Comparing Type Ia Supernovae in the Ultraviolet and Optical

Yaswant Devarakonda and Peter Brown

Mitchell Institute for Fundamental Physics and Astronomy, Texas A&M University

Email: yaswantd@tamu.edu
Website: tx.ag/yaswantd
Twitter: @yastronomy

Background

Type Ia supernovae (SNe Ia) have been well studied in the optical and IR, however their UV properties remain relatively unexplored. This is partially due to the expected blanketing of Fe-group absorption lines in the UV, which could make light curve standardization difficult. And as both Hubble and the Swift telescopes are past their intended lifespans, there may soon be no options available for time-domain UV observations.

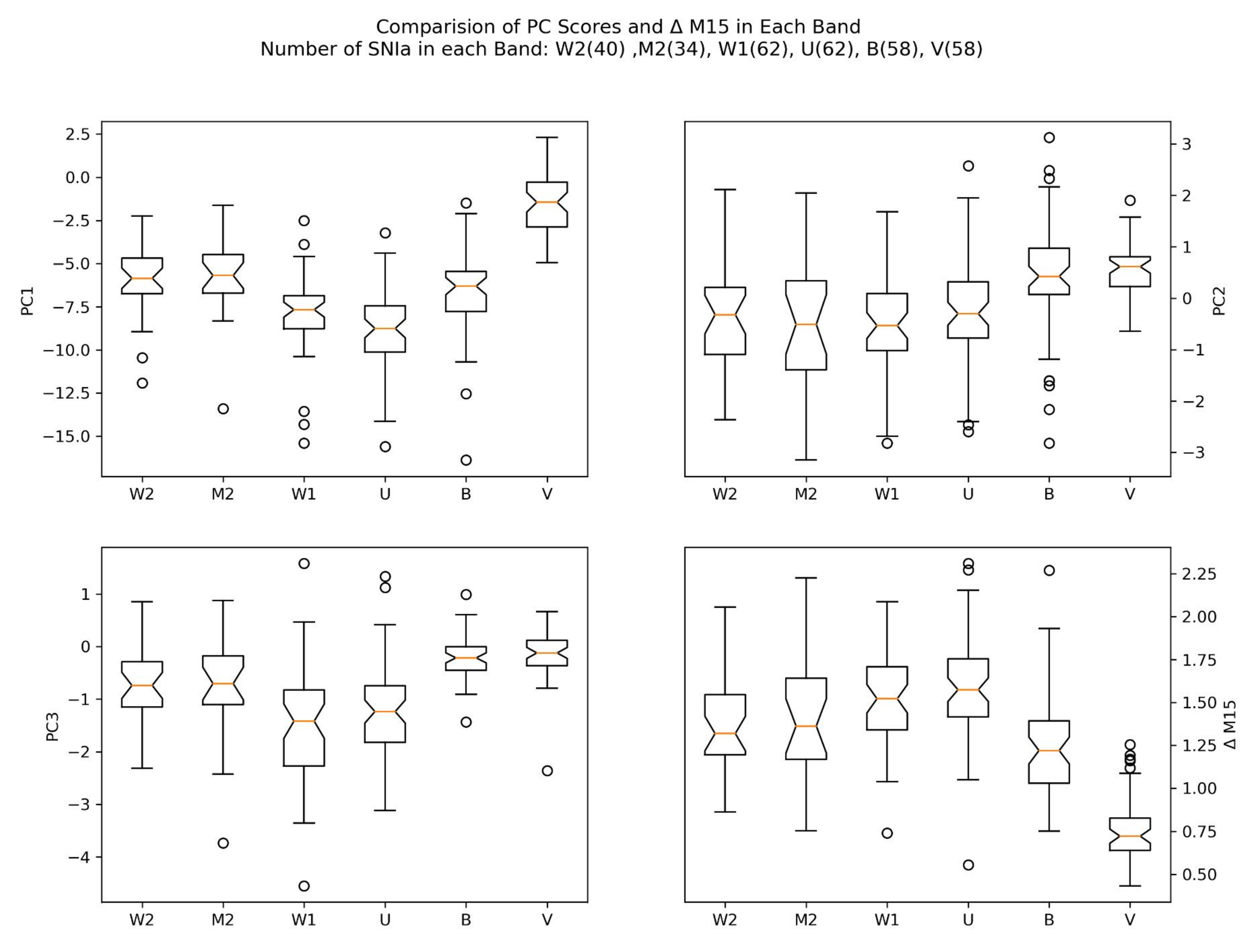
We analyze UV and optical SNIa light curve properties of 97 SNe Ia from the Swift Optical/Ultraviolet Supernova Archive (SOUSA, Brown et al. 2014), covering a range of 1,700-6,500 Å. Our initial studies show remarkable potential for science in the UV regime that could be explored with future time-domain observatories. Here we focus on the signs of SNe Ia progenitors through shock emission and the usefulness of the UV for cosmological studies.

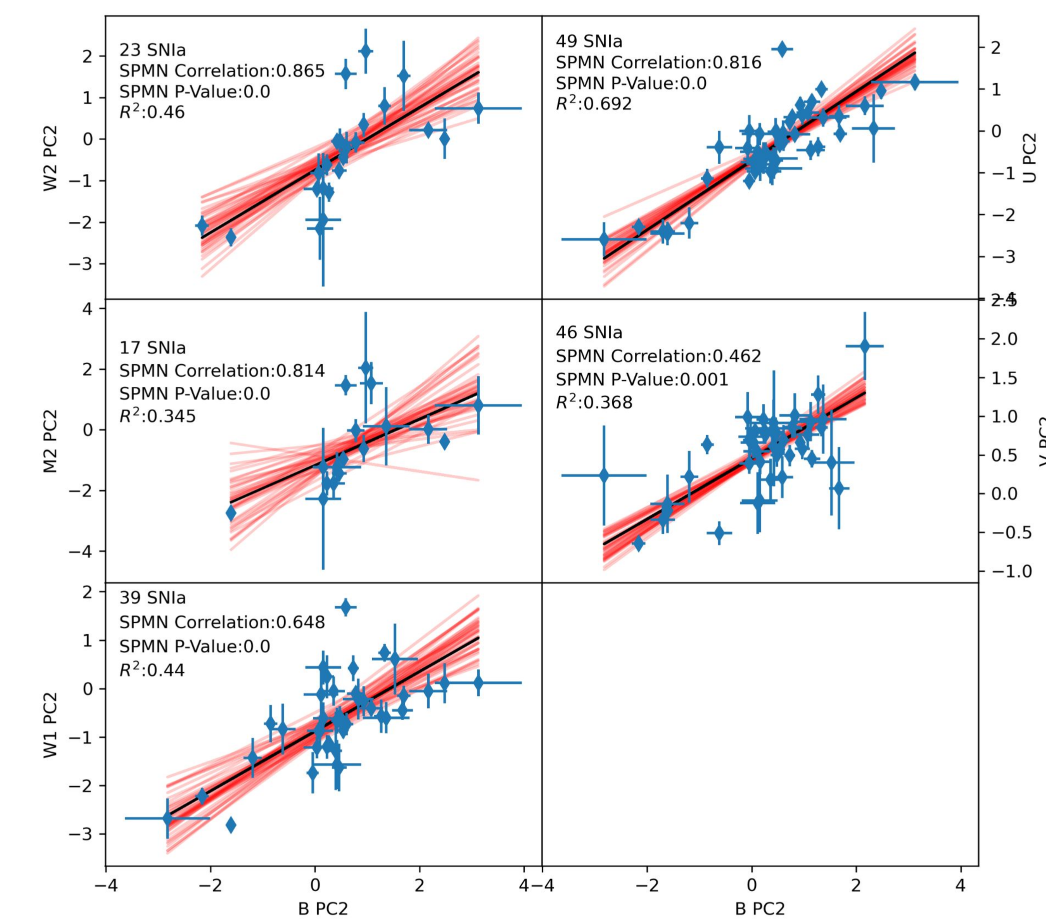
UV/Optical Cosmology

There is no statistical difference in the diversity of light curve shapes of SNe Ia in the UV or optical (Devarakonda & Brown 2022). In addition, there is a strong statistical relationship between the shape parameters, particularly in the near peak decline rate. While the intrinsic UV luminosity may be more diverse than the optical luminosity, the addition of UV observations may add useful constraints for optical standard candle measurements. This will be particularly helpful for high redshift sources, whose rest-frame UV emission will be observable by ground based optical instruments.

Left: Tukey box plots showing the range of light curve parameters in each band based on FPCA modeling. In each case, there is no statistical change in variance between the B band and the UV bands

Right: PC2 weights (related to near-peak decline) in each band relative to the B band, with the Spearman rank-order coefficient statistic and p-values. The black line shows the best linear fit, and the red lines show error in the fit based on random Monte Carlo draws.



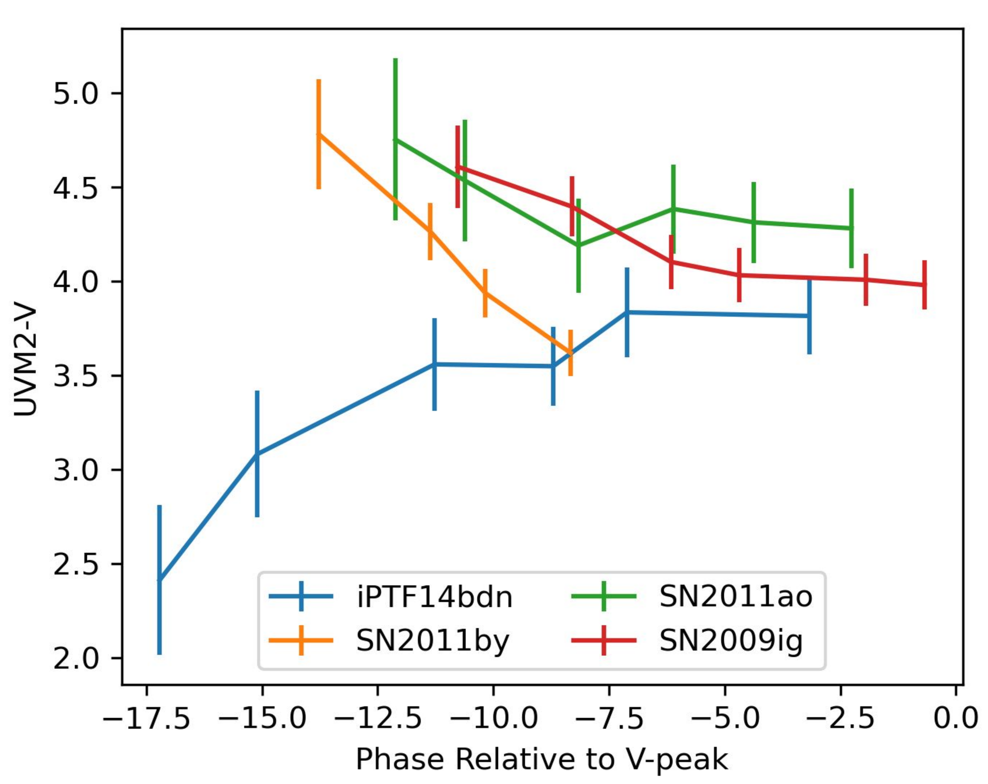


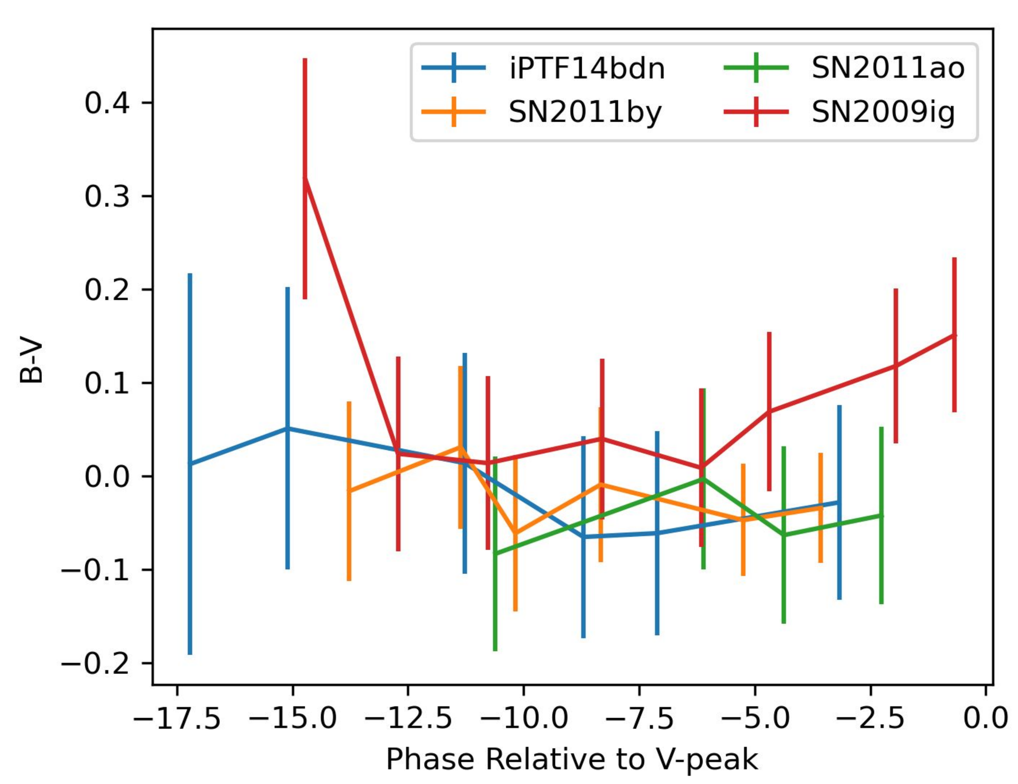
Shock Emission Signatures

Interaction with a non-degenerate companion may lead to an early flux excess that is particularly strong in the UV (Kasen 2010). As a result, the light curve of single degenerate SNe should start out very UV blue and gradually become redder as the shocked ejecta cools (Burke et al. 2022). Such a signal would be difficult to observe with just optical observations.

Left: The UVM2-V evolution. iPTF14bdn starts out much more blue than the other objects, before reddening to match them near peak. This may be a sign of companion interaction.

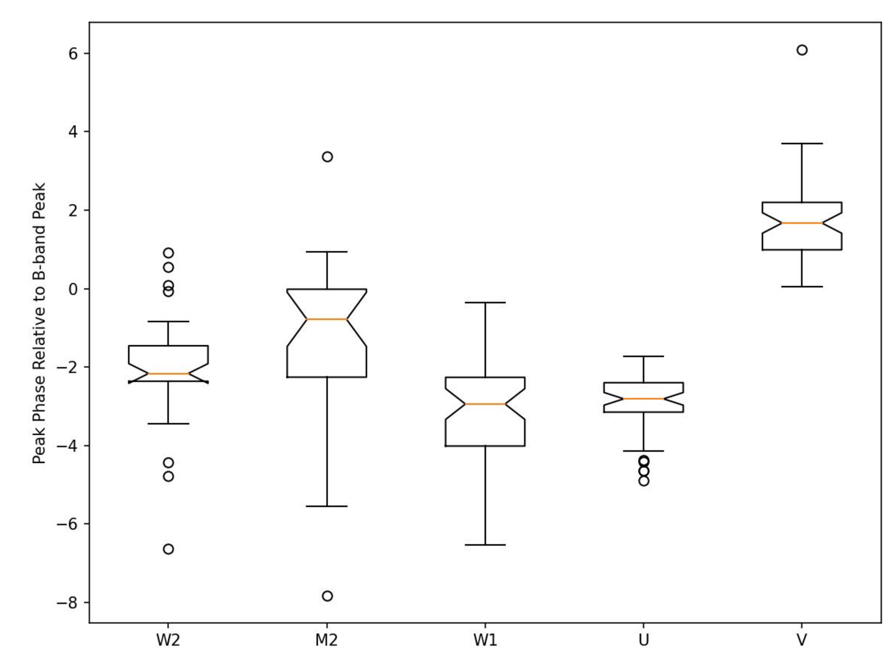
Right: The B-V evolution, which shows no clear distinction between any of the objects.





Time of Peak Variations

On average, SNe Ia peak ~2 days earlier/later in the UV/V relative to the B band (Devarakonda & Brown 2022). This timing can be a useful constraint when measuring the light curve peak with a limited number of observations. In addition, it appears that Super-Chandrasekhar mass SNe peak in the UV 4+ days earlier than in the B band. The UV may this provide interesting insights into the explosion mechanisms of SNe Ia.



Left: Tukey box plots of the peak phase relative to the B band for each of the Swift SNe in our sample.

References

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Conclusion

We examine 97 SNe Ia in the UV and optical (the largest such sample to date) and find no statistical difference in the diversity of the light curve parameters related to the decline rate and stretch. In addition, we find strong correlation between the near-peak decline rate and stretch related parameters between the UV and the B band. These relations can add useful constraints for future multi-band studies of SNe Ia, particularly those with limited observations or at higher redshifts. The UV can also provide useful information on the possible progenitors and the explosion physics of SNe Ia.

To capitalize on the potential of the UV, future facilities will require a number of advancements. SNe Ia are inherently fainter in the UV relative to the optical, and the available UV transmission filters are far less efficient than in the optical. As a result UV detectability remains a major issue that will need to be addressed. Rapid follow-up capabilities will be required to detect progenitor signatures near the explosion date. Finally, compatibility with the planned UV/optical/IR flagship mission recommended in the 2020 decadal will need to be considered.