Assembling Light Curves for ZTF Superluminous Supernovae

Interim Report

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1 Motivation

Core-collapse supernovae (CC SNe) are a class of supernovae caused by gravitational collapse of their progenitor stars. During the last decade, it has been found that some CC SNe seem to out shine all others. These superluminous supernovae (SLSNe) can be up to a hundred times brighter than a normal CC SN.

SLSNe of Type II; SLSNe-II can be explained in a relatively straight-forward way by the presence of an exceptionally thick circumstellar medium surrounding the progenitor star (these show strong hydrogen signatures in their spectra). SLSNe-I do not show any sign of circumstellar material. To explain the extra luminosity in these events, one popular model is that a magnetar is formed when the core of the progenitor star collapses, and that energy from the strong magnetic fields surrounding the magnetar is transferred into the supernova ejecta, driving the extra luminosity. SLSN-I light curves evolve over much longer time scale (2-5 times longer). The long rise time and high luminosity imply much more total energy. This is the driver for magnetar model.

One interesting observational fact about SLSN-I is that as time passes and the luminosity declines, their spectra start to closely resemble those of normal CC SNe of Type Ic. Type Ic SNe belong to a class called Stripped-Envelope (SE) CC SNe, and they originate from very massive stars that lose their outer envelopes due to strong stellar winds, or from stars in binary systems where one star is stripped of its outer envelope due to tidal forces. It has been shown that the luminosity of the majority of "normal" Type Ic SNe can be explained by radioactive decay of nickel formed when the core of the progenitor star collapses. However, there is a large range in the luminosity observed for Type Ic SNe, and some are very close to being just as bright as SLSN-I. Our objective is studying the optical lightcurves of SE SNe and SLSNe, and in particular focus on the transition from normal Type Ic SNe to SLSNe-I. The main questions we want to answer are:

- What is the range of possible light-curves for SLSNe-I?
- Could there be normal Type Ic SNe that are in fact more easily explained if they are powered by a magnetar instead of radioactive decay? Is it also possible that both of these classes always have some level of magnetar power and radioactive power at the same time, but the relative strength of the two varies.

In order to investigate the powering mechanism of these SNe and to meet the above goal, we need high quality lightcurves of all SLSNe and SE SNe thus far discovered by ZTF. During this research, we aim to produce a coherent database of light curves which can be directly fed into modeling softwares to derive physical parameters.

2 Initial Plan

For first few weeks, we aim at understanding the ZTF data systems and the software tools for extracting light-curves. This includes understanding how to obtain Point-Spread-Function (PSF) fitted photometry for non-detections in single epoch frames, and how to coadd non-detections over multi-epoch to achieve better depths. Next, we combine the processed light-curves with the data produced by the automated ZTF pipeline. One important step in the final data combination is to compute the supernova fluxes at the quiescent phases, and apply any existing offsets to the pipeline data. We then combine data from other telescopes to produce a reliable database.

3 Our modified approach

After 7 weeks of research, we found this approach to work better for any of the sources in our list.

- Initially, we started with a list of 25 SLSN-I objects. Forced Photometry was performed on each source and results were stored for further processing.
- Request IPAC PSF Photometry, to remove bad data. IPAC results contain two keys, namely, infobits and sigpix which can be used for filtering.
- We realized that the Forced Photometry package does not have access to Partnership data (MSIP data) recorded in 2019, because it has not been made public yet. We collect that data from Marshal.
- The next step is to perform baseline correction (rather than coadd; as described in the initial plan) for any existing offsets. This is computed in flux space and it varies for each combination of field ID and filter ID.
- Since we do not have flux and field ID values on Marshal, we query Kowalski for those points and pull out "magzpsci", "magzpsciunc", and "field".
- After we have all the necessary data, we begin with computing offset. We visually inspect the light curves to find a quiescent phase which can be considered as the baseline. We remove any outliers with respect to a weighted flux average (>3 x Standard Deviation).
- We then compute final offset and reduced chi square for rescaling error. After applying shift, we visually inspect that there is no supernova flux included in the baseline.
- To make our lightcurve measurements more statistically significant and/or with tighter upper-limits, we attempt to combine the flux measurements within carefully selected time-windows using a suitable method.
- We finally combined the data from all other telescopes and produce a beautiful lightcurve.

References

[1] Generating Lightcurves from Forced PSF-fit Photometry on ZTF Difference Images, Frank Masci and Russ Laher

[2] Type Ia Supernovae Observed by ZTF in 2018. I: Light Curves and Sample Properties, Yuhan Yao et. al.