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Early Blue Excess from the Type Ia Supernova 2017cbv

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Abstract. This paper presented very early, high-cadence photometric observations of the nearby Type Ia SN 2017cbv. The light-curve is unique in that during the first five days of observations it has a blue bump in the U, B, and g bands which is clearly resolved by virtue of our photometric cadence of 5.7 hr during that time span. We modelled the light-curve as the combination of an early shock of the supernova ejecta against a non-degenerate companion star plus a standard Type Ia supernova component. Our best-fit model suggested the presence of a subgiant star 56 $R_\odot$ from the exploding white dwarf, although that number is highly model-dependent. While the model matches the optical light-curve well, it over-predicts the flux expected in the ultraviolet bands. That may indicate that the shock is not a blackbody, perhaps because of line blanketing in the UV. Alternatively, it could point to another physical explanation for the optical blue bump, such as interaction with circumstellar material or an unusual distribution of the element Ni. Early optical spectra of SN 2017cbv show strong carbon absorption as far as day −13 with respect to maximum light, suggesting that the progenitor system contained a significant amount of unburnt material. These results for SN 2017cbv illustrate the power of early discovery and intense follow-up of nearby supernovæ for resolving standing questions about the progenitor systems and explosion mechanisms of Type Ia supernovæ.

Keywords. Supernovæ: general – supernovæ: individual (SN 2017cbv)

A Type Ia supernova is known to be caused by the thermonuclear explosion of a white dwarf in a binary system, yet the nature of that binary companion is still debated (see Maguire 2016, for a review). The white dwarf may accrete from a nondegenerate companion (the single-degenerate model; Whelan & Iben 1973), or merge with another white dwarf (the double-degenerate model; Iben & Tutukov 1984; Webbink 1984). Previous studies have attempted to differentiate between those models using three main approaches: (1) searching for circumstellar material, (2) direct imaging of the supernova location to look for a luminous companion, and (3) watching the early supernova light-curve for signatures of a collision with a companion.

High-resolution spectroscopy of a supernova can reveal narrow absorption lines, especially of Na. If those lines vary in strength over time, it suggests that they are most likely produced by material around the white dwarf. Such observations would be expected from a single-degenerate progenitor, since the white dwarf was actively accreting material at the time of its explosion. Time-variable Na absorption has been seen in several Type Ia supernovæ (e.g., Ferretti *et al.* 2016). If the circumstellar material is hydrogen-rich, hydrogen emission lines may also be observed superimposed on the typical Type Ia supernova spectrum. Type Ia supernovæ with hydrogen emission are called 02ic-like or Type Ia-CSM supernovæ (e.g., Dilday *et al.* 2012). For nearby supernovæ, interactions between the ejecta and circumstellar material are expected to produce observable radio and X-ray emission. However, neither has been detected from a Type Ia supernova.

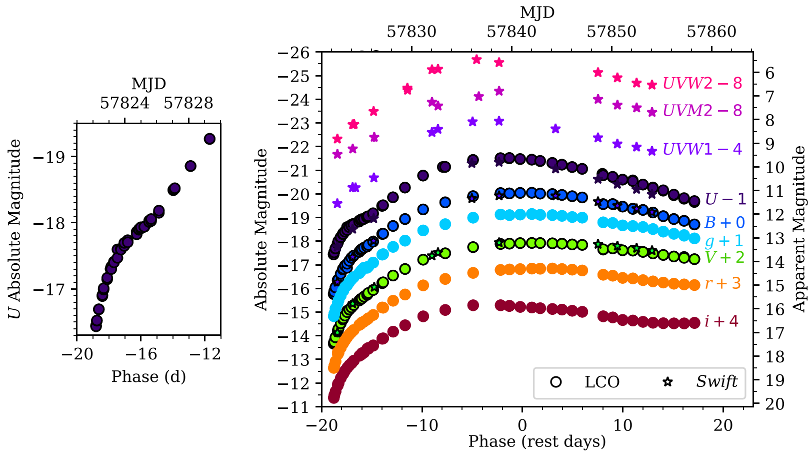

Figure 1. Early UV (*left*) and optical (*right*) light-curves of the Type Ia SN 2017cbv, showing a U-band excess during the first few days. (*From Hosseinzadeh et al. 2017; reproduced by permission of the AAS*).

Archived images of the host galaxy of SN 2011fe provided the best direct imaging constraints of a Type Ia supernova companion, ruling out luminous red giants and most helium stars (Li *et al.* 2011). However, this method can only be used for very nearby supernovæ whose hosts were imaged by the *Hubble Space Telescope* before explosion.

Kasen (2010) predicted that a large binary companion would shock ejecta from a Type Ia supernova, producing excess ultraviolet emission during the first few days after explosion. Cao *et al.* (2015) and Marion *et al.* (2016) claimed to see such effects in iPTF14atg, a rare subluminous Type Ia supernova, and in SN 2012cg, a normal Type Ia supernova, respectively. The present contribution summarized the third claimed observation of companion shocking, as discovered in the normal Type Ia SN 2017cbv. A full analysis has been published by Hosseinzadeh *et al.* (2017).

SN 2017cbv was discovered by the *Distance Less Than 40 Mpc* (DLT40) survey (see Tartaglia *et al.* 2018), and immediately followed-up by our group at Las Cumbres Observatory (Brown *et al.* 2013). Our 5.7-hr cadence during the first several days allowed us to resolve clearly an excess in the U-band emission compared to a smoothly rising light-curve (Fig. 1).

We fitted the models created by Kasen (2010) plus a Type Ia supernova template light-curve (Conley *et al.* 2008) to our observed light-curve. The models provided a good fit to the data for a subgiant companion, but they over-predicted drastically the observed flux in the ultraviolet bands. We attribute that to the assumption by Kasen (2010) that the shock would have a blackbody spectrum.

Other caveats include the fact that, since very few Type Ia supernovæ have been observed this early on in the passage of the event, the available light-curve templates may not be reliable as early as 19 days before the peak. In addition, supernovæ have only recently been observed in the ultraviolet, so there are no reliable light-curve templates. We have also ignored the dependence of this effect on the viewing angle by using the isotropic-equivalent luminosity given by Kasen (2010).

As an independent test of whether SN 2017cbv has a non-degenerate companion, we searched for weak hydrogen emission in its infrared spectrum. No hydrogen was detected for a month after the explosion. However, we will continue to monitor its spectral evolution into the nebular phase. Ferretti *et al.* (2017) also did not detect time-variable Na in high-resolution spectra of SN 2017cbv. These results appear to be in conflict with our interpretation of the early blue excess as due to interaction between the ejecta and the companion.

We consider two other interpretations for the bump in the U band. (1) The ejecta could have collided with 0.01–0.1 $M_\odot$ of circumstellar material, rather than with a companion. However, that much material is difficult to produce in typical progenitor situations, and it may have reduced significantly the photospheric velocity to below what we observed in the early spectra. (2) The bump could have come from an unusual distribution of radioactive Ni in the ejecta, e.g., from a surface detonation before the main explosion. That might produce unusual spectral signatures during the bump, though spectra of SN 2017cbv obtained during that phase appear to be typical for a young Type Ia supernova.

We conclude by mentioning that this study was only possible with the advent of robotic telescopes, enabling early discovery and immediate follow-ups. As large high-cadence surveys come online in the next few years, the number of supernovæ discovered within a day of explosion is likely to increase drastically. Only with statistical samples of day-old supernovæ will we learn how common this behaviour is in an early light-curve.

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