A large, unbiased stripped-envelope supernova sample from ZTF

Summary:

We want to construct the largest stripped-envelope supernova (SE SN) sample in order to determine the progenitor and explosion properties of these transients, namely ejecta masses, explosion energies, Ni masses and distribution, and progenitor radius. To this purpose we want to use SEDM to specifically classify transients brighter than r=19.5 mag (and fainter than r=18.5 mag, as those brighter than 18.5 mag will be covered by other SEDM proposals) at peak with at least 3 epochs on the rising part of the light curve (i.e. ~9 days coverage on the rise of SE SNe discovered not later than 8.5 days post explosion). We will also use an additional *g-r* color selection to reduce SN Ia contamination. With these triggering criteria, based on a MSIP simulation we will need about 78 hrs (9% SED machine time) to classify all these SE SNe during the first 6 months of ZTF. The P48 *g+r* data and a classification SEDM spectrum around peak is all that is needed to answer the main scientific questions.

Science case:

During ZTF we want to observe **the largest sample of stripped-envelope supernovae (SE SNe) with pre-maximum coverage and multiband light curves**. To this purpose we need to ensure the classification of these transients, and the SED machine is ideal for this scope. With this sample we aim to answer at least three important scientific questions, all related to understanding the nature of the progenitor stars of SE SNe:

1) <u>What is the **range and distribution of ejecta masses of SE SNe** and thus of their progenitor initial masses?</u> We know from the literature that most SE SNe have a relatively narrow light curve shape suggesting moderate ejecta mass (~2-4 solar masses). However, with iPTF we discovered a handful of SE SNe with broader light curves which might have more massive progenitors, e.g., iPTF15dtg. We also found an object like iPTF14gqr, with a much narrower light curve than average, very likely arising from an ultra-stripped progenitor. With ZTF we will be able to discover these SNe routinely, and we aim to follow them to characterize their light curve shape in the first couple of months.
2) <u>What is the **progenitor radius of SE SNe**?</u> Most SE SNe have light curves compatible with compact (1-10 solar radii) progenitors, i.e., they do not show early excess before the rising phase of their light curves or they show them only if discovered very early and nearby (e.g., iPTF13bvn). However, with iPTF we found some SE SNe, for example iPTF15dtg and iPTF14gqr, with a clear early peak in the optical, compatible with the presence of an extended envelope (tens to hundreds of solar radii) around their progenitor stars. With ZTF we will find early excesses routinely, allowing us to study how many SE SNe have such envelopes and from which systems (e.g., close binaries) they originate.
3) <u>**Where is the radioactive fuel located**?</u> Early, multi-band observations of SE SN light curve shapes as well as velocity measurements can provide an estimate of how far out in the ejecta the Nickel is mixed, as they allow us to know the evolution of luminosity and temperature, as well as the explosion day with small uncertainty. It is of importance to know the degree of Ni mixing to understand how the SE SN explode and also to clarify to which level the difference in Ni mixing is responsible for different SE SN subtypes, i.e. If a low Ni mixing can produce He-poor/ SN Ic spectra despite the presence of He in the envelopes.

The SE SN samples currently available are mainly targeted (i.e. 34 SE SNe in Taddia+17, CSP), and furthermore non homogenous (i.e. literature collections by Cano+13, Lyman+16, and Prentice+17), or rather small if not targeted and homogeneous (i.e., 20 SNe in Taddia+15, SDSS II). With iPTF we improved on these aspects, and we are preparing 3 papers on SNe Ib, Ic, and Ic-BL which contain a total of about 90 SE SNe with light curves observed before peak, from a clearly untargeted and homogeneous sample. One limitation of iPTF is the lack of early, pre-peak color information for most of these SNe. From the observational point of view, ZTF will obviously provide more targets, but even more important it will provide more color information from the very beginning (g and r band from P48). Bolometric light curves and temperatures can be built with these multi-band data, helping us to answer our three questions without additional photometric data. Spectroscopy, first for classification then for follow up, will be needed and the SED machine can help with the classification part.

Triggering criteria for the SED machine:

Peak magnitude limit and light-curve coverage on the rise:

We plan to trigger the SED machine to classify the SE SNe around peak as soon as we obtain the required light curve and color information. The SED machine can classify SNe up to 19.5 magnitudes in the r band. Based on the detailed MSIP simulations which make use of the SN Ibc light curve template by Nugent, in the first 6 month of ZTF we will find 378 SNe Ibc within this magnitude limit. However, for our science case we want these SNe to be discovered early and to be covered during their rising phase, in order to characterize their light curve shape and thus, ejecta mass, progenitor radius and mixing. We require at least three nights of observations before peak, i.e. that the SNe are discovered at least 9 days before peak, assuming one SN field observation every 3 nights (MSIP). The average rise time for SE SNe is 17.5 days (see Taddia+2015), so we want to follow SNe which are found not later than 8.5 days after explosion on average. This implies, according to the simulation, a number of 125 SE SNe. This is already on the same order as the numbers of SNe Ibc observed before peak with PTF/iPTF in about 7.5 years.

Color cut to reduce the SN Ia contamination:

When triggering, our main problem will be to avoid classifying SNe Ia. Other SNe have light curve shapes before and around 2-3 weeks after discovery that are easier to reject when selecting SNe Ibc (e.g., SNe IIP, IIL or IIn). Without trying to cut the SNe Ia with further triggering criteria, we would find 927 SNe Ia, i.e., out of 10 SED machine triggers 1 will be a SN Ibc, and 9 a SN Ia. Luckily, there are differences between SNe Ibc and Ia. For example, SNe Ia are more luminous on average, with their absolute peak magnitudes being around -19.6 mag. Furthermore, their colors are bluer at peak. However, a selection of the candidates to be classified based on the absolute magnitude at peak implies a selection based on the redshift or photo-redshift of the galaxy, which might bias the sample toward bright galaxies. This we do not want to happen, as one of the advantage of ZTF is the untargeted nature of this survey, so we prefer to select the SNe based on their g-r color around peak. With g-r at r-band peak redder than 0.2 mag we consider our candidates good to be triggered. This is the bluest g-r value at peak for SE SNe from iPTF, CSP and SDSS (here we have considered MW and host extinction correction). It is possible to simulate how many reddened SNe Ia are within this color range at peak, and within the same magnitude cut and phase cut. This will be our contamination after color cut. The MSIP simulation indicates that 42 SNe Ia would contaminate the sample after the color cut, i.e., when applying our criteria we will need 167 SED machine triggers to get the whole SE SN sample (125 for SE SNe, 42 for the contaminating SNe Ia). Assuming 1 hour exposures and 8 hrs/night, the program above would require about 167 hrs = nearly 19% of the total SEDM usage. However, this program will largely overlap with another SED machine proposal on transients which aims to classify everything that peaks brighter than 18.5 mag in the r band. Within this sample, there are 87 of the SE SNe we are interested in and 2 contaminating SNe Ia. Therefore 38 extra SE SNe will be added by our triggering criteria and 40 SNe Ia will also match our triggering criteria, which are less tight on magnitude but tighter with respect to the discovery phase. Assuming 1 hour exposures and 8 hrs/night, the program above will require about 78 hrs = nearly 9% of the total SEDM usage.

Expected outcome and publication plan:

During the first 6 months we plan to start building the datasets for at least 6 sample papers: 1) SN Ib sample; 2) SN Ic sample; 3) SN Ic-BL sample; 4) SN IIb sample; 5) Broad (15dtg like) SE SNe sample; 6) Narrow (14gqr) SE SNe sample.

Manpower available:

4 Post-docs (Barbarino, Fremling, Taddia, Tartaglia) working on SE SNe from ZTF for the whole ZTF period, and at least one PhD starting 2018. We have the machinery developed during iPTF and in the study of other SE SN samples (CSP, SDSS) to rapidly reduce, analyze large numbers of SE SN light curves to derive their progenitor properties.