The Unprecedented Third Outburst of SN 2009ip: A Luminous Blue Variable Becomes a Supernova

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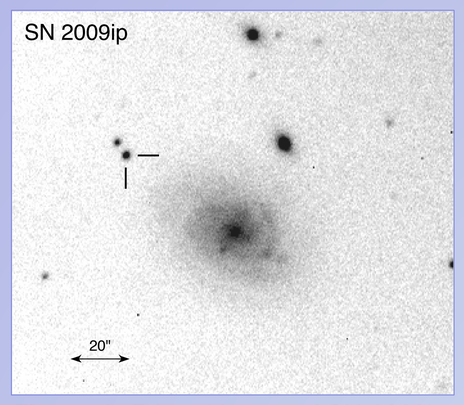

Figure 1: *R*-band image of SN 2009ip and host galaxy NGC 7259, obtained with the Kuiper 61 inch telescope and MONT4K CCD on 2012 Sept 24.

Some reports of supernova (SN) discoveries turn out not to be true core-collapse explosions. One such case was SN 2009ip (Figure 1), which was recognized to be a luminous blue variable (LBV) eruption. This source had a massive (50-80 $M_{\odot}$) hot progenitor star identified in pre-explosion *HST* images, it had documented evidence of pre-outburst variability (Figure 2), and it was subsequently discovered to have a second outburst in 2010. This same source re-brightened again in July 2012, and was initially suggested to be another LBV eruption. Our new photometry and spectroscopy of SN 2009ip, obtained at Steward and Lick Observatories (Figures 3-5), indicates that this object's third observed outburst in under 4 years appears to have transitioned into a genuine SN. As such, SN 2009ip would be the first object to have both an identified massive blue progenitor star and to have LBV eruptions with accompanying spectra that were observed a few years prior to a true Type IIn core-collapse SN.

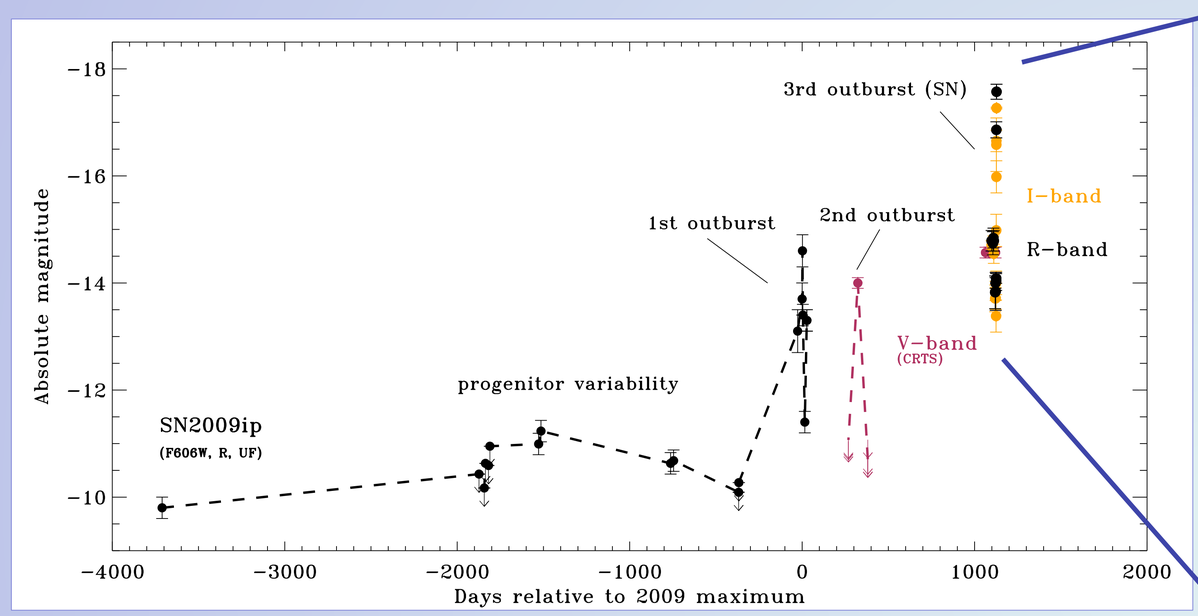

Figure 2: Complete, absolute light curve of SN 2009ip, covering all three outbursts, in addition to the prior variable phase of the LBV progenitor. This figure includes photometry from archival HST data and ground-based observations. See Mauerhan et al. (2012), Smith et al. (2010), and references therein for data details.

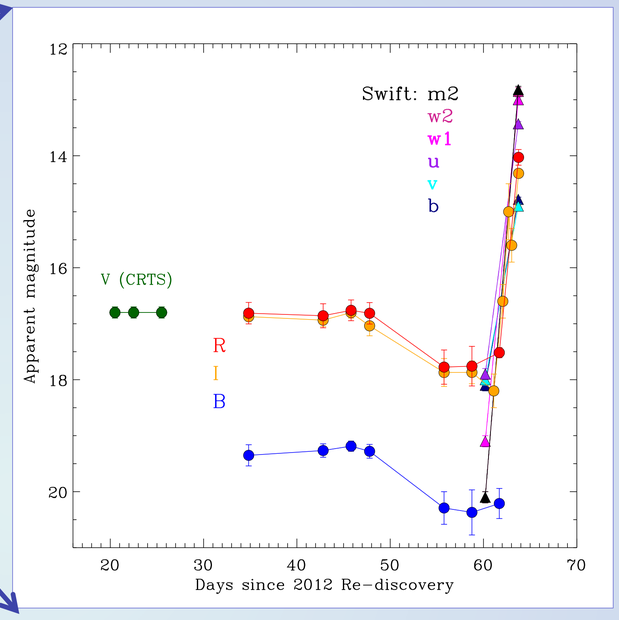

Figure 3: Light curve of SN 2009ip during 2012 outburst. *BVRI* photometry from our observations with the Nickel 1-m telescope at Lick Observatory, and by Drake et al. (2012). UV/optical *Swift* photometry from Margutti et al. (2012)

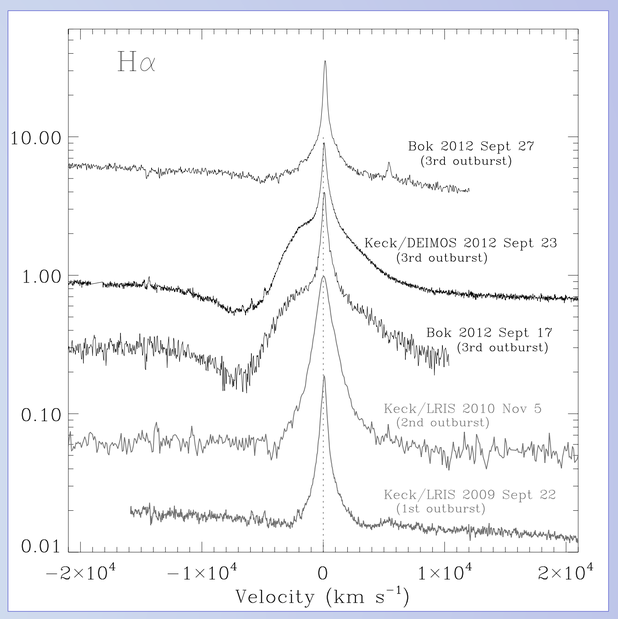

Figure 4: Spectral evolution of SN 2009ip's Hα profile, in velocity coordinates, including Keck/LRIS spectra of 2009 /2010 eruptions, and spectra of the 2012 eruption from Steward (Bok), Keck, and Lick observatories.

In July-Aug 2012, during its third observed outburst, the light curve of SN 2009ip initially appeared to "plateau" at an apparent magnitude of V~16.8, and an absolute mag of M_V=-14.5, comparable to the faintest known Type II SNe. Surprisingly, during this phase the spectrum of the source exhibited Balmer lines having very broad P-Cygni profiles characteristic of normal Type II supernovae, in addition to the narrow emission components seen during SN 2009ip's prior eruptions. The broad emission components exhibit FWHM~8000 km s^{-1}, while the P-Cygni absorption component has blue wings extending out to -13,000 km s^{-1}. The signature of such velocities is typical of Type II core-collapse SN explosions, but has never been seen in a non-terminal LBV eruption. Moreover, around Sept 25th, approximately two months after discovery of the 2012 outburst, the source underwent a rapid, dramatic brightening at UV and optical wavelengths (Figure 3), climbing to M_R=-17.6 mag in a few days. During this bright phase, the broad lines mostly disappeared, and the spectrum became dominated by Lorentzian profiles of Hα and He I, characteristic of the early optically-thick phases of luminous SNe IIn. We suspect that the abrupt brightening and transition to a IIn spectrum marks the collision of the most recently ejected 13,000 km s^{-1} SN ejecta with slower-moving mass (<1000 km s^{-1}) ejected during prior eruptions (Smith et al. 2010).

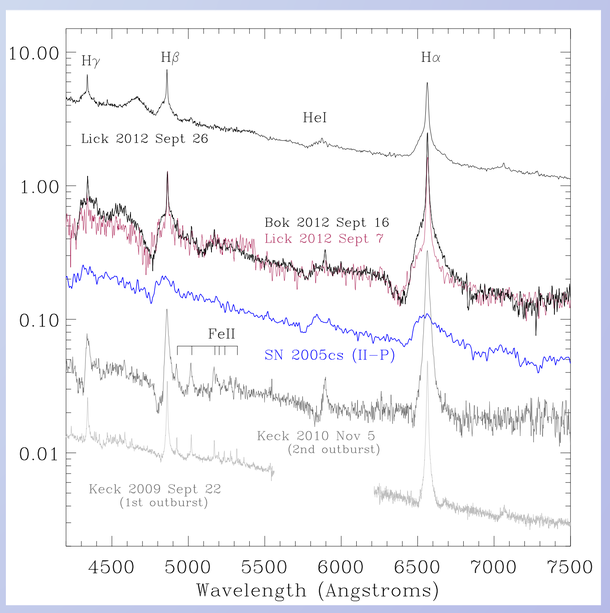

Figure 5: Bok and Lick low-resolution spectra of SN 2009ip, compared to spectra of the Type II-P SN 2005cs and the prior 2009 and 2010 eruptions.

We conclude that the most recent outburst of SN 2009ip is a true core-collapse SN IIn that was initially faint (perhaps as a result of low radioactive yield after substantial ejecta fallback) but then rapidly achieved high luminosities, as a result of interaction with circumstellar material. The pulsational pair instability, LBV-like eruptions, or other instabilities due to late nuclear burning phases in massive stars may provide an explanation for the pre-SN eruptive behavior of SN 2009p in the past few years.

References: **Mauerhan et al. 2012, arXiv:1209.6320**; Smith et al. 2010, ApJ, 139,451; Drake et al. 2012, ATel 4334; Margutti et al. 2012, ATels 4414 and 4425