SED Machine time request:
Measuring the asphericity of CSM around massive stars using ZTF SNe IIn on the rise

Summary

We aim to conduct a survey of ZTF type IIn supernovae (~10 objects) with early multiband monitoring, including Swift UV and ZTF g+r. This will allow us to constrain the rate of SNe IIn that show evidence for non-spherical circumstellar material (CSM). A dedicated Marshal program ("Type IIn Supernovae") was created. In order to send triggers to Swift while the SN is still rising, we need to be able to quickly identify SNe IIn. So far, four ZTF SNe were vetted as SNe IIn while still rising, three of which were observable by Swift when detected by ZTF. In order to identify seven more ZTF SNe IIn on their rise and reach a sample of 10 objects, we request 10 hours of SEDM time for this program.

Science case

Multiple bands measurement of interacting supernovae at early times allows to estimate the bolometric luminosity of the event, to infer the mass of the circumstellar material (CSM) around the SN and to deduce precious information about the yet to be confirmed progenitors of these types of objects. In particular, the early evolution of the effective radius and temperature encapsulates precious information about the geometrical distribution of the CSM around the explosion. Indeed, although observations of SNe IIn are usually analyzed within the framework of spherically symmetric models of CSM, resolved images of stars undergoing considerable mass loss (e.g., η Carinae; Davidson & Humphreys 1997, 2012), as well as polarimetry observations (Leonard et al. 2000, Hoffman et al. 2008, Wang & Wheeler 2008, Reilly et al. 2017) suggest that asphericity should be taken into account for more realistic modeling. Asphericity of the CSM has recently been invoked to interpret spectroscopic and spectropolarimetric observations of a SN IIn (SN SN2012ab, Bilinski et al. 2017). Moreover, Soumagnac et al. (2018) showed that early multiband photometry could trace the geometrical distribution of the CSM around the explosion. Figure 1 summarizes the main results by Soumagnac et al. 2018. Modeling radiative diffusion through a slab of CSM, we showed that an aspherical geometry of the CSM can result in a growing effective radius and explain the peculiarity observed in the case of PTF12glz: a phase of rapid radial expansion observed at the very time when the optically thick CSM should obstruct the observer's view of any expanding material (at early times, the measured blackbody radius of all other SNe IIn observed to date either stalls after a slight increase or stays relatively constant, or even shrinks, e.g. Taddia 2013). A rapidly growing effective radius during the optically-thick CSM emission phase - as observed in the case of SN PTF 12glz - is a possible signature of aspherical CSM. Constraining the geometry of the CSM around SNe IIn and the unknown fraction of events showing evidence for aspherical CSM would constrain the mass loss processes taking place in the months and years preceding the stellar explosive death and help characterize the progenitors of SNe IIn.

Our goal is therefore to obtain UV observations with Swift during the rising phase, use it along with ZTF g+r to quickly compute the effective temperature and radius from multiband photometry and put a lower limit on the rate of type IIn events that show evidence for non-spherical CSM, following the methodology by Soumagnac et al. 2018. In order to send triggers to Swift while the SN is still rising, we need to be able to quickly identify type IIn SNe. So far, ~20 objects have been identified as SNe IIn, but only four ZTF SNe were vetted as SNe IIn while still rising, three of which - ZTF18aavskep and ZTF18abgrlpv and ZTF18abltfho - were observable by Swift when detected by ZTF and we obtained Swift observations for them. We would like to request SEDM time in order to perform this quick identification and reach a sample of 10 objects in the coming months.

In Figure 2, we show the light curve of one of these three SNe IIn, ZTF18aavskep, and in Figure 3, we show the evolution of the effective radius and temperature derived from multiband photometry for all three objects. The blackbody radius of ZTF18abltfho stays relatively constant, which is consistent with the continuum photosphere being located in the unshocked optically thick CSM and is in agreement with the blackbody radius of most SNe IIn observed to date (Taddia et al. 2013). However, the two other objects show the same peculiarity as PTF12glz: the blackbody radius r_{BB} is growing at a velocity characteristic of fast moving ejecta rather than optically thick CSM and this phase of radial expansion takes place while both the spectroscopic data and the bolometric luminosity seem to indicate that the CSM is optically thick.

Following the interpretation applied to PTF12glz by Soumagnac et al. 2018, we deduce that two out of the three ZTF objects we observed show a signature of aspherical CSM. With a sample of 10 objects, we would be able to constrain the fraction of events showing this aspherical CSM, inspect correlations with other parameters (luminosity, spectral features), and test whether simple geometry + line of sight "unifying" models (e.g., broad CSM Tori, "hourglass" or bipolar CSM slabs) can explain the observations.

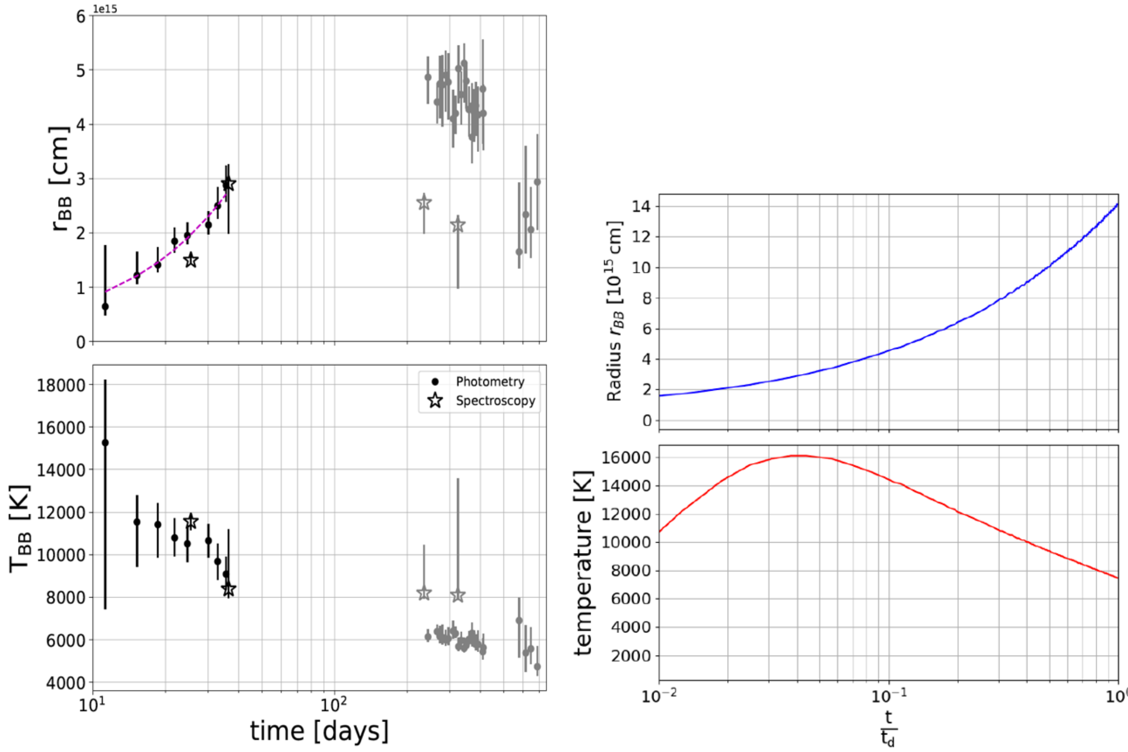

Figure 1: A summary of the results by Soumagnac et al. 2018. **Left:** The evolution in time of: (1) the radius (top panel), (2) the temperature (lower panel) of a blackbody with the same radiation as the SN IIn PTF12glz. The points were obtained by fitting a blackbody spectrum to the observed photometry. The stars indicate the values derived by fitting a blackbody to the spectroscopic data. The dashed line in the top panel shows the best linear fit to the rising radius phase: a linear function with a slope of ~8000km/s. The points shown in grey are less reliable and should be taken cautiously. **Right:** The evolution in time of: (1) the blackbody radius (top panel) and (2) the blackbody temperature (lower panel) at the surface of a slab with constant density. The aspherical geometry of the slab allows to recover the increase of r_{BB} and the decrease in T_{BB} shown on the left panel. The time is given in units of the diffusion time t_d. Soumagnac et al. 2018 showed that the growing radius is preserved with a density profile $\rho \propto z^{-1}$ or a wind density profile $\rho \propto z^{-2}$.

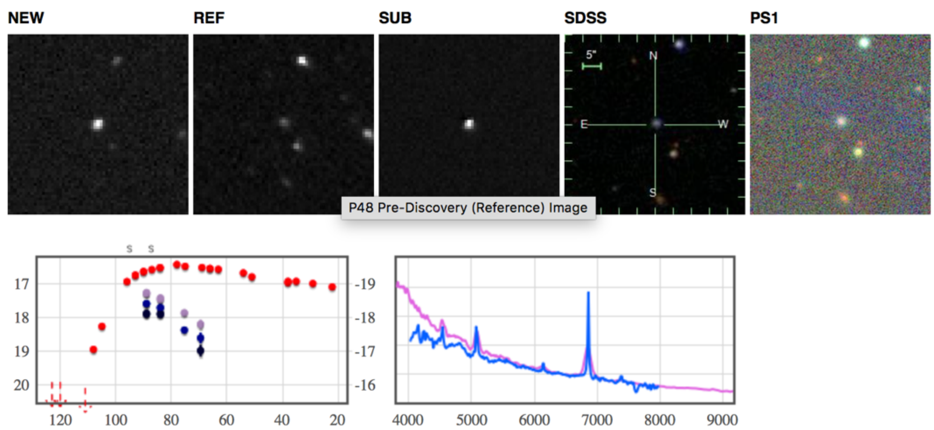

Figure 2: a summary of the observations of ZTF18aavskep. In the photometry panel (lower left), we show P48 r-band (red) photometry, as well as Swift UVW1 (purple) UVW2 (black) and UVM2 (blue) photometry. In the spectroscopy panel (lower right) we show spectra taken by the P60 SEDM (blue) and LT SPRAT (pink) spectrometers.

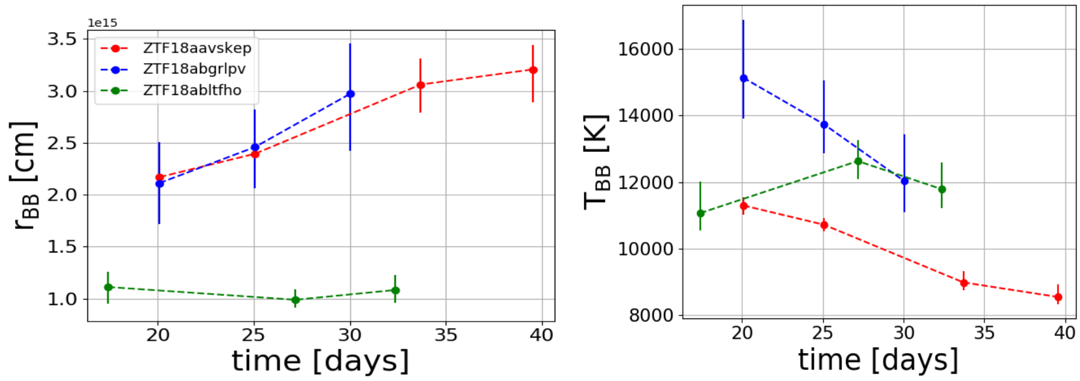

Figure 3: The evolution in time of: (1) the radius (left panel), (2) the temperature (right panel) of a blackbody with the same radiation as the three objects observed so far: ZTF18aavskep (red), ZTF18abgrlpv (blue) and ZTF18abltfho (green). The points were obtained by fitting a blackbody spectrum to the observed photometry. The errors were obtained with Monte Carlo Markov chain simulations. Two out of three objects show the same peculiarity as PTF12glz: a radius r_{BB} growing at velocities characteristic of rapidly expanding material, at the very time when the spectroscopic data seem to indicate that optically thick CSM should obstruct the observer's view of any growing structure.

Uniqueness:

This will be the first survey of early UV observations of SNe IIn. It will also be the first study of the rate of SNe IIn showing evidence for aspherical CSM, and will give new clues about the nature of the progenitor of SNe IIn and the mechanisms at stake in these events.

Expected outcome and publication plan:

We are planning to publish this sample and the results of our analysis in a paper. With about one objects observed per month so far, the 10th and last object of our sample should only be observed in the summer of 2019. However, our analysis tools are already ready and running (see e.g. Figures 2 and 3) and we are analyzing the data and obtaining results on the go. We believe we will be able to submit a paper ~2 months after the observation of the last object, i.e. in the fall of 2019.

Manpower available

For the moment, the people involved in this project are Maayane Soumagnac, Avishay Gal-Yam and Eran Ofek. However, there is interest in SNe-IIn in the SNe SWG and we believe more collaborators will join the project in the coming months.

Triggering criteria:

The following four criteria will be applied in order to select targets for SEDM vetting:

1. The apparent magnitude should be lower than 18.5, to allow observation by the SEDM.
2. The rise time should be longer than 20 days, which will allow to exclude the most standard SNe Ib, Ic and most SNe Ia and restrict the sample to SLSNe (including type IIn) and SNe Ia.
3. In case there is redshift information from the host galaxy, the absolute magnitude should be lower than -19, which would further restrict the sample to SLSNe (including type IIn) and only bright SNe Ia.
4. In order to further exclude SNe Ia, we will use the new fitting functionalities of AMPEL, and perform a quick comparison of the g+r data to SNe Ia templates and SLSNe templates.

Of the population of long-rising non-SNe Ia events (SNe IIn, SLSN-I, SLSN-II), we expect SLSN-I to be no more than 10% (this is supported by PTF SN statistics). The majority of these events will be SNe IIn, and as for SLSN-II, we cannot distinguish them from luminous SNe IIn. Indedd, as explained in Gal-Yam 2018, the majority of SLSNe-II show strong narrow emission lines in their spectrum, and although the separation between these events and their lower luminosity SNe-IIn "cousins" remain unclear, it seems like CSM interaction plays an important role in these events. Our analysis - which will constrain the geometrical distribution of the CSM - will be interesting and relevant to SLSN-II too.

Under the conditions above, SEDM will be triggered with priority 4, for targets that have not been classified by other programs. We emphasize that we need the classification before peak, so we cannot wait for peak SEDM spectra obtained by programs such as RCF, but our identification spectra will save some time for these other programs (both if we succeed in selecting SNe IIn and if we fail).

Given that we need 7 more objects to complete our sample, and taking into account the SLSNe-I and other possible peculiar objects which will pass our selection criteria, we request 10 hours of SEDM for this program.

1. References

Bilinski, C., et al. 2017, arXiv:1712.03370
Ofek, E. O., et al. 2013b, ApJ, 763, 42
Davidson, K., & Humphreys, R. M. 1997, ARA&A, 35, 1
Davidson, K., & Humphreys, R. M., eds. 2012, ASSL, Vol. 384
Smith, N. 2014, ARA&A, 52, 487
Gal-Yam, A. 2016, ArXiv e-prints, arXiv:1611.09353
Gal-Yam, A. 2018, ArXiv e-prints, arXiv: 1812.01428
Hoffman, et al. 2008, ApJ, 688, 1186
Soumagnac, M. T., et al. 2018, arXiv :1808.04232
Taddia, F., et al. 2013, A&A, 555, A10
Leonard, D. C., et al. 2000, ApJ, 536, 239
Reilly, E., et al. 2017, MNRAS, 470, 1491
Wang, L., & Wheeler, J. C. 2008, ARA&A, 46, 433