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INTERACTING SUPERNOVAE AND SUPERNOVA IMPOSTORS. I. SN 2009IP, IS THIS THE END?

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ABSTRACT

We report the results of a 3 year-long dedicated monitoring campaign of a restless Luminous Blue Variable (LBV) in NGC 7259. The object, named SN 2009ip, was observed photometrically and spectroscopically in the optical and near-infrared domains. We monitored a number of erupting episodes in the past few years, and increased the density of our observations during eruptive episodes. In this paper we present the full historical data set from 2009-2012 with multi-wavelength dense coverage of the two high luminosity events between August - September 2012. We construct bolometric light curves and measure the total luminosities of these eruptive or explosive events. We label them the 2012a event (lasting $\sim$50 days) with a peak of 3×10^{41} ergs^{-1}, and the 2012b event (14 day rise time, still ongoing) with a peak of 8×10^{42} ergs^{-1}. The latter event has reached an absolute R-band magnitude of about -18, comparable in brightness and luminosity to that of a core-collapse supernova (SN). Our historical monitoring has detected high-velocity spectral features ($\sim$13000 km s^{-1}) in September 2011, one year before the current SN-like event. This suggests that the detection of such high velocity outflows cannot, conclusively, point to a core-collapse SN origin. We suggest that the initial peak in the 2012a event was unlikely to be due to a faint core-collapse SN. We propose that the high intrinsic luminosity of the latest peak, the variability history of SN 2009ip, and the detection of broad spectral lines indicative of high-velocity ejecta are consistent with a pulsational pair-instability event, in which the star may have survived the last outburst. The question of the survival of the LBV progenitor star and its future fate remain open issues, only to be answered with future monitoring of this historically unique explosion.

Subject headings: supernovae: general — supernovae: individual (SN 2009ip), supernovae: individual (SN 2000ch)

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1. INTRODUCTION

Luminous Blue Variables (LBVs) are among the most luminous and massive stars found in late-type galaxies. In a few cases, these stars have been observed to produce major eruptions that mimic a genuine supernova (SN) explosion. For this reason, they gained the label of SN impostors (Van Dyk et al. 2000). The discrimination between SN impostors (i.e. LBV-type eruptions) and type IIn SNe can be ambiguous (see e.g. the SN 2011ht-like objects, Roming et al. 2012; Mauerhan et al. 2012a; Humphreys et al. 2012; Kankare et al. 2012; Dessart et al. 2009; Chugai et al. 2004).

LBVs have been widely studied in the Milky Way, Local Group galaxies and beyond (e.g. Humphreys & Davidson 1994; Humphreys et al. 1999; Maund et al. 2006; Smith et al. 2011b). They have high mass-loss rates and frequently show what is known as S-Doradus variability during which mass-loss is enhanced, possibly due to temperature changes and ionization balance of atomic species that drive the wind (Vink & de Koter 2002). Giant eruptions have been observed during which several solar masses of material can be ejected and the intrinsic stellar luminosity increases substantially. The physical mechanism that triggers these giant eruptions is still unknown. Based on analysis of SN data, a link between *some* LBVs and SNe IIn has been proposed (see e.g. Kotak & Vink 2006; Smith & Owocki 2006; Smith et al. 2007; Trundle et al. 2008, 2009). There is one case (SN 2005gl) in which a likely LBV has been observed to explode as luminous SNe IIn (Gal-Yam et al. 2007; Gal-Yam & Leonard 2009), and one other case (SN 2010jl) for which there is a plausible argument for a massive progenitor star of a type IIn SN (M > 30 $M_\odot$, Smith et al. 2011a). [25]

In an exciting turn of events, a well observed LBV in the spiral galaxy NGC 7259 (designated as SN 2009ip during a giant outburst in 2009) has recently been proposed to have now exploded as a core-collapse SN (Mauerhan et al. 2012b, and references therein). The object was first discovered on August 26, 2009 by the CHASE SN Search (Maza et al. 2009) as a faint transient at ≈ 17.9 mag, and was later classified as a SN impostor by a number of teams (Miller et al. 2009; Li et al. 2009; Berger et al. 2009). The nature of SN 2009ip was widely discussed in Smith et al. (2010, 2011b) and Foley et al. (2011). Through the analysis of pre-outburst archival HST images these studies provided robust evidence that the progenitor was a very massive star (M_{ZAMS} > 60 $M_\odot$) that experienced repeated eruptions typical of the LBV phase.

Subsequent re-brightenings were announced by the Catalina Real-Time Survey team on October 1, 2010 (Drake et al. 2010) and, very recently, on July 24, 2012 (Drake et al. 2012), which were first labeled as new LBV-type eruptions (e.g. Foley et al. 2012). However, from the detection of high-velocity spectral features on September 15 and 16, 2012 Smith & Mauerhan (2012a) first mentioned the possibility that SN 2009ip exploded as a real core-collapse SN [26]. High-cadence optical imaging in the R and I bands showing the strong September 2012 re-brightening has been presented by Prieto et al. (2012b). We also note that no (Margutti et al. 2012a,b; Chandra & Soderberg 2012; Hancock et al. 2012) or marginal (Campana 2012; Margutti & Soderberg 2012) X-ray and radio detections of SN 2009ip have been reported so far.

In this paper we present observations of the LBV known as SN 2009ip in NGC 7259 over a period of 3 yrs including: **i)** data showing erratic variability starting from August 2009, when the object closely resembled NGC 3432-LBV1 (aka SN 2000ch, Wagner et al. 2004; Pastorello et al. 2010), a SN impostor that experienced multiple energetic outbursts. Our data of SN 2009ip also include observations of repeated outbursts during the period May to October 2011 which have not been reported to date; **ii)** the recent evolution of the LBV as a putative SN.

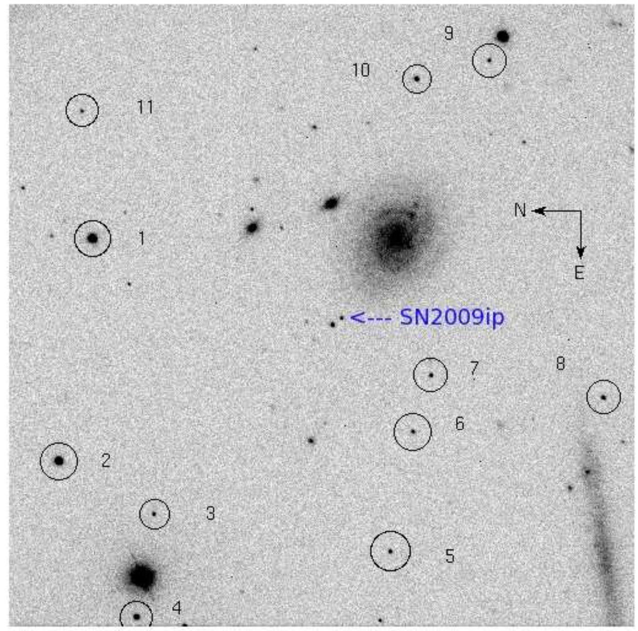

FIG. 1.— SN 2009ip in NGC 7259, and reference stars in the host galaxy field.

2. OBSERVATIONS

Three years ago, after the first announcement of the discovery of a transient in NGC 7259 (Maza et al. 2009), we initiated an extensive spectroscopic and photometric monitoring campaign in the optical bands using a number of telescopes available to our collaboration. After about 100 days, the follow-up strategy was relaxed and the photometric monitoring was limited to the R band.

[25] We note that eruptions of Wolf-Rayet stars producing impostors with a luminosity similar to that of an LBV outburst have later on been observed to explode as He-rich Ibn SNe (Pastorello et al. 2007, 2008a; Foley et al. 2007) or hybrid IIn/Ibn events (Pastorello et al. 2008b; Smith et al. 2012).

[26] We note that after the Smith & Mauerhan communication there has been a proliferation of electronic telegrams on this transient, with different interpretations on its nature - SN vs. SN impostor - (Margutti et al. 2012a; Martin et al. 2012a; Brimacombe 2012; Margutti et al. 2012b; Smith & Mauerhan 2012b; Leonard et al. 2012; Burgasser et al. 2012; Vinko et al. 2012; Prieto et al. 2012a; Martin et al. 2012b; Gall et al. 2012; Bohlsen 2012), although it is quite clear that most authors now favor the SN explosion scenario.

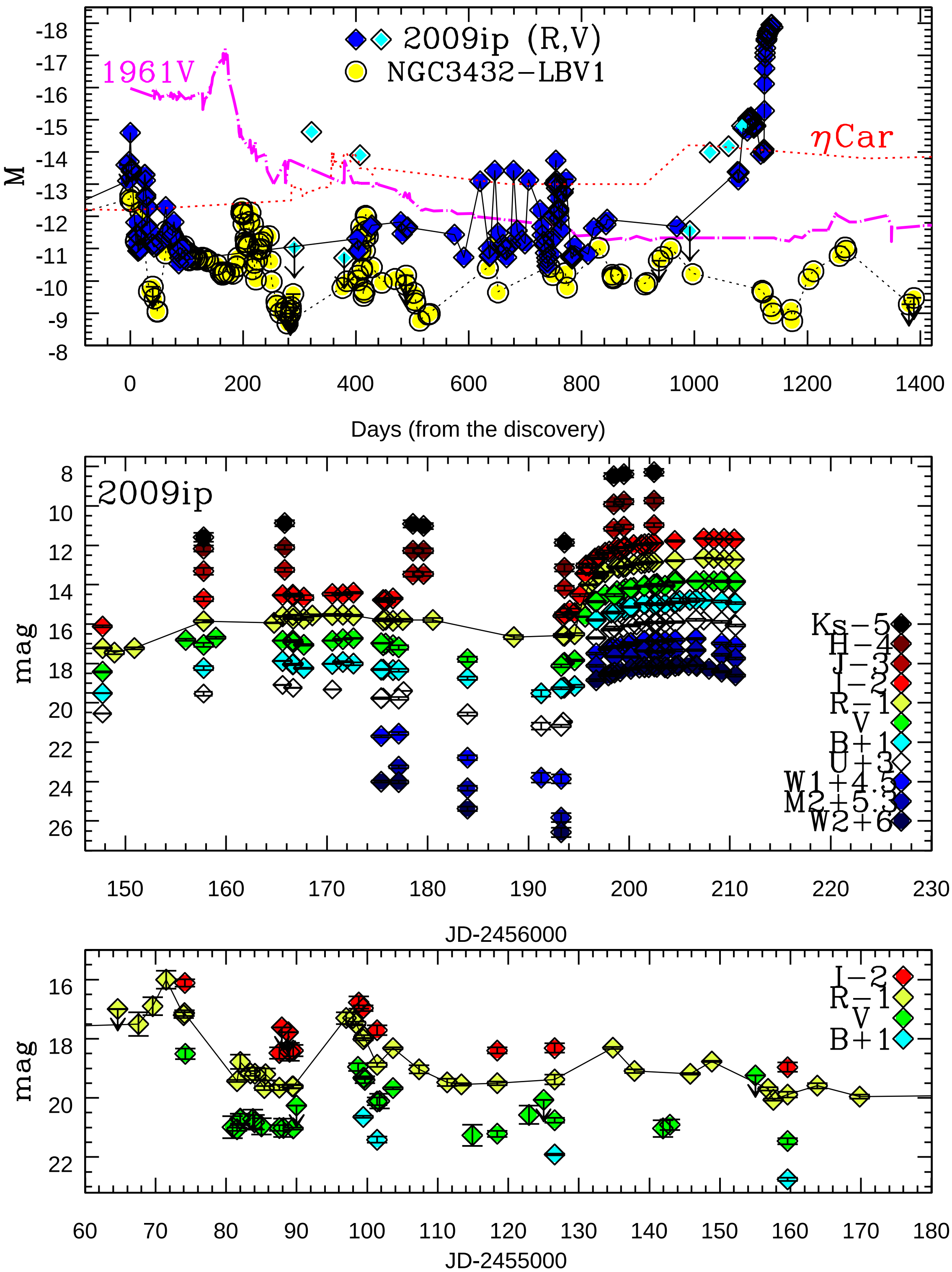

FIG. 2.— **Top:** R-band absolute light curve of SN 2009ip (blue diamonds) compared with those of the impostor NGC 3432-LBV1 (yellow circles), the debated SN/impostor 1961V (photographic plate magnitudes, magenta dot-dashed line) and the historical visual light curve of η Carinae during the period 1842-1845 (revised by Smith & Frew 2011, red dotted line). The cyan diamonds represent CRTS V-band measurements (see also Drake et al. 2010, 2012). The data showing NGC 3432-LBV1 during the period 2008-2012 are from Pastorello et al. (2010), plus additional recent unpublished observations (see Appendix). The epoch 0 of the η Carinae light curve is year 1842.213 (UT). The erratic photometric variability is a common property of major eruptions of LBVs. **Middle:** Ultra-violet/optical/near-infrared apparent light curves of the transient from Aug 8, 2012, 2 weeks before the publication of the announcement of a new re-brightening from Drake et al. (2012). Shifts of $\Delta U = +0.27$, $\Delta B = +0.018$ and $\Delta V = -0.042$ have been applied to the u,b,v Swift/UVOT magnitudes of SN 2009ip to match the U,B,V Johnson photometry. The shifts have been computed after a comparison of the magnitudes of the reference stars in the SN field in the two photometric systems. **Bottom:** BVRI light curves of the impostor SN 2009ip during the first 3 months from the first ever detection in 2009 (Maza et al. 2009).

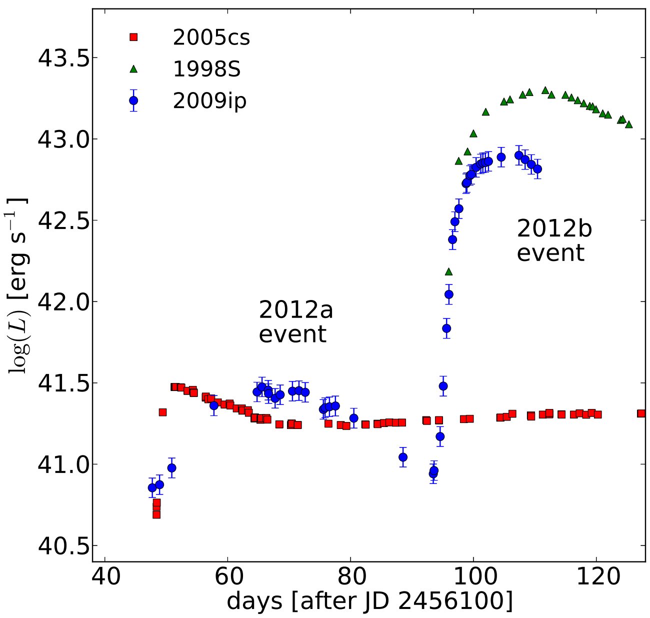

FIG. 3.— Bolometric light curve of SN 2009ip from August to October 2012 (showing both the 2012a and 2012b events), compared with the bolometric light curves of the faint type IIP SN 2005cs (Brown et al. 2007; Pastorello et al. 2006, 2009) and the type IIn/IIL SN 1998S (Liu et al. 200; Fassia et al. 2000; Gerardy et al. 2002; Pozzo et al. 2004). The light curves of SNe 2005cs and 1998S are shown in an arbitrary temporal scale to well match respectively the 2012a and 2012b eruptive events of SN 2009ip.

Due to its unpredictable behavior, we kept up a monitoring campaign of this object during the following 3 years.

After the recent re-brightening of SN 2009ip announced by the Catalina Real-Time Survey team on July 24, 2012 (Drake et al. 2012), we intensified our observing cadence and secured multi-color photometry and spectroscopy from the optical to the near-IR domains. In addition, SWIFT optical and ultra-violet observations have been triggered (PIs: R. Margutti and P. W. A. Roming) and included in our analysis[27], particularly to give a wide wavelength bolometric light curve of the 2012 eruptions.

2.1. *Photometry*

SN 2009ip is located close to a red (R = 18.05 ± 0.04, R-I = 0.72 ± 0.05) foreground star, in a remote position North-East of the host galaxy (Figure 1). Our photometric measurements were performed using the PSF-fitting technique, with the simultaneous fit of the transient and the nearby star. A number of reference stars in the SN field were calibrated using observations of standard fields from the catalog of Landolt (1992), and used to improve the photometric calibration of SN 2009ip in non-photometric nights. The final photometry of the transient and the magnitudes of the reference stars are listed in Appendix[28].

The R-band absolute light curve of SN 2009ip starting from August 2009 and spanning a period of more than 3 years is shown in Figure 2 (Top panel) along with that of a similar event, NGC 3432-LBV1 (Pastorello et al. 2010), the debated transient (SN or impostor) 1961V (photographic mags, Bertola 1963, 1964, 1965, 1967) and the revised visual light curve of the Giant Eruption of η Carinae in 1842-1845 (see Smith et al. 2011b, and references therein). The same distance modulus ($\mu = 31.55$ mag) and interstellar extinction ($A_R = 0.051$) adopted by Smith et al. (2010) and Mauerhan et al. (2012b) for SN 2009ip have been used in the absolute R-band light curve of Figure 2. The erratic light curves of all these transients show similar features. SN 2009ip experienced a few intense eruptive phases, including those on August-September 2009 and from May to October 2011, characterized by a sequence of sharp luminosity peaks followed by rapid magnitude declines; the multi-band light curve of the 2009 event covering a period of about 3 months is shown in the bottom panel. The 2009 eruptive phase presents the erratic evolution typical of on LBV-type giant eruption, and is very similar to those observed in the Giant Eruption of η Carinae and in NGC 3432-LBV1.

Other re-brightenings were registered by CRTS (to magnitudes V$\sim$ 17 on Jul 15, 2010, and V$\sim$ 17.7 on Sep 29, 2010, Drake et al. 2010, shown as cyan diamonds in Figure 2, top). Older records (before August 2009) from the CRTS archive[29] and from Smith et al. (2010) have never registered the transient at a magnitude brighter than about $\sim$ 20.4. These new data are more comprehensive, and reveal a recent variability history for SN 2009ip which is more complex than one can infer from the schematic light curve representation of Mauerhan et al. (2012b).

During July-August 2012 a new re-brightening was announced by Drake et al. (2012, cyan diamonds in Figure 2, top). This event was then followed by a strong unprecedented burst (starting around September 23) which is about 30 times more luminous than the previous oscillations. This SN-like rise in luminosity will be extensively discussed later in this paper. The phase between August to October 2012 is shown in the middle panel of Figure 2, with panchromatic light curves of SN 2009ip obtained with the ground-based telescopes and the SWIFT satellite.

Figure 3 shows the bolometric light curve of SN 2009ip from the August 2012 re-brightening announced by Drake et al. (2012) to the current epoch. It appears to show 2 distinct phases: a broader (and fainter) earlier peak (that we will label as “2012a event” for simplicity), that ends around September 23 and reaches a luminosity of 3×10^{41} erg s^{-1}, and a fast-rising, higher luminosity second peak (“2012b event”) with a maximum at about 8×10^{42} erg s^{-1}. Mauerhan et al.

[27] Independent measurements using the images from the same dataset were published in Mauerhan et al. (2012b).

[28] We find excellent agreement with the CRTS and Prieto et al. (2012b) photometry, while the data of Mauerhan et al. (2012b, see their Table 2) show a large and significant discrepancy with our photometry. In particular, the photometry of SN 2009ip from Mauerhan et al. (2012b) is too faint by more than 2 mags in the B band and 0.3 in the I band. The R-band data are in reasonable agreement to the order of a few hundredths of a magnitude. Hence the average B-R color computed with the Mauerhan et al. photometry is $\sim$ 2.5, vs. B-R $\sim$ 0.5-0.7 that is calculated with our data. We are confident that our calibration is correct because we used standard photometric calibration procedures based on the Landolt catalog, and our photometry provides blue colors that are in agreement with the very blue spectral continuum of this transient.

[29] http://nesssi.cacr.caltech.edu/catalina/current.html

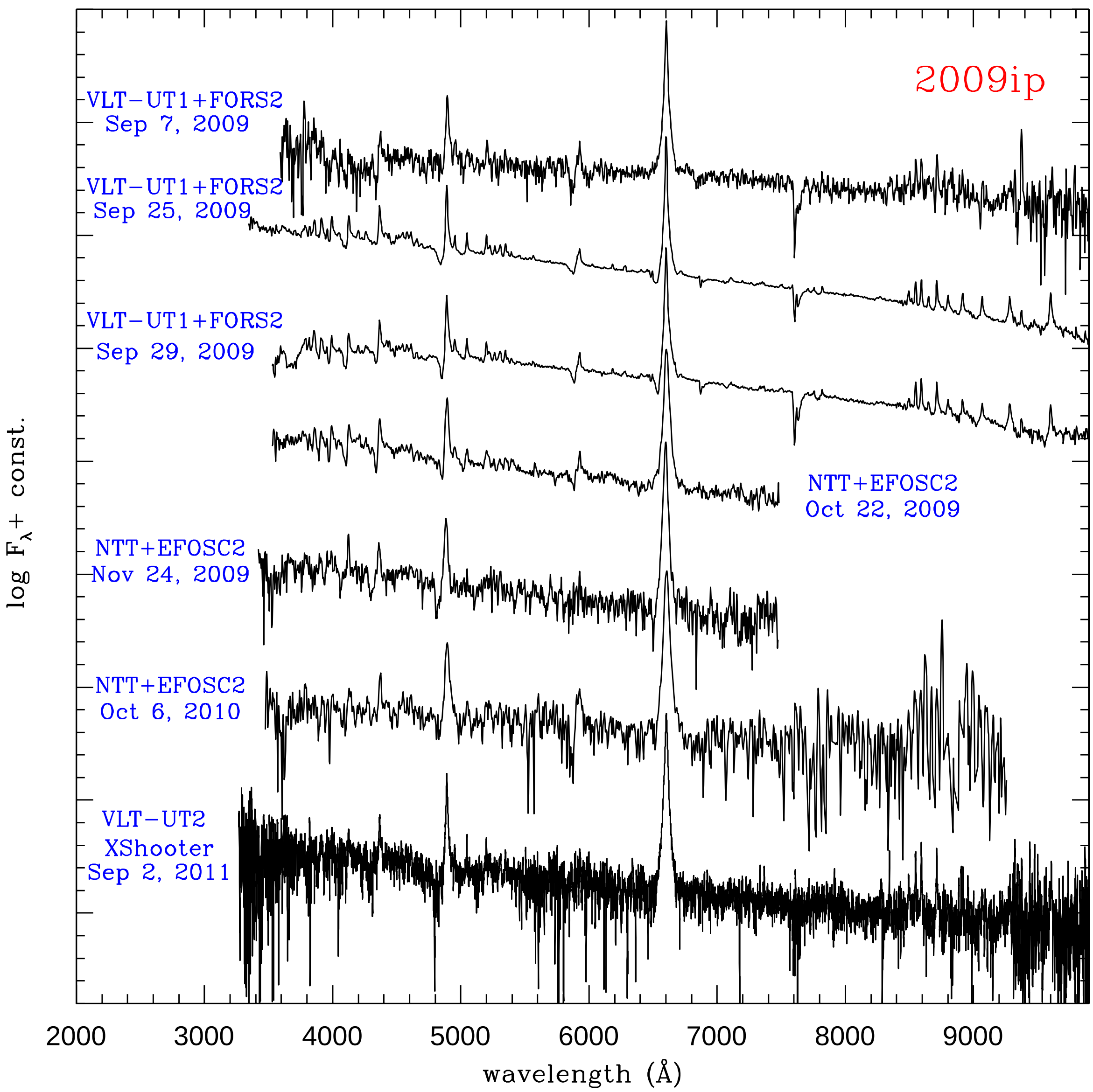

FIG. 4.— Sequence of spectra of the LBV in NGC 7259, obtained from September 2009 to September 2011. All spectra are in the host galaxy wavelength frame.

(2012b) noted that the maximum luminosity of the 2012a event is consistent with the luminosity of a faint SN IIP (Pastorello et al. 2004), although with a faster evolving light curve. Along with spectral similarities, this led Mauerhan et al. (2012b) to suggest that the 2012a event was the true core-collapse SN event of the LBV star. We confirm that the bolometric luminosity of the 2012a event is similar to SN 2005cs, as one can note from Figure 3. The subsequent faster rise to the second peak (the 2012b event) presents an even tighter similarity with that of the type IIn/IIL SN 1998S. The 2012b event was proposed by Mauerhan et al. (2012b) to be due to strong SN ejecta-CSM interaction. We measure a 2 week long rise-time, reaching a peak apparent magnitude of B = 13.80 (R = 13.65) on October 6, 2012 and then it declines in luminosity, more rapidly in the ultra-violet and the blue optical bands. We will see in Section 3 that the 2012a and 2012b sequence of events may have an alternative explanation.

We also remark that none of the comparison objects in Figure 2 shows the regular, SN-like light curve that characterized SN 2009ip during the 2012b event. This late photometric evolution combined with the bright luminous peak ($M_R \approx$ -18) may support the claim that *at least* during the 2012b event SN 2009ip has finally exploded as a real supernova. We note that the color of SN 2009ip at the light curve peak (on October 6, 2012) is U-V $\approx$ -1 mag, significantly bluer than that of the 2012a event at maximum (U-V $\approx$ -0.5 mag). At the pre-burst minimum of September 23, the U-V color was instead

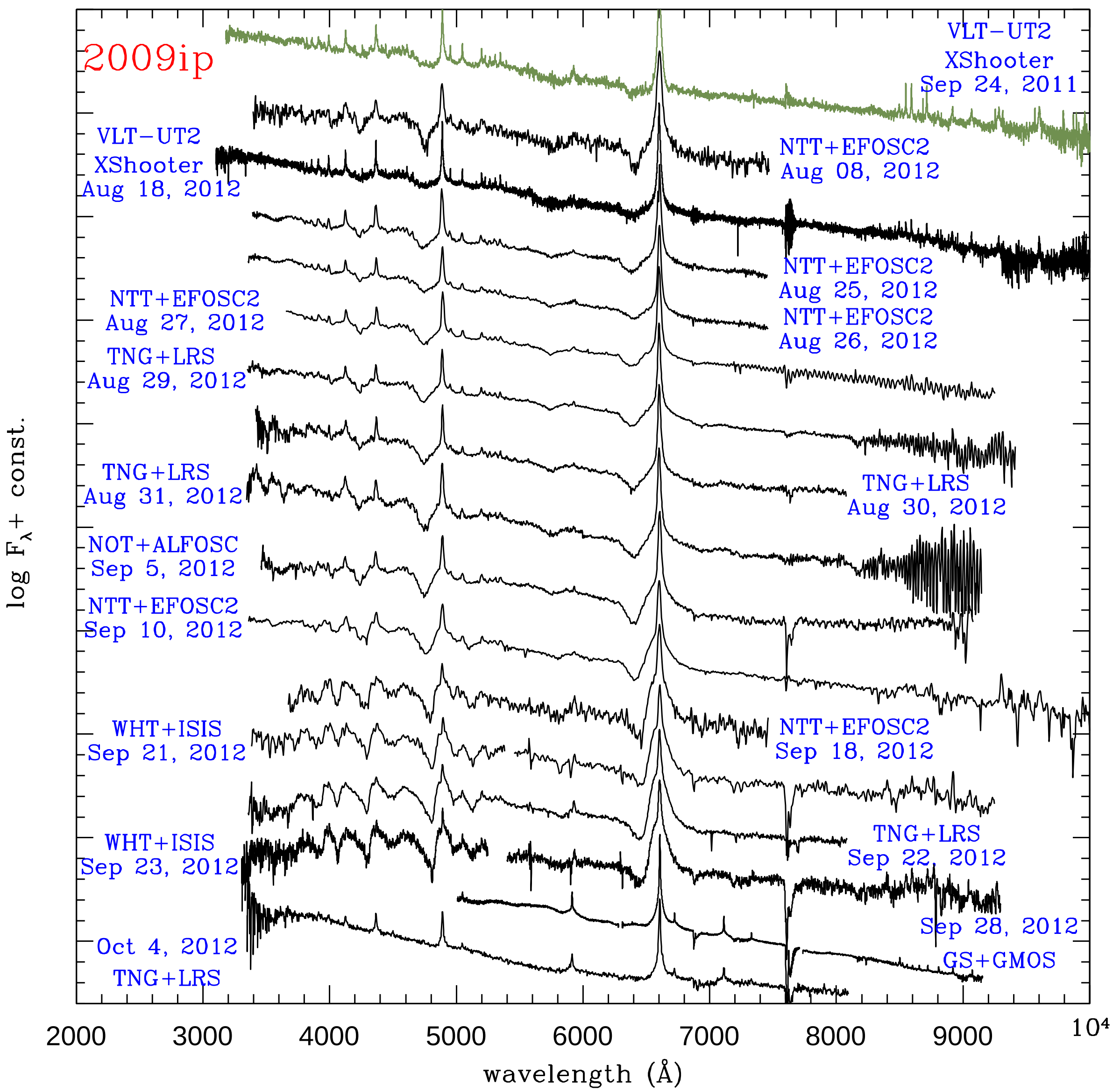

FIG. 5.— Sequence of spectra obtained between August and September 2012, including those of the putative SN explosion. A higher resolution XShooter spectrum obtained on September 24, 2011, i.e. before the 2012 re-brightening, is also shown at the top of the sequence (green color). All spectra are all in the host galaxy wavelength frame.

significantly redder, i.e. $\approx$ 0 mag.

2.2. *Spectroscopy*

Optical and near-infrared spectra of SN 2009ip (Figures 4, 5, 6 and 7; the log of observations is in Appendix) were collected using the 8.2-m Very Large Telescope (VLT) UT1 (+ FORS) and UT2 (+XShooter) at the Cerro Paranal Observatory (ESO Chile), the 3.58-m ESO-NTT (+ EFOSC2 and SOFI) at the La Silla Observatory (ESO Chile), the 8.2-m Gemini South Telescope (with GMOS) in Cerro Pachón (Chile), the 3.58-m Telescopio Nazionale Galileo (TNG, equipped with LRS), the 4.2-m William Herschel Telescope (WHT, with ISIS) and the 2.56-m Nordic Optical Telescope (+ ALFOSC) located in La Palma (Canary Islands, Spain).

The spectra relative to the 2009 outburst reported in Figure 4 are all dominated by prominent Balmer lines with a complex profile. The weak absorption features indicate that the bulk of the ejected material is moving with a velocity of 2900 $\pm$ 700 km s^{-1}, but the blue edge of the isolated Hβ absorption suggests the presence of fast-moving material which is expanding at a velocity of about 5000-6000 km s^{-1}. The Hα emission component in September 2009 has a Lorentzian profile with a FWHM velocity of about 700-800 km s^{-1}, which increases to about 1100-1200 km s^{-1} during the period October-November, 2009 (when the object was receding to a more quiescent stage).

After a further outburst (September 2010) reported by

Drake et al. (2010), a spectrum obtained on October 6, 2010 shows SN 2009ip at a similar stage as the November 24, 2009 spectrum, i.e. with the star again quiescent. The FWHM velocity of the Lorentzian Hα component in this phase is still around 1300 km s^{-1}. The September 2, 2011 VLT spectrum reported at the bottom of Figure 4 shows SN 2009ip to be back to a dormant stage, and the FWHM velocity of the Lorentzian Hα component is about 940 km s^{-1}.

Figure 5 shows the spectra of the transient during the period August-October 2012, compared with a VLT spectrum obtained on September 24, 2011 (green line), during another outburst episode. In the September 24, 2011 spectrum, the FWHM velocity of Hα, which still has a Lorentzian profile, has slightly decreased to around 790 km s^{-1}, and other Balmer lines clearly show very broad absorption components, with a blue edge that indicates that there is material moving with a velocity as high as 12500 km s^{-1} *already* at this epoch (see also Figure 6). This is the highest velocity outflow that has been detected in an LBV-like eruption of any sort and indicates that high velocities are observed without core-collapse or the catastrophic destruction of the star. This has important consequences for the interpretation of high velocity ejecta as evidence for the core-collapse mechanism in the 2012a event. We subsequently obtained an NTT spectrum on August 8, 2012 (JD = 2456148.91, i.e. 10 days before the new outburst - the 2012a event - was announced by Drake et al. 2012). The broad absorption features were present also at this epoch, and indeed were stronger than in the September 24, 2011 spectrum (Figure 5). The minimum of the broad absorption components of the Balmer lines has a core at 8600 $\pm$ 400 km s^{-1}, with a blue wing extending up to 14000 km s^{-1}, while the Lorentzian emission survives at a FWHM velocity of about 1380 km s^{-1}. The presence of these components was observed in September 15 and 16, 2012 spectra by Smith & Mauerhan (2012a), and this was the critical measurement that led the authors to propose that the LBV had exploded as a core-collapse SN, i.e. that the 2012a event was due to stellar core-collapse and an explosion with fairly low kinetic energy like SN 2005cs.

Our spectra collected between August 18 and September 5, 2012 show little evolution: the H features show prominent P-Cygni profiles, with deep minima at 8000-9000 km s^{-1} and edges possibly extending to 14000-15000 km s^{-1}. The Hα narrow emission component still has a FWHM velocity of 800 $\pm$ 100 km s^{-1}, while the highest resolution spectra allow us to measure the FWHM velocity from the clearly detected narrow Fe II emissions (multiplet 42) to be about 240 $\pm$ 20 km s^{-1}.

As highlighted by Mauerhan et al. (2012b), the spectra from September 10 to 23 (2012a event) do closely resemble those of type II SNe (the similarity with early spectra of the under-luminous type IIP SN 2005cs shown in their Figure 2 is remarkable). Both H and Fe II lines now show broad P-Cygni profiles with a prominent broad emission component. However we now present spectra of the 2012a event covering a period from August 8, 2012 to September 23, 2012 (47 days), and we do not observe the typical evolution of a type II SN over this period. In particular, 15-20 days after explosion, type II-P SNe develop the strong, broad near-infrared Ca II triplet feature (Pastorello et al. 2006), but we don't observe this for the 2012a event. The cores of the absorptions of the Balmer features indicate expansion velocity of the ejected material of $\sim$ 5000-6000 km s^{-1} (4200 $\pm$ 500 km s^{-1} from the Fe II lines), but the blue edge of the wings still reach to much higher velocities (about 13800 km s^{-1}). Figure 6 (top) shows a comparison of SN 2009ip at 3 representative epochs (September 24, 2011; August 8 and September 28, 2012) with a spectrum of NGC 3432-LBV1 in outburst (April 24 2009). The high velocity P-Cygni absorption (in the Balmer lines) is certainly stronger in the 2012a event than we observed in 2011 and in NGC3432-LBV1 in outburst, but we illustrate here that the detection of high velocity gas is not only restricted to core-collapse SNe. Similar high velocity edges are clearly detected in SN 2009ip in 2011 (13800 km s^{-1}) and in NGC3432-LBV1 ($\sim$9000 km s^{-1}, Pastorello et al. 2010). We will discuss the implications of this in Section 3.

These broad absorptions disappear at the time of the 2012b event, in September 28 and October 4 spectra (Figures 5 & 6, top), when the luminosity of SN 2009ip reaches the unprecedented maximum. At these times, the spectra are very similar to those of many type IIn SNe (e.g. SN 1999el, Di Carlo et al. 2002), with the H lines presenting a narrow emission component with a FWHM velocity of about 290 km s^{-1} and very broad wings ($\sim$3600 km s^{-1}). Similar velocities are measured in the He I lines, which are now more prominent than in past spectra, whilst the Fe II lines are no longer visible.

The spectrum of SN 2009ip obtained on 25 September 2009 with VLT-UT1 equipped with FORS2 has a very high signal-to-noise ratio. This gives us the opportunity to identify the most important lines in the spectrum of SN 2009ip (Figure 6, bottom). The spectrum is dominated by strong Balmer and Paschen lines of H, showing weak and narrow (2850 $\pm$ 490 km s^{-1}) P-Cygni profiles. Weak He I lines (being the 5876Å feature blended with Na I D 5890-5896 Å) and a number of Fe II multiplet lines are also detected. We note that in the September 28, 2012 spectrum of SN 2009ip (during the 2012b outburst, Figure 6), the spectral properties are quite similar to those observed in the afore-mentioned VLT spectrum, although the detection of Fe II lines is not obvious. Most of these lines are also visible in the spectrum of the impostor NGC3432-LBV1 shown as a comparison, with quite similar velocity of the narrow components ($\leq$ 650 km s^{-1}). Narrow O I and Ca II lines are relatively prominent in SN 2009ip, while they were not unambiguously detected in NGC 3432-LBV1 (although this might be due to the lower signal-to-noise spectrum).

A sequence of near-infrared spectra of SN 2009ip is shown in Figure 7. The continuum is always quite blue in these spectra. The strongest lines are detected as broad features with P-Cygni profiles, and narrower emissions superimposed to the broad components. The broad P-Cygni components become more evident with time and in the September 23, 2012 spectrum (at the time of the onset of the 2012b eruption) they dominate over the narrow lines. We identify Br γ at 2165 nm, Pa α (that is barely visible in the middle of the telluric absorption around 1875 nm), Pa β at 1282 nm and Pa γ at 1094 nm, blended with He I 1083 nm. The September 23, 2012 spectrum, in particular, shows a broad Pa β with FWHM veloc-

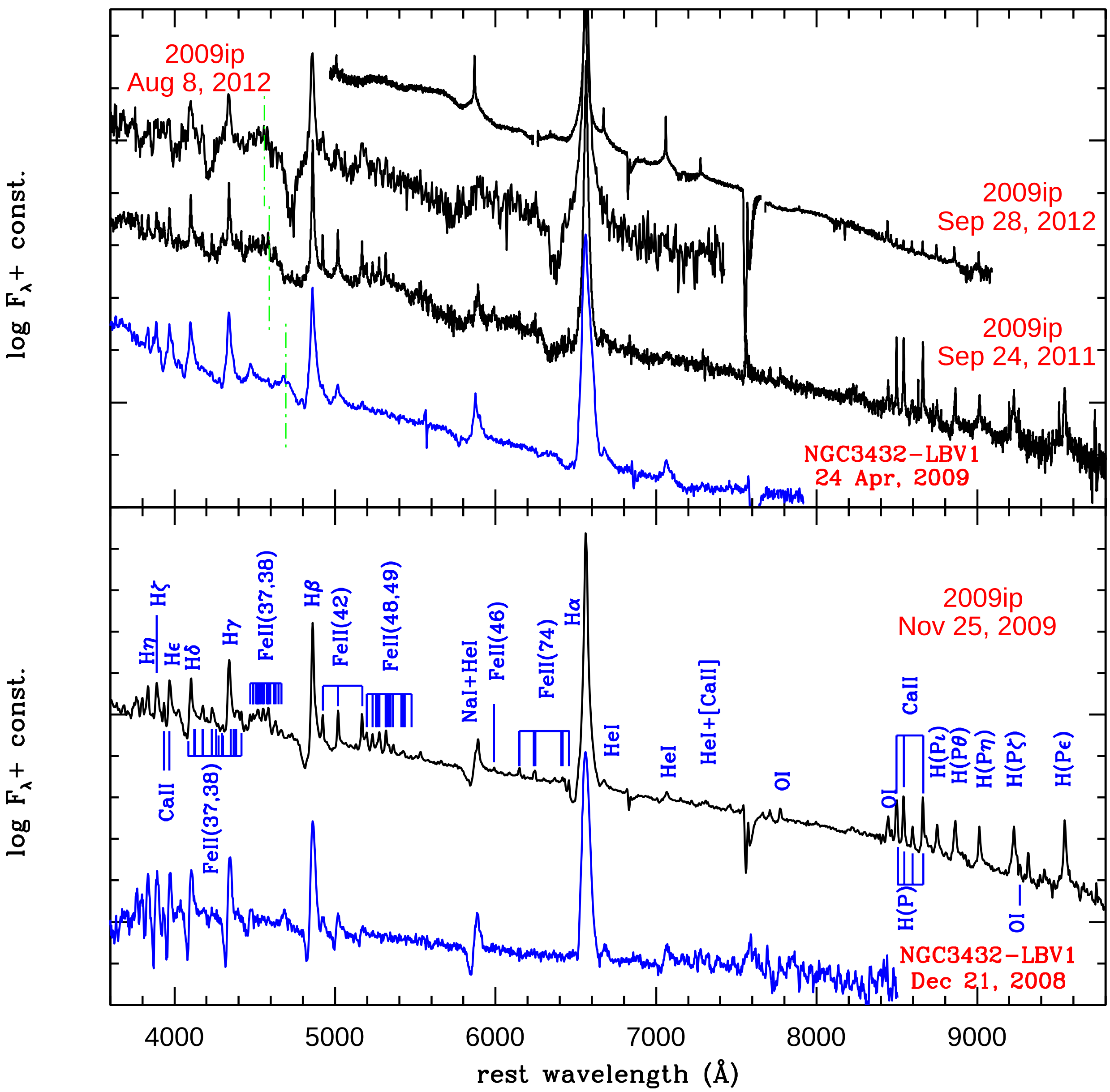

FIG. 6.— **Top:** comparison of spectra of SN 2009ip at 3 representative epochs (24 September 2011, and during the 2012a and 2012b events) with a spectrum in outburst of NGC3432-LBV1. The vertical dashed green lines mark the position of the highest velocity edges of the Hβ components in the 2 objects. **Bottom:** line identification in the optical spectrum of SN 2009ip obtained on September 25, 2009 (VLT+XShooter), and comparison with a spectrum of NGC 3432-LBV1 in outburst.

ity of about 6200 km s^{-1} and a prominent blue-shifted absorption of Pa γ + He I 1083 nm with an expansion velocity of about 10000 km s^{-1}, as obtained from the position of the broad absorption minimum. The narrow He I 1083 nm line, which was marginally detectable in previous spectra, is now clearly visible, and is well separated from Pa γ. The narrow Paschen lines have Lorentzian profiles with a FWHM velocity of about 400 km s^{-1}, whilst the narrow He I λ 1083 nm appears to be slightly broader ($\sim$800-1000 km s^{-1}) and with a roughly Gaussian profile.

3. REAL SUPERNOVA OR SUPERNOVA IMPOSTOR?

SN 2009ip is a remarkable object for a number of reasons: **i)** it experienced a series of energetic outbursts since 2009, when the transient reached absolute peak magnitudes between -14 and -15; **ii)** the spectral features reveal the presence of ejected material at very high velocities (several $\times$ 10^3 km s^{-1}); **iii)** the progenitor star was observed to be extremely luminous in quiescence (M_V = -10.0 $\pm$ 0.3) and was proposed to be a massive LBV (> 60 $M_\odot$, Foley et al. 2011; Smith et al. 2010); **iv)** finally, in September 2012 the star displayed a further, exception-

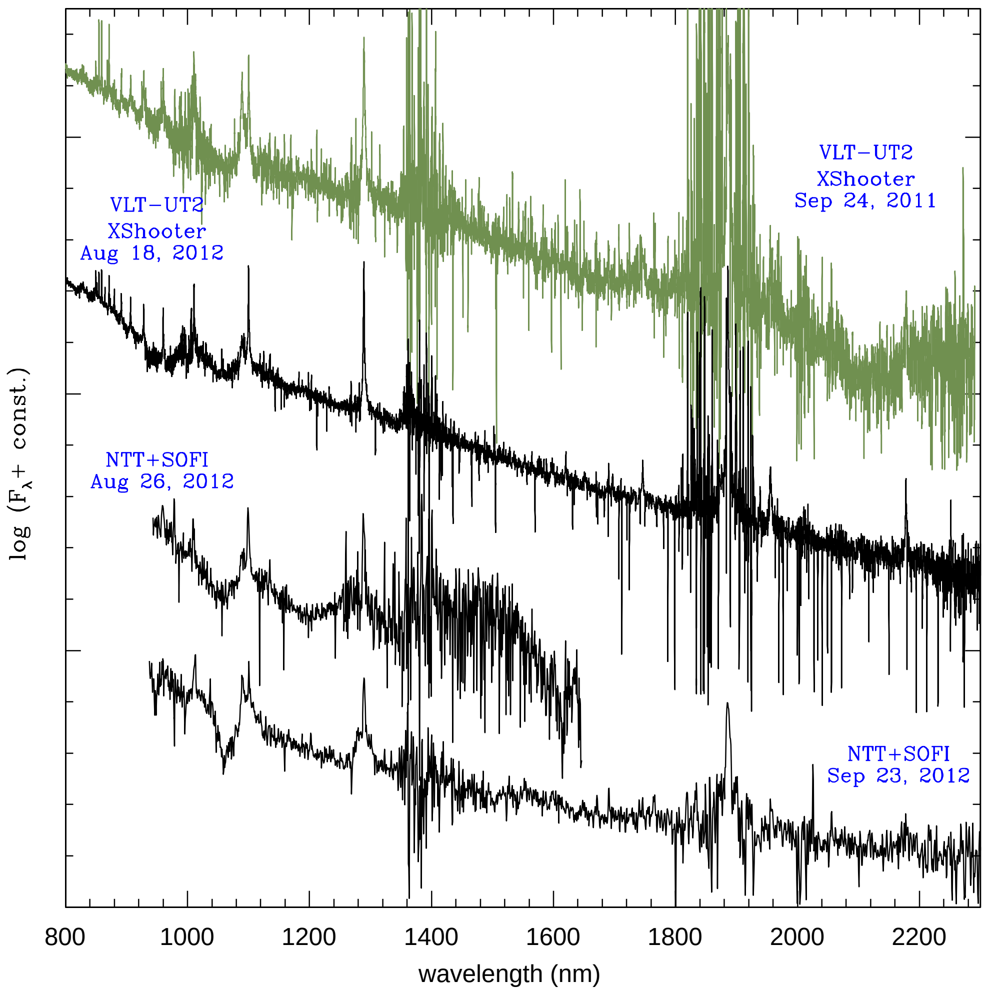

FIG. 7.— Sequence of near-infrared spectra of SN 2009ip obtained from August to September 2012. The XShooter spectrum of September 24, 2011 is also shown in green.

ally luminous outburst (the 2012b event, with $M_V \approx$ -18, Mauerhan et al. 2012b, and references therein), suggesting that the LBV may have experienced a core-collapse SN explosion. The luminosity during that event, and its similarity to SNe IIn spectra are possibly the strongest indicators that a core-collapse SN has occurred, more so than the broad lines of the spectra during the 2012a pre-cursor event.

The complex, erratic 2009-2012 light curve of SN 2009ip (Section 2.1) indicates that the LBV entered a very active variability phase resembling those of the unusual NGC 3432-LBV1 or η Carinae during the Giant Eruption of the 19th century. In the case of NGC 3432-LBV1, multiple eruptions on short time scales (about 200-220 days) have been proposed to be the result of violent pulses of a very massive star (possibly via the pulsational pair-instability mechanism) that is approaching the end of its life, presumably with the core-collapse. Alternatively, the pulses may be regulated by the passage of a companion star to the periastron (Pastorello et al. 2010)[30].

The presence of very fast material ($\sim$ 13000 km s^{-1}) in SN 2009ip *already almost 1 year before the putative SN explosion (i.e. in the 24th September 2011 spectrum)*, and also in NGC 3432-LBV1 ($\sim$ 9000 km s^{-1}) suggests that these LBV related eruptions could quite feasibly be linked with the 2012a event. The highest velocity in the Homunculus Nebula surrounding η Carinae reaches $3500-6000$ km s^{-1} (Smith 2008). Typical LBV eruptions are discussed in terms of extreme stellar winds driven by the super-Eddington luminosity of the star. However, these winds are expected to have velocities of the order of a few $\times$ 10^2 km s^{-1} (e.g. Smith 2008). The detection of this high-velocity gas in some LBV outbursts (including the afore-mentioned events) suggests that these episodes probably originate in explosions deeper in the star, perhaps in the core. These release an energy that may compete with those of weak SNe (e.g. faint SNe IIP, such as SN 1999br, Pastorello et al. 2004), producing a blast wave that allows the star to expel massive portions of the envelope (Smith 2008). All of this is expected to

[30] The presence of a companion was proposed to explain the modulated, quasi-periodic light curve of NGC 3432-LBV1 (Pastorello et al. 2010).

produce transients that closely mimic the energy and the overall properties of a real SN exploding in a dense CSM (type IIn).

3.1. *No core-collapse SN during the 2012a event*

One of the most remarkable findings inferred from the analysis of the August and early September spectra of SN 2009ip (during the 2012a event) is that the bulk of the ejected material has extremely high expansion velocities (8000-9000 km s^{-1}, with edges extending up to 14000 km s^{-1}, see Section 2.2, and Mauerhan et al. 2012b). This, and the striking similarity between the early September spectra of SN 2009ip and those of the weak type IIP SN 2005cs (Pastorello et al. 2006, 2009) led Mauerhan et al. (2012b) to conclude that SN 2009ip had likely exploded as a faint, ^{56}Ni-poor core-collapse SN during the August re-brightening episode. The fact that we can observe features from the SN ejecta inside an extended and dense CSM is explained with a non homogeneous, possibly clumpy distribution of the material lost by the LBV in pulsations preceding the explosion. While this is plausible, we would caution that the detection of high-velocity ejecta cannot be regarded as a conclusive proof, because very high velocity material was also observed in NGC 3432-LBV1 (Pastorello et al. 2010, where the broad wing of the Hβ absorption extended to 9000 km s^{-1}), during an eruption of a known SN impostor.

The core-collapse SN scenario proposed by Mauerhan et al. (2012b) is unlikely, since there is a number of observables that require a rather ad-hoc combination of events: **i)** the high-velocity absorption wings measured in the spectra obtained after the announcement of the 2012a outburst episode (Drake et al. 2012) are actually similar to those we have seen in the September 24, 2011 and August 8, 2012 spectra, which raises the question whether and in case when the SN explosion occurred; **ii)** the peak absolute magnitude ($M_R \sim$ -15) and the evolutionary timescales of the 2012a event are consistent with those of previous eruptive episodes (in particular the 2009 event, see Figure 2); finally **iii)** it is not trivial to explain how an extremely massive LBV (M>60 $M_\odot$, likely with $M_{ZAMS} \geq$ 90-100 $M_\odot$) can explode as a weak type II SN: we may need to invoke sub-sequent eruptions to explain the events before July-August 2012, and subsequently a fall-back core-collapse SN with formation of a black hole.

In the Mauerhan et al. (2012b) interpretation, the 2012b event is fairly simply explained as core-collapse SN ejecta-CSM interaction. However it is also plausible that the 2012a event was an eruptive phase, and the 2012b luminosity comes from the actual core-collapse, similar to what is assumed to occur in IIn SNe, or even from the collision of material ejected in the previous eruption with pre-existing CSM.

3.2. *SN 2009ip, a pulsational pair-instability event*

The detection of high velocity ejecta (12500 km s^{-1}) on September 24, 2011 indicates that the star has managed to eject material at velocities that we would normally associate with a SN explosion. It is very unlikely that the core collapsed at this point (see Section 3.1), which implies that the high velocity material has been ejected in the 2012a event without invoking a core-collapse SN explosion. What triggers these ejections is still unclear, but the very high progenitor mass (Smith et al. 2010; Foley et al. 2011) indicates that the events may be signatures of pulsational pair-instability (Barkat et al. 1967; Woosley et al. 2007)[31].

The Woosley et al. (2007) model of a pulsational pair-instability SN suggests that colliding shells of material can dissipate most of the relative kinetic energy as radiation. One solar mass of material moving at 8000 km s^{-1} has a kinetic energy of more than 10^{50} erg, enough to power the measured bolometric light curve of the 2012b event shown in Figure 3. As SN 2009ip has experienced multiple mass ejections, perhaps even more than those we have detected due to possible gaps in the observational coverage (Figure 2), it is plausible there are shells, or clumps of slower moving gas that will slow the fast ejecta of 2009ip during the 2012a episode.

As discussed in Mauerhan et al. (2012b), there are no known line-driven wind mechanism or continuum driven wind mechanism for driving material off the stellar surface at the high velocities observed. The energy to provide $\gtrsim 10^{50}$ erg per solar mass ejected must presumably come from a core-related event.

There is also some consistency in the velocity of the material ejected during the 2012a event and the radius of the emitting region in the 2012b episode. The 2012a event lasts approximately 50 days, during which the bulk of material starts at 8000-9000 km s^{-1} on 5 September 2012, slowing to 5000-6000 km s^{-1} after about 10 days. The fast ejecta likely travelled around $5 \times 10^4 R_\odot$, before impacting on a surrounding shell and causing the dramatic increase in luminosity in the rise to the 2012b light curve peak. If the kinetic energy of the shell is then converted into radiative energy, one would expect that an emitting sphere of radius $5 \times 10^4 R_\odot$ at a black-body temperature of around 10000 K would emit at $L \simeq$ a few $\times 10^{43}$ erg s^{-1}. This crude luminosity estimate is of the same order of magnitude to that we see in Figure 3.

The pulsational pair-instability SN model requires a star of initial mass to be in the range 95-130 $M_\odot$. The standard mass-loss prescriptions for such massive stars has to be relaxed so that in the final stages the star should retain enough mass to enhance the core temperature to cause the pair-instability. The progenitor has been estimated to have more than 60 $M_\odot$, implying that has retained most of its envelope. This is supported by the evidence that broad hydrogen features are detected in all the ejection episodes (Smith et al. 2010; Foley et al. 2011, see also Section 2.2). An interesting measurement would be the metallicity at the distance of SN 2009ip from the host galaxy nucleus (about 4 kpc) to determine if it is significantly metal poor. At the current stage, only a statistical approach is possible to estimate the local oxygen abundance. Adopting the host galaxy distance and reddening of Smith et al. (2010), the host galaxy has an absolute B-band magnitude of -17.9. Following

[31] The pulsational pair-instability scenario discussed by Woosley et al. (2007) is applicable for stars with main-sequence masses in the range 95-130 $M_\odot$. This is apparently above the mass proposed for the precursor of SN 2009ip. We note, however, that the absolute magnitude of the LBV progenitor of SN 2009ip (see e.g. Figure 3 in Foley et al. 2011) is also consistent with evolutionary tracks of stellar masses that are much higher than 60 $M_\odot$, that has to be regarded as a lower mass limit.

Pilyugin et al. (2004), the characteristic (at R = $0.4R_{25}$) oxygen abundance of NGC 7259 would be 12 + log(O/H) = 8.34, which gives 12 + log(O/H) = 8.07 at the SN position, clearly sub-solar.

As a consequence, a pulsational pair-instability scenario may provide a plausible explanation for the 2012 events, without necessarily invoking the core-collapse of the star. According to this, the 2012a event may have been a pulsational pair-instability eruption followed by collisions of these ejecta with pre-existing CSM. The late September - early October spectra of SN 2009ip, again dominated by narrow lines with Lorentzian profiles, indicate that the high-velocity material is covered by electron scattering in a high-density interaction shell (Mauerhan et al. 2012b; Chugai et al. 2004). We note that, as mentioned in Section 1, there is no robust X-ray or radio detection of SN 2009ip. Although this would not support strong ejecta-CSM interaction, it does not necessarily rule it out. According to the pulsational pair-instability scenario, the star's core is slowly contracting and is finally expected to become a real core-collapse supernova (within a few years) with a potentially very luminous display (Woosley et al. 2007).

3.3. *Was the historical SN 1961V similar to the 2012b eruptive event?*

The photometric comparison between SN 2009ip and SN 1961V shown in Figure 2, including the major eruption when SN 1961V reached an absolute peak magnitude of above -17, and the spectra (Branch & Greenstein 1971) dominated by relatively narrow H lines, suggest a close similarity between these two transients, hence supporting the statement that SN 1961V may have been another pulsational-pair instability SN.

SN 1961V had a very troublesome genesis. For many years, from 1937 to 1954, its quiescent progenitor was the most luminous star in the host galaxy, NGC 1058. It had an apparent photographic magnitude of 18 (Bertola 1964, corresponding to an absolute mag $M_B \approx$ -12). With this luminosity, the star -likely an LBV- had an estimated $M_{ZAMS} > 80$ $M_\odot$ (adopting metallicities from 1/3 to 1 $Z_\odot$, Kochanek et al. 2011). Then the object was observed at a constant magnitude of about 14.1-14.3 from July 1961 to November 1961, and finally rose to a sharp maximum at mag $\approx$ 13 on December 11, 1961 (Bertola 1964, 1967). The peak was followed by a complex luminosity decline, which lasted for a few years with highly variable slopes (see Figure 2).

The nature of this transient has been widely debated, and independent studies gave contradictory results on its real nature (genuine SN or SN impostor; see discussion in Smith et al. 2010). On the one hand, some authors state that a post-outburst surviving star (known as "Object 7", see Van Dyk & Matheson 2012, and references therein) is visible in HST optical archival images. The December 1961 light curve peak and the fluctuations in the post-maximum luminosity decline of SN 1961V could have been be produced by strong interaction between fast-moving, high-density material produced in an eruptive episode before 1961 with a lower-density, pre-existent circumstellar shell, without the need of a proper SN explosion, as also suggested by Van Dyk & Matheson (2012). On the other hand, on the basis of the lack of sufficient infrared emission from the survived putative progenitor, Kochanek et al. (2011) proposed that SN 1961V had effectively exploded as a real SN, and its unusual observed properties could be explained via the ejecta interacting with a dense circumstellar medium.

Even after half a century from the outburst, we can only speculate about the nature of SN 1961V, without giving definitive answers. Many years after that event, we tackle an analogous situation. SN 2009ip shares many strong similarities with SN 1961V, and the available information collected for SN 2009ip so far favor the pulsational pair-instability scenario of an extremely massive LBV. Whether the star has ended its life in the final core-collapse SN explosion, or the 2012b re-brightening event was due to shell-shell collisions is not known yet. Only long term monitoring of this erupting LBV will perhaps unveil its fate.

Given this spectacular latest event, it would seem incumbent upon us to secure long-term monitoring campaigns (spectroscopy and imaging from both targeted and archival work) to track the variability history of the SN impostors. These long term campaigns are probably the most fruitful method to understanding the mechanisms that cause the unpredictable variability and determine the fate of LBVs, the most massive stars in the Local Universe. SN 2009ip should be one of best studied transient events in history. Already, the data collected on the progenitor star outstrips all the information we have on all other SN progenitors to date.

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This paper is based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Fundación Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica). It is also based on observations made with the William Herschel Telescope (WHT) operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofsica de Canarias; the Liverpool Telescope (LT) operated on the island of La Palma at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias; the Nordic Optical Telescope (NOT), operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish

Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias; the 2.2m telescope of the Centro Astronómico Hispano Alemán (CAHA) at Calar Alto, operated jointly by the Max-Planck Institut für Astronomie and the Instituto de Astrofísica de Andalucía (CSIC); the 1.82m Copernico telescope of INAF-Asiago Observatory; the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership; and the Panchromatic Robotic Optical Monitoring and Polarimetry (PROMPT) Telescopes, which are by the National Science Foundation, the University of North Carolina at Chapel Hill, Leonard Goodman, the National Aeronautics and Space Administration, Dudley Observatory, Henry Cox, and the Pisgah Astronomical Research Institute.

Facilities: NTT (ESO), VLT (ESO), TNG, LT, NOT, Prompt, Gemini, SWIFT.

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APPENDIX

SPECTROSCOPY LOG AND PHOTOMETRY TABLES

TABLE 1
Log of observed spectra of SN 2009ip.

Date (dd/mm/yy)	JD-2400000	Instrumental configuration	Range (Å)	Resolution (Å)
07/09/09	55081.57	VLT(UT1)+FORS2+300V+300I	3500-10350	10;9
25/09/09	55099.58	VLT(UT1)+FORS2+300V+300I	3250-10000	10;9
29/09/09	55103.66	VLT(UT1)+FORS2+300V+300I	3500-10030	10;9
22/10/09	55126.7	NTT+EFOSC2+gm11+gm16	3530-9440	14;12
24/11/09	55159.58	NTT+EFOSC2+gm11	3350-7470	14
06/10/10	55475.60	NTT+EFOSC2+gm11+gm16	3360-9540	21;20
02/09/11	55807.48	VLT(UT2)+XShooter	3030-10400	1.0;0.8
24/09/11	55828.64	VLT(UT2)+XShooter	3150-22900	1.0;0.8;2.8
08/08/12	56148.93	NTT+EFOSC2+gm11	3360-7470	14
18/08/12	56157.76	VLT(UT2)+XShooter	3100-24790	1.0;0.8;2.8
25/08/12	56164.77	NTT+EFOSC2+gm11	3390-7450	14
26/08/12	56165.58	NTT+EFOSC2+gm11	3360-7450	14
26/08/12	56165.78	NTT+SOFI+GB	9370-16440	27
27/08/12	56166.64	NTT+EFOSC2+gm13	3650-9250	18
29/08/12	56168.50	TNG+Dolores+LRB+LRR	3170-9800	10.5;9.5
30/08/12	56169.54	TNG+Dolores+LRB	3280-8080	10.5
31/08/12	56170.50	TNG+Dolores+LRB+LRR	3280-9300	14;13
05/09/12	56175.55	NOT+ALFOSC+gm4	3350-9070	18
10/09/12	56180.56	NTT+EFOSC2+gm11+gm16	3360-10040	22;20
18/09/12	56188.55	NTT+EFOSC2+gm11	3360-7450	14
21/09/12	56192.43	WHT+ISIS+R300B+R158R	3200-9250	4.3;7.2
22/09/12	56192.52	TNG+Dolores+LRB	3320-8080	14
23/09/12	56193.50	WHT+ISIS+R300B+R158R	3180-9490	8.6;14
23/09/12	56193.53	NTT+SOFI+GB+GR	9370-25200	27;30
28/09/12	56198.5	GS+GMOS+R400	5000-9140	4
04/10/12	56205.40	TNG+Dolores+LRB	3320-8090	10

TABLE 2
Optical photometry of SN 2009ip.

Date	JD-2400000	U	B	V	R	I	Source
30/08/09	55074.14	-	-	-	-	18.11 (0.13)	1
30/08/09	55074.10	-	-	-	18.13 (0.09)	-	2
30/08/09	55074.24	-	-	18.51 (0.18)	-	-	2
06/09/09	55080.92	-	-	20.99 (0.37)	-	-	2
07/09/09	55081.56	-	-	21.06 (0.05)	20.43 (0.03)	-	3
07/09/09	55082.00	-	-	20.70 (0.17)	-	-	2
07/09/09	55082.02	-	-	20.73 (0.20)	-	-	2
07/09/09	55082.03	-	-	-	19.78 (0.24)	-	1
08/09/09	55083.43	-	-	-	20.17 (0.08)	-	4
09/09/09	55083.80	-	-	20.72 (0.32)	-	-	5
09/09/09	55084.03	-	-	20.82 (0.25)	-	-	2
09/09/09	55084.06	-	-	-	20.18 (0.20)	-	1
10/09/09	55084.99	-	-	20.96 (0.27)	-	-	6
10/09/09	55085.42	-	-	-	20.66 (0.07)	-	4
12/09/09	55087.54	-	-	21.01 (0.10)	20.65 (0.09)	20.48 (0.19)	7
13/09/09	55087.92	-	-	-	-	>19.61	1
13/09/09	55088.10	-	-	21.01 (0.30)	-	-	6
14/09/09	55088.81	-	-	-	-	>19.78	5
14/09/09	55088.98	-	-	-	-	20.44 (0.30)	1
14/09/09	55089.42	-	-	-	20.61 (0.06)	-	4
14/09/09	55089.53	-	-	21.04 (0.03)	20.62 (0.05)	20.40 (0.19)	7
23/09/09	55098.39	-	-	-	18.48 (0.06)	-	4
24/09/09	55098.72	-	-	18.95 (0.13)	-	-	5
24/09/09	55098.78	-	-	-	-	18.78 (0.21)	5
24/09/09	55099.42	-	19.64 (0.03)	19.32 (0.04)	19.01 (0.04)	18.97 (0.10)	4
25/09/09	55099.56	-	-	19.33 (0.02)	18.93 (0.06)	-	3
25/09/09	55099.65	-	-	19.39 (0.12)	-	-	5
26/09/09	55101.39	-	20.41 (0.11)	20.12 (0.13)	19.89 (0.07)	19.71 (0.16)	4
27/09/09	55101.73	-	-	20.11 (0.25)	-	-	5
29/09/09	55103.64	-	-	19.67 (0.03)	19.32 (0.03)	-	3
02/10/09	55107.37	-	-	-	20.04 (0.14)	-	4
06/10/09	55111.36	-	-	-	20.47 (0.13)	-	4
08/10/09	55113.37	-	-	-	20.54 (0.05)	-	4
10/10/09	55114.91	-	-	21.26 (0.36)	-	-	6
13/10/09	55118.46	-	-	21.21 (0.10)	20.51 (0.06)	20.39 (0.10)	4
18/10/09	55122.91	-	-	20.57 (0.31)	-	-	6
22/10/09	55126.60	-	20.91 (0.03)	20.76 (0.09)	20.38 (0.17)	20.31 (0.16)	7
30/10/09	55134.83	-	-	-	19.31 (0.04)	-	4
02/11/09	55137.87	-	-	-	20.09 (0.06)	-	4
06/11/09	55141.94	-	-	21.04 (0.28)	-	-	6
07/11/09	55142.93	-	-	20.91 (0.18)	-	-	6
10/11/09	55145.82	-	-	-	20.18 (0.03)	-	4
13/11/09	55148.83	-	-	-	19.77 (0.02)	-	4
21/11/09	55156.82	-	-	-	20.69 (0.06)	-	4
22/11/09	55157.55	-	-	-	21.06 (0.04)	-	7
24/11/09	55159.60	-	21.75 (0.06)	21.46 (0.10)	20.89 (0.09)	20.96 (0.16)	7
29/11/09	55163.83	-	-	-	20.59 (0.09)	-	4
05/12/09	55169.83	-	-	-	20.95 (0.07)	-	4
04/10/10	55473.79	-	-	-	20.29 (0.15)	-	7
06/10/10	55475.60	-	-	-	20.67 (0.07)	-	7
06/10/10	55475.63	-	-	-	20.65 (0.03)	-	7
06/10/10	55475.70	21.36 (0.06)	21.66 (0.02)	21.29 (0.08)	20.65 (0.08)	20.63 (0.12)	7
28/10/10	55497.67	-	-	-	19.92 (0.03)	-	7
30/10/10	55499.56	-	20.57 (0.02)	20.25 (0.05)	19.88 (0.06)	-	7
30/10/10	55499.63	-	-	-	-	19.80 (0.12)	7
20/12/10	55550.95	-	-	-	19.77 (0.10)	-	8
23/12/10	55553.95	-	-	-	20.14 (0.16)	-	8
31/12/10	55561.55	-	-	-	19.96 (0.12)	-	7
02/01/11	55563.55	-	-	-	19.93 (0.08)	-	7
25/03/11	55645.91	-	-	-	20.16 (0.40)	-	7
11/04/11	55662.90	-	-	-	20.87 (0.20)	-	7
10/05/11	55691.89	-	-	-	18.50 (0.07)	-	7
25/05/11	55707.13	-	-	-	20.59 (0.15)	-	8
26/05/11	55708.20	-	-	-	20.83 (0.11)	-	8
27/05/11	55709.19	-	-	-	20.81 (0.18)	-	8
04/06/11	55717.27	-	-	-	18.18 (0.07)	-	8
10/06/11	55723.26	-	-	-	20.12 (0.17)	-	8
19/06/11	55732.22	-	-	-	20.48 (0.22)	-	8
24/06/11	55736.82	-	-	-	20.63 (0.10)	-	7
24/06/11	55737.17	-	-	-	20.60 (0.07)	-	8
26/06/11	55738.78	-	-	-	20.87 (0.09)	-	7
03/07/11	55746.06	-	-	-	20.48 (0.16)	-	8
08/07/11	55751.11	-	-	-	18.18 (0.05)	-	8
14/07/11	55757.02	-	-	-	20.03 (0.41)	-	8

TABLE 2 — *Continued*

Date	JD-2400000	U	B	V	R	I	Source
23/07/11	55766.20	-	-	-	20.34 (0.09)	-	8
28/07/11	55771.21	-	-	-	20.45 (0.08)	-	8
03/08/11	55777.24	-	-	-	18.46 (0.05)	-	8
24/08/11	55797.93	-	-	-	19.40 (0.05)	-	8
27/08/11	55801.12	-	-	-	19.91 (0.03)	-	8
28/08/11	55802.13	-	-	-	20.17 (0.05)	-	8
30/08/11	55804.24	-	-	-	20.39 (0.05)	-	8
01/09/11	55805.90	-	-	-	20.49 (0.14)	-	8
03/09/11	55808.01	-	-	-	20.73 (0.07)	-	8
05/09/11	55809.90	-	-	-	20.89 (0.15)	-	8
06/06/11	55810.66	-	-	-	21.00 (0.08)	-	7
07/09/11	55811.04	-	-	-	21.14 (0.25)	-	8
10/09/11	55815.02	-	-	-	>19.67	-	8
13/09/11	55817.90	-	-	-	20.77 (0.17)	-	8
16/09/11	55821.18	-	-	-	20.29 (0.11)	-	8
17/09/11	55821.92	-	-	-	19.56 (0.05)	-	8
19/09/11	55823.94	-	-	-	18.57 (0.03)	-	8
21/09/11	55826.15	-	-	-	17.86 (0.04)	-	8
22/09/11	55826.91	-	-	-	18.48 (0.04)	-	8
22/09/11	55826.98	-	-	-	18.58 (0.03)	-	8
22/09/11	55827.09	-	-	-	18.72 (0.03)	-	8
24/09/11	55829.18	-	-	-	19.02 (0.24)	-	8
26/09/11	55830.90	-	-	-	19.36 (0.07)	-	8
26/09/11	55830.98	-	-	-	19.40 (0.03)	-	8
26/09/11	55831.13	-	-	-	19.45 (0.06)	-	8
27/09/11	55831.99	-	-	-	19.65 (0.07)	-	8
30/09/11	55834.90	-	-	-	20.02 (0.05)	-	8
04/10/11	55838.91	-	-	-	18.85 (0.04)	-	8
09/10/11	55843.90	-	-	-	>18.45	-	8
18/10/11	55852.52	-	-	-	20.87 (0.09)	-	7
18/10/11	55852.99	-	-	-	20.82 (0.08)	-	8
20/10/11	55854.59	-	-	-	20.90 (0.14)	-	7
21/10/11	55855.91	-	-	-	20.84 (0.07)	-	8
22/10/11	55856.02	-	-	-	20.84 (0.08)	-	8
24/10/11	55858.91	-	-	-	20.50 (0.06)	-	8
17/11/11	55882.57	-	-	-	20.77 (0.10)	-	7
27/11/11	55892.94	-	-	-	19.96 (0.06)	-	8
19/12/11	55914.54	-	-	-	19.85 (0.09)	-	7
21/12/11	55916.53	-	-	-	19.70 (0.11)	-	7
23/04/12	56040.43	-	-	-	19.92 (0.13)	-	7
08/08/12	56147.73	17.54 (0.01)	18.51 (0.01)	18.43 (0.04)	18.22 (0.03)	18.12 (0.05)	7
09/08/12	56148.91	-	-	-	18.46 (0.08)	-	7
11/08/12	56150.90	-	-	-	18.23 (0.05)	-	7
18/08/12	56157.76	16.54 (0.22)	17.24 (0.10)	17.05 (0.11)	16.86 (0.06)	16.73 (0.11)	9
25/08/12	56164.78	-	-	-	16.94 (0.02)	-	7
26/08/12	56165.59	16.09 (0.01)	16.88 (0.01)	16.84 (0.02)	16.61 (0.02)	16.53 (0.02)	7
27/08/12	56166.65	16.24 (0.01)	17.02 (0.01)	16.93 (0.01)	16.73 (0.03)	16.58 (0.03)	7
29/08/12	56168.54	-	-	-	16.56 (0.05)	-	10
31/08/12	56170.54	16.32 (0.02)	17.02 (0.01)	16.84 (0.02)	16.54 (0.05)	16.48 (0.08)	10
01/09/12	56171.60	-	16.92 (0.03)	16.77 (0.03)	16.52 (0.04)	16.49 (0.05)	11
02/09/12	56172.62	-	17.02 (0.08)	16.73 (0.02)	16.57 (0.04)	16.41 (0.04)	11
05/09/12	56175.57	16.72 (0.03)	17.31 (0.06)	17.09 (0.04)	16.82 (0.03)	16.77 (0.03)	12
05/09/12	56175.85	-	-	16.99 (0.07)	16.78 (0.07)	16.79 (0.10)	11
06/09/12	56176.56	-	17.34 (0.06)	17.08 (0.03)	16.85 (0.04)	16.70 (0.05)	11
07/09/12	56177.53	-	-	-	16.80 (0.08)	-	7
07/09/12	56177.60	16.39 (0.12)	-	-	-	-	7
10/09/12	56180.53	-	-	-	16.79 (0.10)	-	7
18/09/12	56188.54	-	-	-	17.66 (0.10)	-	7
22/09/12	56193.46	17.96 (0.02)	18.23 (0.04)	18.00 (0.04)	17.58 (0.09)	17.58 (0.06)	10
23/09/12	56193.59	-	18.22 (0.07)	17.97 (0.04)	17.61 (0.06)	17.48 (0.07)	11
23/09/12	56194.10	-	-	-	-	17.32 (0.10)	2
24/09/12	56194.58	-	18.14 (0.06)	17.84 (0.03)	17.53 (0.06)	17.45 (0.06)	11
24/09/12	56195.09	-	-	-	16.32 (0.05)	16.53 (0.07)	2,6
25/09/12	56195.63	-	-	15.62 (0.02)	15.48 (0.05)	15.43 (0.04)	11
25/09/12	56195.70	-	-	-	-	15.03 (0.12)	5
25/09/12	56196.01	-	-	-	15.00 (0.03)	15.04 (0.06)	2,6
26/09/12	56196.60	-	-	14.84 (0.02)	14.65 (0.03)	14.67 (0.04)	11
26/09/12	56196.98	-	-	-	14.52 (0.05)	14.56 (0.05)	2,6
27/09/12	56197.63	-	-	14.52 (0.02)	14.37 (0.03)	14.39 (0.04)	11
27/09/12	56198.03	-	-	-	-	14.33 (0.08)	2
28/09/12	56198.80	-	14.32 (0.03)	14.32 (0.02)	14.09 (0.04)	14.12 (0.03)	11
28/09/12	56198.93	-	-	-	14.14 (0.05)	14.21 (0.07)	2,6
28/09/12	56199.42	13.20 (0.03)	14.20 (0.02)	14.28 (0.02)	14.11 (0.01)	14.11 (0.02)	4
29/09/12	56199.65	-	14.28 (0.02)	14.20 (0.01)	14.09 (0.02)	14.08 (0.02)	11
29/09/12	56200.43	13.03 (0.03)	14.09 (0.02)	14.15 (0.02)	13.98 (0.01)	13.98 (0.02)	4

TABLE 2 — *Continued*

Date	JD-2400000	U	B	V	R	I	Source
30/09/12	56201.19	-	-	-	13.91 (0.04)	13.98 (0.03)	2,6
01/10/12	56201.94	-	-	-	13.85 (0.03)	13.94 (0.03)	2,6
01/10/12	56202.44	12.98 (0.03)	13.97 (0.02)	14.03 (0.02)	13.86 (0.01)	13.88 (0.02)	4
01/10/12	56201.53	-	14.02 (0.04)	14.03 (0.02)	13.91 (0.02)	13.95 (0.01)	11
02/10/12	56202.76	-	-	13.96 (0.05)	-	-	5
04/10/12	56204.52	-	13.95 (0.05)	13.75 (0.02)	13.78 (0.03)	13.79 (0.05)	11
06/10/12	56207.40	12.82 (0.04)	13.80 (0.02)	13.82 (0.02)	13.65 (0.02)	13.66 (0.02)	4
07/10/12	56208.41	-	-	13.83 (0.02)	13.65 (0.01)	13.67 (0.02)	4
08/10/12	56209.42	-	-	13.88 (0.02)	13.73 (0.01)	13.68 (0.02)	4
09/10/12	56210.43	12.99 (0.03)	13.91 (0.02)	13.92 (0.01)	13.73 (0.01)	13.70 (0.02)	4

[1] 0.3-m Mewlon Telescope + ST10 XME camera, Coral Tower Observatory, Cairns (Australia)

[2] 0.41-m RCOS Telescope + STL6K camera, Coral Tower Observatory, Cairns (Australia)

[3] 8.2-m Very Large Telescope UT1 + FORS2, European Southern Observatory - Cerro Paranal (Chile)

[4] 2-m Liverpool Telescope + RATCAM, La Palma, Canary Islands (Spain)

[5] 0.51-m RCOS Telescope + STL11K camera, New Mexico Skies, Mayhill, New Mexico (USA)

[6] 0.33-m RCOS Telescope + STL6K camera, in 2009 at the Macedon Ranges Observatory, Melbourne; in 2012 at the Coral Tower Observatory, Cairns (Australia)

[7] 3.58-m New Technology Telescope + EFOSC2, European Southern Observatory - La Silla (Chile)

[8] 2-m Faukes Telescope South + EM03, Siding Spring Observatory (Australia)

[9] 8.2-m Very Large Telescope UT2 + XShooter (spectrophotometry), European Southern Observatory - Cerro Paranal (Chile)

[10] 3.58-m Telescopio Nazionale Galileo + Dolores, La Palma, Canary Islands (Spain)

[11] 0.41-m Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT) (3+5), at Cerro Tololo Inter-American Observatory (Chile)

[12] 2.56-m Nordic Optical Telescope + ALFOSC, La Palma, Canary Islands (Spain)

TABLE 3
Swift/UVOT photometry of SN 2009ip.

Date	JD	UVw2	UVm2	UVw1	u	b	v
10/09/09	55085.17	>21.64	>21.10	>21.18	>20.87	>21.22	>20.30
04/09/12	56175.40	18.00 (0.08)	-	17.20 (0.05)	16.49 (0.04)	17.29 (0.04)	17.01 (0.02)
06/09/12	56177.14	18.02 (0.08)	17.95 (0.08)	17.06 (0.07)	16.51 (0.06)	17.33 (0.07)	17.23 (0.12)
13/09/12	56183.94	19.38 (0.32)	19.04 (0.16)	18.29 (0.12)	17.31 (0.07)	17.73 (0.08)	17.83 (0.14)
20/09/12	56191.25	-	-	19.30 (0.24)	17.91 (0.13)	18.50 (0.17)	-
22/09/12	56193.26	20.58 (0.26)	20.52 (0.32)	19.36 (0.23)	17.91 (0.07)	18.24 (0.06)	18.17 (0.07)
26/09/12∗	56196.73	12.85 (0.07)	12.82 (0.06)	13.00 (0.05)	13.43 (0.04)	14.78 (0.04)	14.90 (0.04)
27/09/12	56197.95	12.61 (0.04)	-	12.78 (0.04)	-	-	-
27/09/12	56198.20	12.50 (0.04)	-	12.68 (0.04)	13.02 (0.04)	14.40 (0.04)	-
28/09/12	56198.54	12.47 (0.04)	12.36 (0.04)	12.66 (0.04)	12.90 (0.04)	14.40 (0.05)	14.58 (0.06)
28/09/12	56199.09	12.39 (0.04)	-	12.63 (0.04)	-	-	-
29/09/12	56199.96	-	-	12.57 (0.04)	-	-	-
29/09/12	56200.15	12.28 (0.04)	12.38 (0.05)	12.45 (0.04)	12.81 (0.04)	14.11 (0.04)	14.22 (0.04)
30/09/12	56200.74	-	-	-	12.75 (0.04)	-	-
30/09/12	56201.01	12.21 (0.04)	-	-	-	-	-
30/09/12	56201.49	12.18 (0.04)	12.07 (0.04)	12.35 (0.04)	12.67 (0.04)	13.94 (0.04)	14.12 (0.04)
01/10/12	56201.55	12.19 (0.04)	-	-	-	-	-
01/10/12	56201.93	12.20 (0.04)	-	-	-	-	-
01/10/12	56202.49	12.16 (0.04)	12.10 (0.04)	12.36 (0.04)	12.65 (0.04)	13.99 (0.04)	14.04 (0.04)
02/10/12	56202.76	12.18 (0.04)	12.11 (0.04)	12.36 (0.04)	12.65 (0.04)	13.95 (0.04)	14.08 (0.04)
03/10/12	56203.56	12.20 (0.04)	12.11 (0.04)	12.36 (0.05)	12.65 (0.05)	13.96 (0.04)	14.09 (0.04)
03/10/12	56203.79	12.23 (0.04)	-	-	-	-	-
04/10/12	56204.55	12.14 (0.04)	12.04 (0.04)	12.30 (0.05)	12.63 (0.05)	13.86 (0.04)	13.92 (0.04)
04/10/12	56204.89	12.10 (0.04)	-	-	-	-	-
04/10/12	56205.01	-	-	-	-	13.80 (0.12)	-
05/10/12	56205.90	12.10 (0.04)	-	-	-	-	-
05/10/12	56206.02	-	-	-	-	13.77 (0.10)	-
06/10/12	56206.62	12.10 (0.04)	12.02 (0.04)	12.24 (0.04)	12.52 (0.05)	13.75 (0.05)	13.86 (0.04)
06/10/12	56206.70	12.13 (0.04)	-	-	-	-	-
07/10/12	56207.93	12.27 (0.04)	-	-	-	-	-
08/10/12	56209.17	12.42 (0.04)	12.26 (0.04)	12.48 (0.05)	12.62 (0.05)	13.84 (0.05)	13.87 (0.04)
10/10/12	56210.56	12.61 (0.05)	12.44 (0.04)	12.59 (0.05)	12.80 (0.05)	13.92 (0.05)	13.88 (0.04)

Note. — The photometry at the epoch marked with ∗ has been published by Margutti et al. (2012b).

TABLE 4
Near-infrared photometry of SN 2009ip obtained during the 2012a and 2012b events.

Date	JD	J	H	Ks	Source
18/08/12	56157.76	16.322 0.177	16.163 0.164	16.596 0.220	1
26/08/12	56165.80	16.246 0.098	16.106 0.119	15.875 0.151	2
08/09/12	56178.53	16.471 0.132	16.275 0.134	15.919 0.184	3
09/09/12	56179.60	16.463 0.102	16.279 0.124	16.024 0.152	2
22/09/12	56193.59	17.174 0.120	17.146 0.177	16.859 0.171	2
27/09/12	56198.48	14.170 0.097	13.916 0.114	13.483 0.156	3
28/09/12	56199.47	14.064 0.108	13.781 0.128	13.378 0.167	3
01/10/12	56202.46	13.974 0.110	13.733 0.137	13.292 0.178	3

[1] 8.2-m Very Large Telescope UT2 + XShooter (spectro-photometry), European Southern Observatory - Cerro Paranal (Chile)
[2] 3.58-m New Technology Telescope + SOFI, European Southern Observatory - La Silla (Chile)
[3] 2.56-m Nordic Optical Telescope + NOTCam, La Palma, Canary Islands (Spain)

TABLE 5
UNPUBLISHED OPTICAL PHOTOMETRY OF NGC3432-LBV1 (AKA SN 2000CH).

Date	JD-2400000	U	B	V	R	I	Source
02/07/10	55380.37	-	-	-	19.78 (0.05)	-	1
14/07/10	55392.37	-	-	-	19.09 (0.05)	-	1
20/07/10	55398.36	-	-	-	20.53 (0.31)	-	1
10/10/10	55489.70	-	-	-	19.74 (0.10)	-	1
26/10/10	55495.66	-	22.25 (0.40)	20.97 (0.17)	19.99 (0.06)	20.17 (0.22)	1
17/11/10	55517.71	-	-	-	19.93 (0.11)	-	1
20/11/10	55520.65	-	-	-	20.38 (0.09)	-	1
15/01/11	55576.75	-	-	-	19.14 (0.05)	-	1
08/02/11	55600.70	-	-	-	19.98 (0.07)	-	2
09/02/11	55601.53	-	21.21 (0.12)	20.90 (0.10)	20.05 (0.09)	19.97 (0.15)	3
09/02/11	55602.49	-	-	-	20.09 (0.05)	-	3
22/02/11	55615.77	-	-	-	19.97 (0.05)	-	4
06/04/11	55658.49	-	21.26 (0.15)	21.25 (0.19)	20.28 (0.18)	>19.99	3
10/04/11	55662.40	-	-	-	20.23 (0.12)	-	1
01/05/11	55683.40	-	-	-	>19.54	-	3
07/05/11	55689.48	-	-	-	19.42 (0.04)	-	1
22/05/11	55704.35	-	-	-	19.17 (0.05)	-	1
30/06/11	55743.37	-	-	-	19.96 (0.11)	-	1
01/11/11	55866.56	>19.61	>22.21	>21.35	20.48 (0.23)	>20.22	3
02/11/11	55867.69	-	-	21.80 (0.36)	20.53 (0.19)	20.91 (0.28)	1
16/11/11	55881.72	-	-	-	20.95 (0.33)	-	1
20/11/11	55885.63	-	-	-	21.18 (0.20)	-	3
22/12/11	55917.62	-	-	-	21.07 (0.07)	-	2
24/12/11	55919.57	-	-	-	21.42 (0.19)	-	1
21/01/12	55948.41	-	-	-	20.12 (0.47)	-	3
30/01/12	55957.47	-	-	-	19.87 (0.22)	-	3
17/03/12	56003.51	-	-	-	19.40 (0.07)	-	3
26/03/12	56013.36	-	-	-	19.13 (0.08)	-	3
28/03/12	56015.45	-	-	-	19.23 (0.08)	-	3
17/07/12	56126.34	-	-	-	>20.90	-	3
26/07/12	56135.35	-	-	-	>20.70	-	3

[1] 2.2-m Calar Alto Telescope + CAFOS, Calar Alto, Almeria (Spain)
[2] 2.56-m Nordic Optical Telescope + ALFOSC, La Palma, Canary Islands (Spain)
[3] 1.82-m Copernico Telescope + AFOSC, Mt. Ekar, Asiago (Italy)
[4] 4.2-m William Herschel Telescope + ACAM, La Palma, Canary Islands (Spain)

TABLE 6
Magnitudes of the reference stars in the field of SN 2009ip, including the near-infrared magnitudes from the 2MASS catalo

Filter	Star 1	Star 2	Star 3	Star 4	Star 5	Star 6	Star 7	Star 8	Star 9	Star 10
					Optical					
U	15.70 (0.01)	16.14 (0.04)	-	-	21.06 (0.07)	20.44 (0.05)	-	-	-	20.33 (0.02
B	15.76 (0.02)	16.20 (0.01)	21.13 (0.02)	19.10 (0.05)	20.14 (0.04)	20.01 (0.02)	20.76 (0.03)	20.10 (0.01)	20.95 (0.02)	19.38 (0.02
V	15.20 (0.01)	15.62 (0.03)	19.56 (0.02)	17.68 (0.01)	19.08 (0.02)	19.17 (0.01)	19.47 (0.01)	18.96 (0.01)	19.70 (0.03)	18.37 (0.02
R	14.87 (0.01)	15.26 (0.01)	18.67 (0.01)	16.81 (0.01)	18.39 (0.01)	18.64 (0.01)	18.58 (0.02)	18.19 (0.01)	18.73 (0.02)	17.74 (0.01
I	14.54 (0.01)	14.94 (0.01)	17.76 (0.02)	15.99 (0.02)	17.80 (0.02)	18.18 (0.02)	17.59 (0.01)	17.47 (0.01)	17.68 (0.01)	17.15 (0.02
					SWIFT					
UVw2	18.34 (0.15)	18.81 (0.13)	-	-	-	-	-	-	-	-
UVm2	18.20 (0.18)	18.61 (0.15)	-	-	-	-	-	-	-	-
UVw1	16.92 (0.08)	17.39 (0.07)	-	-	-	-	-	-	-	-
u	15.64 (0.05)	16.01 (0.05)	-	-	-	-	-	-	-	20.25 (0.20
b	15.70 (0.07)	16.19 (0.05)	-	-	20.10 (0.27)	19.84 (0.33)	20.60 (0.34)	-	20.70 (0.19)	19.33 (0.20
v	15.28 (0.07)	15.65 (0.09)	-	-	19.23 (0.22)	19.09 (0.21)	19.37 (0.21)	-	19.73 (0.16)	18.50 (0.22
					Near-Infrared					
J	14.12 (0.03)	14.43 (0.03)	-	15.05 (0.05)	-	-	16.61 (0.15)	16.75 (0.10)	16.61 (0.15)	16.58 (0.15
H	13.84 (0.04)	14.02 (0.05)	-	14.35 (0.05)	-	-	15.85 (0.18)	15.90 (0.19)	15.83 (0.18)	15.80 (0.17
Ks	13.71 (0.06)	14.13 (0.07)	-	14.18 (0.07)	-	-	-	15.56 (0.24)	15.73 (0.26)	15.29 (0.17