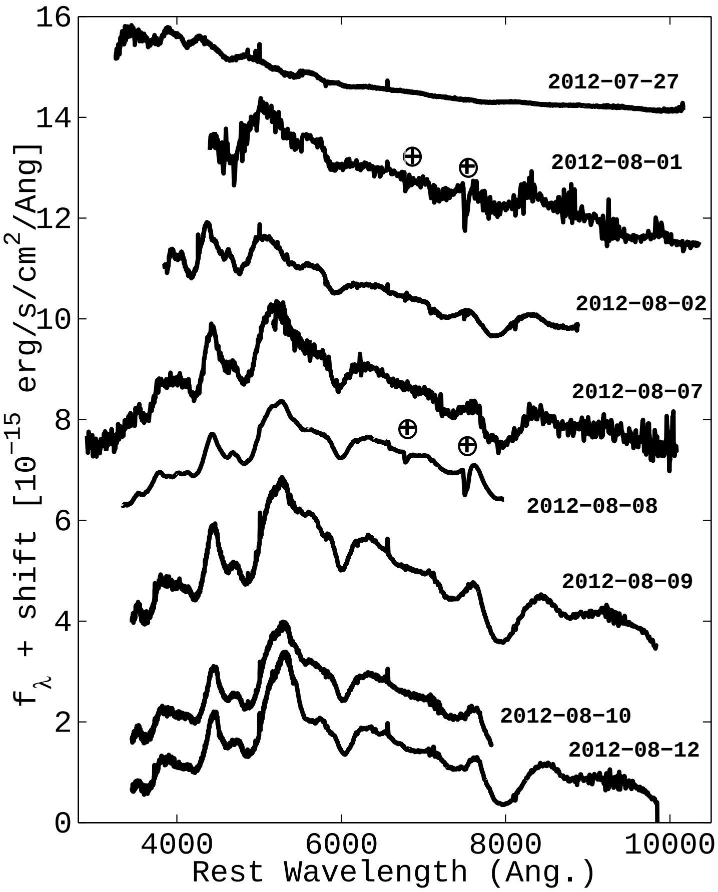
The August 1 spectrum was taken with the FLOYDS spectrograph mounted on the FTN, a low-dispersion spectrograph ($R \approx 400$) with a single, fixed grating and a cross-dispersing prism, placing the first- and second-order spectra onto the CCD with a single-exposure wavelength coverage of 3200–10,000 Å. While the identical twin FLOYDS spectrographs on FTN and FTS will ultimately be robotically operated, the present spectrum was taken during hardware commissioning under human control.

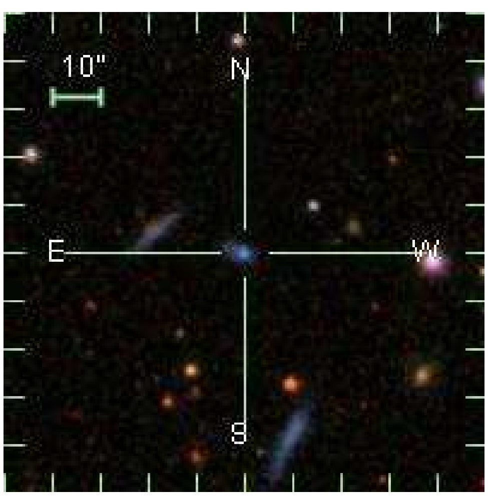
Classification with the help of SNID (Blondin & Tonry 2007) of the August 9 Lick 3-m/Kast spectrum suggests that the best fit is to the peculiar SN Ic SN 2004aw near peak brightness (Taubenberger et al. 2006). A good match is also obtained for PTF10qts, a Type Ic-BL SN, at ~ 30 days after explosion. All spectra show prominent, broad absorption lines of Ca II, Si II, Fe II, and O I, with SYNOW fits yielding maximum velocities of $\sim 35,000\,\mathrm{km\,s^{-1}}$ for the July 27 spectrum, and $\sim 20,000\,\mathrm{km\,s^{-1}}$ for the August 9 spectrum. See Figure 3 and § 5 for further discussion.

The absence of the $2.1\,\mu$m He I feature in the IR TSPEC spectrum taken on August 7 (Figure 3, bottom-right panel) suggests that He is not abundant in the envelope (Hachinger et al. 2012). While a strong absorption line is present at $1\,\mu$m, which could be identified with He I $1.0830\,\mu$m, in this case it is likely contaminated by other elements such as C, Mg, S, and Ca (e.g., Mazzali& Lucy 1998; Sauer et al. 2006; Hachinger et al. 2012).

The first *HST* UV spectrum, obtained by the Space Telescope Imaging Spectrometer with the near-UV Multi-Anode Microchannel Array (STIS/MAMA), was taken between

[6] All ground-based spectra presented in this paper are released on WISeREP, http://www.weizmann.ac.il/astrophysics/wiserep/; Yaron & Gal-Yam (2012).





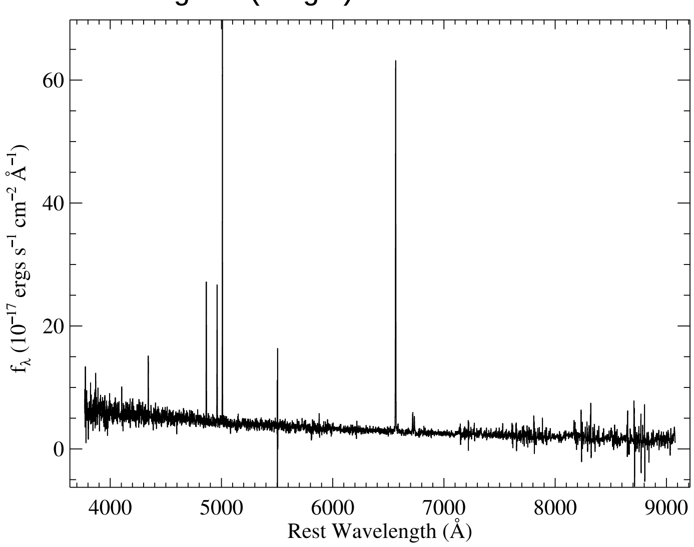


Fig. 2.— **Top:** PTF12gzk optical spectra; telluric features are marked. **Bottom**: The host galaxy of PTF12gzk. Left: SDSS image; note the blue color and small spatial size ($1'' = 280\,\mathrm{pc}$). Right: SDSS spectrum; note the strong emission lines and blue continuum.

20:06 August 6 and 03:35 August 7, with a total exposure time of 11,278 s. We also obtained optical spectra with the STIS/CCD, using grisms centered at 4300 and 7500 Å. A mosaic of all three *HST* spectra is given in Figure 3, with a focus on the UV spectrum in the bottom-right panel. The flux deficit with respect to blackbody spectra seen in the STIS/MAMA UV spectrum is characteristic of all SNe I (Panagia 2007) and indicates strong line blanketing, evidence for a highly mixed outer envelope devoid of hydrogen. Full analysis of the *HST* UV spectra will be presented by Ben-Ami et al. (in prep.).

4. Host-Galaxy Analysis

An image and a spectrum of the host galaxy obtained by the SDSS prior to explosion are shown in Figure 2. The SN exploded very close to the center of the host galaxy (offset 0.0″ N and 0.4″ E). We downloaded the host-galaxy spectrum from the SDSS 9th Data Release (DR9; Ahn et al. 2012). After correcting for the host-galaxy redshift, we measure integrated emission-line fluxes using standard procedures via *splot* in IRAF, and follow Perez-Montero & Diaz (2003) to compute statistical errors[7]. Using the SDSS Petrosian magnitudes, correcting for Galactic and host-galaxy extinction (see below), and applying K-corrections via *kcorrect* (v4.2, Blanton & Roweis 2007) at the host-galaxy redshift, we derive an absolute magnitude of $M_r = -14.8$ mag. This is an extremely underluminous dwarf galaxy, well below the luminosities of the Large and Small Magellanic Clouds. It is one of the least luminous host galaxies of CCSNe discovered by PTF, and it is not a common host galaxy for a SN Ic, even considering those found via untargeted surveys (Arcavi et al. 2010), except for SNe Ic-BL. In addition, the clear detections of numerous bright emission lines allow us to apply standard diagnostics of the star-formation rate (SFR), extinction, and metallicity to this galaxy.

4.1. Star-Formation Properties

Using the observed intensity ratio of Hα/Hβ, and assuming the Case B recombination value of 2.86 and the Cardelli et al. (1989) extinction law with $R_V = 3.1$, we estimate a reddening of $E(B-V) = 0.14 \pm 0.05$ mag. The values of the intensity ratios [N II]/Hα and [O III]/Hβ indicate that the prominent emission lines are due to recent vigorous star formation rather than to an active galactic nucleus (Baldwin et al. 1981). Furthermore, we do not detect any absorption features nor a Balmer break that may indicate the presence of

[7]The measured Hγ, Hβ, Hα, [O III] λ4959,[O III] λ5007, and [N II] λ6584 emission-line fluxes are 34.1±3.3, 88.5±3.6, 290.9±3.4, 81.5±3.2, 232.7±4.8, and $10.3 \pm 1.0 \times 10^{-17}$ erg s^{-1} cm^{-2} before extinction correction, respectively. Errors include statistical measurement uncertainties

an older stellar population.

From the measured rest-frame equivalent width of Hβ, $\mathrm{EW_{H\beta}} = 23.3 \pm 1$ Å, we derive an age of 6.4 ± 0.1 Myr for the young stellar population using the relations of Levesque et al. (2010, §3.4 and Table 4) and the measured metallicity of the host (for $Z = 0.004$; see below). From the measured integrated Hα emission-line flux, corrected for extinction, we obtain $L(\mathrm{H}\alpha) = (16 \pm 2) \times 10^{38}\,\mathrm{erg\,s^{-1}}$, which translates to $\mathrm{SFR(H\alpha)} = 0.013 \pm 0.002\,\mathrm{M_\odot\,yr^{-1}}$ using the conversion from Kennicutt (1998). Since the SDSS spectrum was obtained through a $3''$ diameter fiber encompassing an area of $0.55\,\mathrm{kpc^2}$ at the host-galaxy redshift, we measure a normalized SFR of $0.023 \pm 0.003\,\mathrm{M_\odot\,yr^{-1}\,kpc^{-2}}$. Since the Petrosian radius (from DR9) is $3.4''$, the fraction of global host-galaxy light entering the fiber, which is also at the SN position, is 20%.

4.2. Oxygen Abundance

For computing the oxygen abundance (Modjaz et al. 2011, and references therein), we correct the detected emission-line fluxes of [O III], [N II], Hβ, and Hα for reddening, and employ the scales of Pettini & Pagel (2004, PP04-O3N2) and of Kewley & Dopita (2002, KD02) to obtain values of $12 + \log(\mathrm{O/H})_{\mathrm{PP04-O3N2}} = 8.12^{+0.04}_{-0.02}$ and $12 + \log(\mathrm{O/H})_{\mathrm{KD02}} = 8.13^{+0.05}_{-0.04}$, respectively. We conclude that the metallicity of the host galaxy is 0.2–0.3 $\mathrm{Z_\odot}$, having used the solar oxygen abundance of $12 + \log(\mathrm{O/H}) = 8.69$ (Asplund et al. 2009).

The oxygen abundance of the PTF12gzk host is well below that of the hosts of normal SNe Ic found via untargeted surveys as presented by Modjaz et al. (2011; mean $12 + \log(\mathrm{O/H})_{\mathrm{PP04}} = 8.7 \pm 0.1$) and Sanders et al. (2012, $12 + \log(\mathrm{O/H})_{\mathrm{PP04}} = 8.61 \pm 0.2$). Indeed, it is much closer to that of the hosts of SNe Ic-BL and GRB-SNe (Modjaz et al. 2008; Sanders et al. 2012), and of SLSNe-I (Young et al. 2010; Stoll et al. 2011).

5. Discussion

PTF12gzk is a luminous SN Ic, at the high end of the SN Ic luminosity distribution (Drout et al. 2011). It exhibits a slow rise of 18 days to its peak r-band magnitude, with B peaking ~ 10 days earlier. This is a large gap relative to other SN I, though similar to SN 2004aw (Taubenberger et al. 2006); it is caused by metal-line absorption from heavy elements in the outer layers of the ejecta, as is evident from spectra taken after August 1.

A least-squares fit to a $f(t) \propto (t - t_0)^n$ behavior of our well-sampled early photometry places the explosion date between 10 and 40 hr prior to our discovery at the 95% confidence level[8]. We cannot rule out the popular quadratic fireball model, but higher values of n are possible as well for larger areas in the fit parameter space (Figure 1, bottom panels).

Spectroscopically, PTF12gzk exhibits high expansion velocities, $\sim 30,000\,\mathrm{km\,s^{-1}}$ (Si II absorption velocity). Other SNe Ic with similar velocities are broad-lined SNe Ic (Figure 4), some of which are associated with GRBs (Woosley & Bloom 2006, and references within), while no such association was determined for PTF12gzk (see also SN 2009bb; Soderberg et al. 2009). Most similar is SN 2003lw, a SN associated with a GRB (Mazzali et al. 2006a). A possible explanation is a burst misaligned with our line of sight, or a failed GRB. Such a scenario is further supported by the host-galaxy characteristics, resembling those of a broad-lined SN Ic host galaxy. We know of no typical SN Ic exploding in a host with similar luminosity and oxygen abundance. The observed relatively narrow lines give a dispersion of $\Delta v/v \approx 0.25$, compared to ~ 1 in the case of broad-lined SNe Ic, and may suggest a nonspherical explosion geometry (Leonard et al. 2006), or that the ejecta mass is high or has a very steep density gradient (a discussion on the effects of a steep density gradient on the LC can be found in Piro & Nakar 2012). Late-time, nebular spectra will probe the geometry of the explosion in more detail.

From the Si II line velocity at peak brightness of PTF12gzk (15,300 $\mathrm{km\,s^{-1}}$ from the August 12 spectrum) and SN 2004aw (12,400 $\mathrm{km\,s^{-1}}$; Deng et al., in prep.), and the rise time of these two SNe, we use the following scaling relations (Arnett 1982; Mazzali et al. 2009; see also Mazzali et al., in prep.) to estimate the physical properties of PTF12gzk: $\tau \approx \kappa^{1/2}\mathrm{M}^{3/4}\mathrm{E}^{-1/4}$ and $v = (2E/M)^{1/2}$, where τ is the light-curve rise time, E is the kinetic energy, and κ is the opacity. The derived ejecta mass is $7.5\,\mathrm{M}_\odot$ (6–$12\,\mathrm{M}_\odot$), pointing to a large initial progenitor mass of 25–$35\,\mathrm{M}_\odot$, though the latter values are highly uncertain (Mazzali et al. 2000). We derive a kinetic energy of 7.5×10^{51} erg [(5–10) $\times 10^{51}$ erg]. Using L_{max} and t_{max} we get an estimated ^{56}Ni mass of $0.37\,\mathrm{M}_\odot$ (scaling the PTF12gzk light curve to that of SN 2003dh; Mazzali et al. 2003). Using the V-band peak magnitude vs. nickel mass relation presented by Perets et al. (2010), we derive a ^{56}Ni mass of $0.35\,\mathrm{M}_\odot$, in agreement with the results derived from the scaling relations. These physical properties, as well as the high expansion velocities and the host galaxy, are unlike those of normal SNe Ic, which typically occur in large hosts and have low ejecta masses, and kinetic energies, ($1.7\,\mathrm{M}_\odot$, and 10^{51} erg Drout et al. 2011. For nickel mass in Type Ic SNe see for example Taubenberger et al. 2006, and Sauer et al. 2006). Instead, they are reminiscent of GRB-SNe (Mazzali et al. 2009).

PTF12gzk is a remarkable example of a SN Ic in terms of expansion velocities, evolution

[8]The fireball models can at best give an underestimate on the explosion date, since they do not incorporate the photon diffusion time.

timescale, the ejected mass, and the kinetic energy released in the explosion. We conclude that these properties point to the explosion of a massive star deficient in H and He, at the higher-mass end of SN Ic progenitors. This further illustrates the peculiar population of SNe Ic exploding in dwarf hosts (Arcavi et al. 2010), as seen also in the case of GRB-SNe and most SLSNe-I.

PTF12gzk demonstrates the advantages of using an untargeted sky survey such as PTF with an extensive network of instruments and telescopes in various wavebands to detect and rapidly characterize unusual cases of cosmic explosions.

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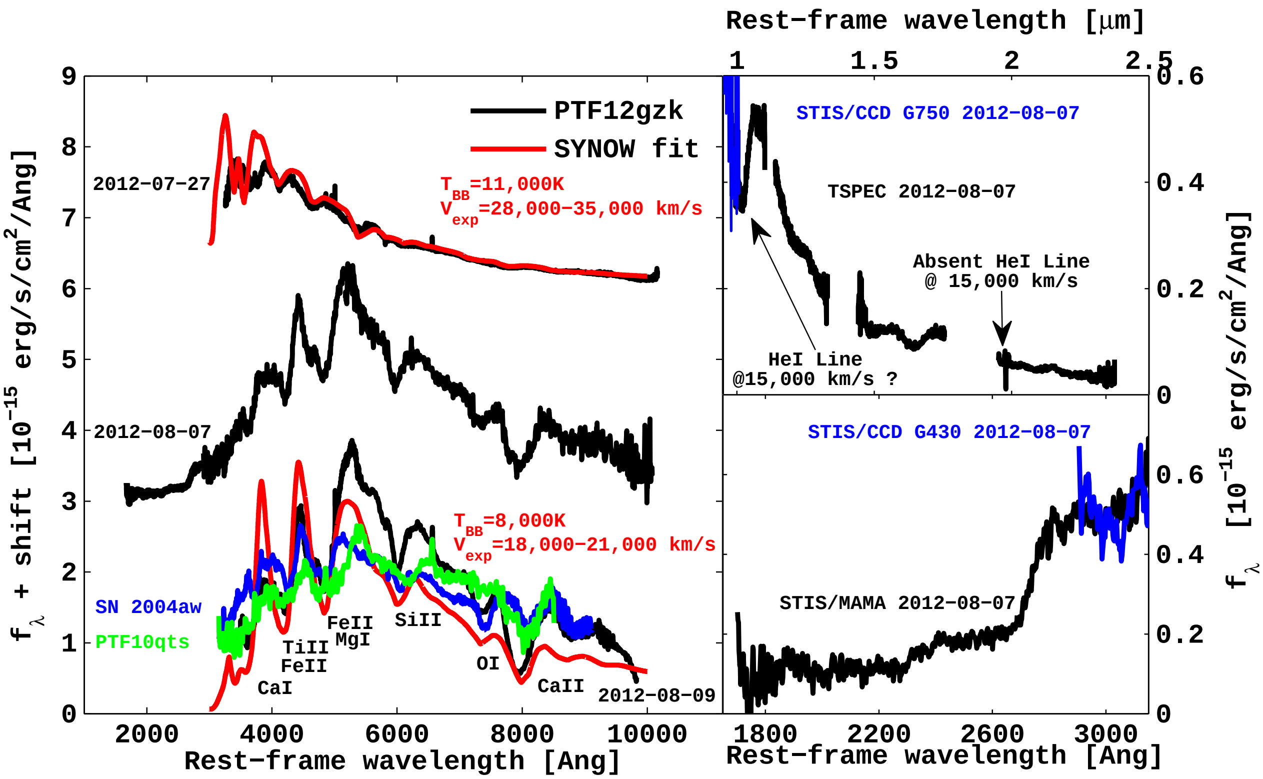

Fig. 3.— **Left:** Spectroscopic analysis; top to bottom. The DBSP spectrum taken on July 27. An *HST* STIS/MAMA and STIS/CCD (G430 and G750) spectrum taken on August 7. A Lick/Kast spectrum taken on August 9. The continuum is consistent with blackbody temperatures of 11,000 K and 8000 K in the July 27 and August 9 spectra, respectively. A SYNOW fit shows that the July 27 spectrum is dominated by Ca II, Ti II, and Fe II lines at velocities of 35,000 km s^{-1}, and by O I, Mg II, and Si II at 28,000 km s^{-1}; the corresponding velocities for the August 9 spectrum are 21,000 and 18,000 km s^{-1}. The best match suggested by SNID(Blondin & Tonry 2007) is to a spectrum of SN 2004aw near peak brightness (blue curve). A good match is also obtained for PTF10qts, a Type Ic-BL SN, at $\sim$ 30 days after explosion. **Top right:** The Palomar 5-m TSPEC IR spectrum obtained on August 7, together with the long-wavelength end of the *HST* STIS/CCD spectrum. **Bottom right:** The *HST* STIS/MAMA UV spectrum taken on August 7. The flux deficit with respect to a blackbody spectrum indicates strong line blanketing, evidence for a highly mixed outer envelope.

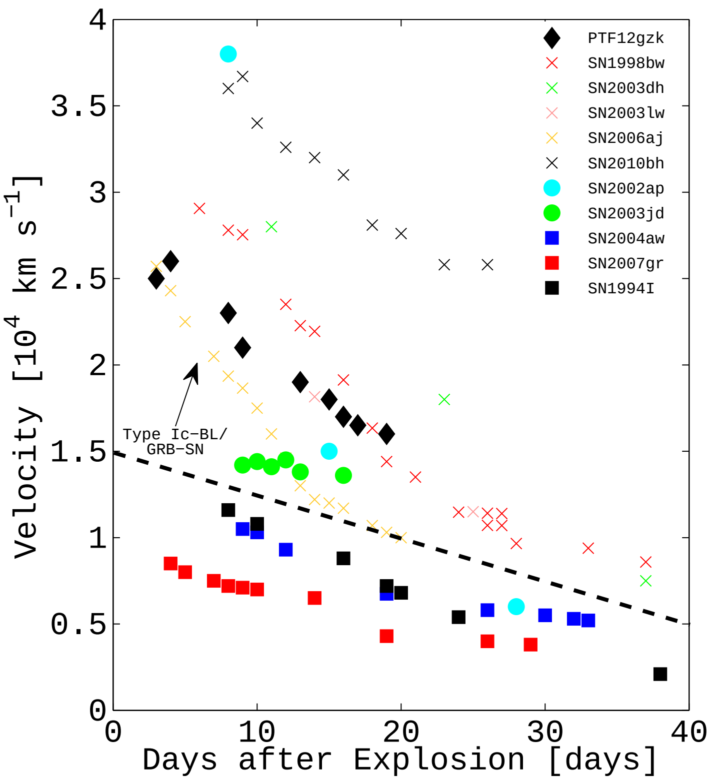

Fig. 4.— PTF12gzk has characteristic velocities of a broad-lined SN Ic. All SNe above the dashed line, besides PTF12gzk, are GRB-SNe (Xs) or Type Ic-BL with no GRB association (circles), while those below it are normal SNe Ic (squares). Velocities are obtained through modeling of the spectrum or through direct measurements of the Si II 6355 Å line (SNe 2010bh, 2002ap, 2003jd, 2004aw, and 2007gr).

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