Response to ZTF-EFC comments and suggested strawman surveys

Cosmology with Type Ia supernovae

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All state-of-the-art SN Ia cosmology surveys at $z > 0.1$ during the past decade have in common that they were carried out in so called "rolling-search" mode, with one instrument, using at least three filters. This means that the surveys were used both for discovery and follow-up simultaneously, which secures early discovery and automatic follow-up before the objects have been spectroscopically classified. It also facilitates the accurate calibration of the complete data set. All are crucial components for doing high-precision SN Ia cosmology. **With the uniqueness of ZTF, we see an opportunity to carry out such a program, for the first time, also at the low-z.** This will allow us to obtain a high-quality and complete sample also in a redshift region that is paramount for anchoring the Hubble diagram and for studying SN brightness and environmental relations.

Suggested strawman surveys

Table 1: Summary of the number of expected objects that will fulfil the requirements stated in the WP.

Strawman	Fast	Wide	Combo
SNe Ia	0	300	650

Fast

This strawman survey is only using two bands and cannot be used for the proposed program (see also below).

Wide

Depending on the exact strategy, this survey could discover up to $\sim$ 300 SNe within $z < 0.1$ during the first year. The expected redshift distribution is shown in Figure 1a). The quality of the individual lightcurves will meet the criteria specified in the WP. If the campaign continues over three years it would result in a data set of the same size as competing campaigns. The advantage of the ZTF SN Ia set is that it would not be affected by many of the selection effects that are expected to plague other samples. However, the size of the total sample would not be sufficient to reach our ambitious goals of setting the error floor for future SN Ia cosmology surveys, or measuring anisotropies in the local Universe at the level predicted by standard cosmology.

Combo

If the survey is optimized to pick $6,700$ sq. deg. with the visibility and with a compromise of allowing for higher airmass than was assumed in our WP calculations, it can be used to discover and follow ~ 650 SNe Ia at $z < 0.1$ during the first year (Figure 1b). Both the sample size and the cadence would then be sufficient to meet the criteria that were specified in the WP. The drawback would be that less total area would be covered which affects our anisotropy studies, but out of the three suggested strawman surveys, this is the one that would be preferred. Another advantage of this survey over Wide, is that it has the flexibility that a high number of SNe Ia with i-band coverage can be obtained even if the upper redshift limit of the survey is lowered.

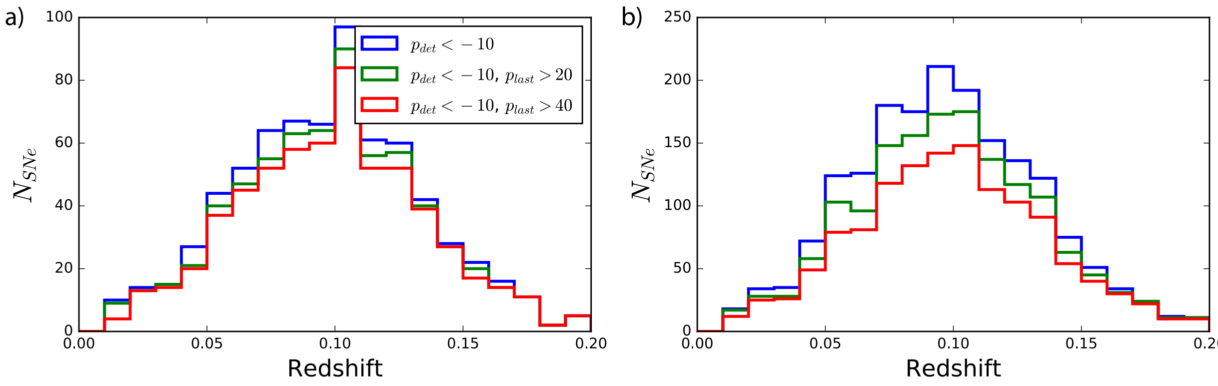

Figure 1: Simulated redshift distributions of SNe Ia with i-band coverage for the wide (a) and combo (b) strawman surveys. The distributions are shown for three different cuts in lightcurve coverage; SNe that are detected at least 10 days before peak brightness (blue) and that are followed until 20 (green) and 40 (red) days past maximum.

Reviewer comments

Figure of Merit

> *First, there did not seem to be any attempt made to define a (quantitative) figure of merit (FOM). Typically in such cosmology efforts I see this defined as proportional to the confidence interval of some parameter of interest (e.g., w), so I'm not sure why the authors did not do so here. It would help make their case, for example, if they could claim that the FOM would be 50% lower if we did not execute this i-band survey.*

The FOM, as defined by the Dark Energy Task Force, i.e. the (scaled) inverse enclosed area of the (w_0, w_a) confidence contour, increases from 6.54 to 11.25 when the proposed ZTF survey is added to a future WFIRST survey (together with existing data). If the i-band data were to be obtained elsewhere and the calibration between ZTF and the other site would be $\sim 2\,\%$ (see below), it would translate into a systematic uncertainty between ZTF and the high-z sample which would decrease the FOM with a factor 2–3. In other words, it would not add any statistical weight to future cosmological analyses.

It should be emphasized that calculating a cosmological FOM similar to above will always depend on the assumptions of systematic errors once the statistical floor has been reached. An important goal for this proposal is to be able to **quantify this floor** by subdividing the data into smaller samples, based on SN or host galaxy properties, that are by themselves competitive cosmological samples. One example of a property that has been shown to correlate with SN distances is host galaxy mass, and all current SN cosmology analyses are correcting for this relation. However, existing data does not allow to characterize the relation beyond a simple binary classification (high/low host mass), and the size and significance vary between different data sets. Clearly both statistics and selection effects are limiting the current data, which become systematic errors in cosmology analyses. This serves as a good example of one open issue that we plan to address with the ZTF SN Ia sample.

It should also be pointed out that the impact on cosmology of the sample does not stand and fall with future data. The ZTF SN Ia sample alone will be sufficient for measuring the local value of H_0 and for studying anisotropy in the local universe at a precision that can test standard cosmology.

Follow-up

> *Second, I'm seriously concerned about the planned follow-up. As it stands, the authors claim they require high SNR (10 per resolution element, though this is not justified anywhere) spectra of all SNe in their "core" sample. Presumably this corresponds to ~ 2000 events, or ~ 2 per day. Many (most!) ZTF discoveries will be too faint for*

SEDM spectra - with iPTF it is really only possible to get classification spectra for sources with g/R < 19 mag, and these definitely do not have SNR > 10 per resolution element. Where will these spectra come from? Even if the team just limits themselves to sources with g/R < 19 mag (maybe their 2000 number corresponds to this peak brightness?), and even if they had no contamination from other transient classes (it would be nice to see this discussed, by the way) this would still occupy ∼ 2/3 of the SEDM time available to the collaboration (65 % of time x 60 % weather = a bit less than 4 hours per night).

First, we wish to clarify two calculations from the original WP:

- Thanks to the "rolling search" mode of the survey we can afford to wait until maximum brightness (which can be predicted from the early lightcurve) before obtaining spectroscopy. Within 2 days from maximum 90 % of the SNe Ia within $z < 0.1$ will be brighter than 19.2 mag.

- The contamination from other transient classes is expected to be moderate. The lightcurves of SN Ia are similar to SN Ib/c, but the fraction of the latter is not expected to be more than $\sim 8\,\%$ (based on iPTF). In fact, the main source of contamination will be SNe Ia at $z > 0.1$ that could represent as much as $\sim 25\,\%$ of our photo-typed sample. This contamination fraction can be decreased, but at the expense of loosing SNe Ia $z < 0.1$.

- SNR estimates were calculated as follows: medium-resolution Type Ia spectra are cropped and rebinned to the wavelength range and resolution of the SEDM. The spectra are then degraded, and finally typed using SNID. We find that a SNR∼5 classifies SNIa at $\sim 90\,\%$ efficiency. However, to *sub-classify* within the Ia family our simulations show that a SNR∼10 is required to reach the same efficiency.

The core of the ZTF Ia program can be executed also with SEDm SNR< 10 through only classifying transients as Ia at peak (SNR∼5, < 19.2 mag). This sample would then have to be complemented with high signal-to-noise follow-up spectroscopy obtained for a random subsample of the full ZTF Ia data set. The latter can be used to determine the contamination fraction of different sub-classes. However, it would require SEDm and additional spectroscopic observations of the **same** targets. OKC and Humboldt University are members of the ePESSTO consortium and have applied for a program to obtain such spectra of ∼ 200 SNe Ia during the first two years. In addition to this, we can also obtain ∼ 30 spectra with the NOT for the same time-frame. A homogeneous ZTF Ia lightcurve + spectroscopic sample can further be used to improve, and possibly develop new, photometric typing methods which are in high-demand for future transient surveys such as LSST.

For the existing SEDM observing strategy (A/B pairs) we find that a SNR∼5 can be reached with a total exposure time of ∼ 2600 s which would sum up to a requirement of 1.5–2.2 hours per night for if we were to classify the entire SN Ia sample with the SEDm. A fraction of these will already be typed by the community, or the collaboration, and thus not require observations to be triggered. We are further looking into the possibility of buying additional spectroscopy time to observe the SNe that are not classified elsewhere.

Planned improvements of the SEDm

We expect the SEDm depth to be significantly improved during the coming six months, and it is expected to approach the original expectation. In some more detail:

- The camera will be disassembled during the coming months, and modifications will be made to reduce the level of scattered light. In particular, the Caltech crew will experiment with inserting a black grid over the slicing optical element. The most troublesome IFU scattered light usually occur with light hitting the edges separating spaxels.

- We will investigate using additional arc lamp exposures, which could be used either regularly during the night or directly adjacent to challenging exposures. With that data, a wavelength solution without systematic effects due to instrument flexure can be derived. Systematic shifts in the IFU wavelength solution directly impacts the SNR as the uncertainty gets propagated into shifts in the spatial dimension extraction.
- Mickael Rigault is already working with Don Neil in rewriting the SEDm pipeline, incorporating much of the lessons learned in writing the SNIFS pipeline. A proper pipeline will, at a minimum, be able to avoid the A/B exposure model, which in itself should boost SNR with $\sqrt{2}$. (https://github.com/ZwickyTransientFacility/pysedm)
- Currently missing from the SEDm pipeline is removal of the host galaxy light. Doing this correctly for an IFU is a computer intensive task, but has in principle been solved (see Bongard et al 2011, or https://github.com/kbarbary/cubefit). This methodology will be applied also to SEDm data.

Combined, these ongoing tasks target the known weak areas for IFU data and will improve the SEDm SNR.

Other facilities

> *Finally, there was some discussion why this project could not be conducted with other facilities. The total requested time did not seem too overwhelming: a few hours per night on a 1–2 m class telescope (such resources are available, e.g., from LCO) . Some additional discussion of the difficulties of a second level of calibration would be appreciated.*

The real-time calibration from the IPAC pipeline will produce photometry at the few % level – not sufficient for modern SNIa cosmology. A number of surveys have now demonstrated the path towards % level photometry (SDSS, SNLS, PS) through a series of additional steps ("second level calibration"). These include: sensitivity maps that are continuously updated using star-flats, accurate estimate and removal of ghost/halos, determination of filter profile vs spatial and temporal variations, construction of an accurate PSF model and "scene" model fit to an entire lightcurve with host galaxy light, determination of a model for the atmosphere (to relate to external catalogues) or an internal magnitude full ubercal. All of these are instrument and site specific, meaning that they have to be repeated for every instrument, but can in most cases be applied to several filters. It will be a demanding, multi-year project to implement these steps for ZTF. Doing it for a second telescope in addition is not realistic, especially since this would require that facility to grant the necessary calibration time and equipment.

Using ZTF for discovery only and do all the follow-up up photometry (including calibration) at another facility, e.g. LCO, would therefore be a major investment in the second facility. Assuming observations in three filters for 650 SNe of 10 points on each lightcurve and with the expected redshift distribution from ZTF would require ~ 180 **nights per year** assuming 15 % overhead (but not including calibration). Further, with this approach we lose the benefit of "rolling search" and would have to type candidates earlier to initiate follow-up (thus increasing spectroscopy demand). We would also only get high-quality lightcurves of our core-sample, while with this proposal we get high-quality lightcurves of a much larger sample of SNe that can be used for studies of e.g. SN rates and large photometrically typed samples.