Discovering Failed Supernovae with ZTF

Response to ZTF-EFC Comments and Suggested Strawman Surveys

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1 Suggested Strawman Surveys

Table 1: Summary of the number of failed supernova shock breakouts expected to be discovered by the different survey options. The absolute numbers are very uncertain (this is a theoretically-predicted phenomenon yet to be observed), but the relative numbers are much more firm. The numbers for the "Coadds" case assume that the transient detection pipeline is run on nightly coadds prior to the subsequent night.

Strawman	Fast	Wide	Combo
Standard	0.4	0.8	0.4
Coadds	1.1	N/A	0.6

The fiducial case we presented in our white paper of 6000 sq degrees (outside of the Galactic plane) surveyed in g with nightly cadence for twelve months had an expected yield of $\sim$2 failed supernova shock breakouts per year. We acknowledge considerable uncertainty in this prediction given the uncertainties in theoretical models, but the *relative* rates that we present for the different survey options are more firm. We also stress that confirming a single event would constitute an important discovery.

1.1 Standard Image Processing

We first consider the expected yields for discovery pipelines being run only on individual images. In §1.2 we will consider the potential of running the discovery pipeline on nightly coadds to improve the nominal yields for the fast survey options.

1.1.1 Wide Survey

As we discussed in our white paper, the optimal strategy for discovering a shock breakout from a failed supernova is to maximize the areal coverage with nightly g cadence. Thus, the best strawman option for this is the "wide" survey. The I band component would not increase our discovery sensitivity (since these events are expected to be much brighter in g than I). Scaling from the prediction for the fiducial survey in the white paper by ratio of the g-band survey areas (3240 sq-deg/6000 sq-deg) and times (9 months/12 months), the expected yield for the wide survey would be $\sim$0.8/yr.

1.1.2 Combo & Fast

Similarly scaling for the combo and fast surveys the expected yield in each case would be $\sim$0.4/yr.

1.2 Coadds

Although the wide survey is clearly the best strategy for this science case when running the image-subtraction/transient discovery pipeline on individual images, the increased depth of nightly coadds could potentially offset the hit in areal coverage in the fast survey, but only if the coadds are generated and processed before the subsequent night (and preferably in nearly real-time). A nightly coadd from the four (three) visits in the fast (combo) survey would be $\sim$0.8 (0.6) mag deeper than a single visit. Scaling by these depths (as well as the areal coverage) the nightly g-band survey volume of the fast survey would actually exceed that of the wide survey (since the latter spends half the time on I-band imaging; see Table 1). We do note, however, that the coadd approach would make candidate follow-up more expensive (since the typical candidate with this approach would be more distant and, because of the delay in making the coadds, follow-up of these rapidly fading events would likely be pushed back past their peak by an additional night).

2 Reviewer Comments

> *Given that the signal extends over a day timescale I encourage the authors to consider implementation of a search on nightly coadded images to go beyond the 60 Mpc, which could increase the signal rate in a narrow, high cadence survey. This could be done jointly with other groups in the partnership (early SN Ia, lensed SNe, ...) and would correspondingly help many efforts.*

This is a good point that we consider in §1.2.

> *I think that the suggested strategy is not adequate for this specific project. SN shock breakout are short lived - even for RSG it is <1 hr. This reduces the claimed rate by factor of >24. In fact we can rule out the claimed rate based on PTF non-detections... In addition, the assumed SN rate which is likely too optimistic.*

The shock breakout from a failed SN would be much longer lived than for a normal SN because the shock velocity would be on the order of 100 km/s rather than 10,000 km/s. Both analytical and numerical models of shock breakouts from failed SNe predict durations of a few days (see Piro 2013 and Lovegrove & Woosley 2013 and Fig. 2 of the white paper).

The optimal survey strategy with 70% of the collaboration used as the fiducial case in the white paper only has an expected yield of 2 failed SNe per year for ZTF. Simply scaling by the ratio of the volumetric survey rates of ZTF to PTF (~ 11) and survey times (0.28 for 70% of 40%) the expected yield from PTF would only have been 0.6 per year if PTF had been operating in an optimal mode (maximizing the areal coverage with nightly cadence) with spectroscopically-complete follow-up for these particular candidates. PTF operated with at least twice per night cadence, which already knocks down the expected rate in the PTF data to less than 0.3 per year even before accounting for incompleteness in the follow-up. The assumed SN rate is probably correct within a factor of 2 (see, e.g., Horiuchi et al. 2011).

> *The suggestion to find transients based on single observation was never tested in PTF on large scales.*

As discussed in §3 of the white paper we propose to select candidates based on *two* detections in two consecutive nights following a non-detection.