ZTF Whitepaper: Building a Statistical Sample of Early TDE Light Curves with ZTF

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Abstract: Our goal is to produce a statistically significant sample of tidal disruption events (TDEs) over the 3 year ZTF survey in order to study rates and TDE parameters (black hole mass, star mass and radius, impact parameter, etc) as a function of host galaxy properties. ZTF will be the first to yield a sample large enough (previous surveys have produced a sample of at most 4 TDEs) to allow us to infer the existence of statistically significant relations between the TDE parameters and host properties, and measure rates.

While wide and shallow surveys (like the ZTF MSIP) will capture general TDE demographics (rates and peak luminosities and temperatures), here we focus on the unique returns from the ZTF partnership survey with regard to extracting the ***physical parameters of the events*** (black hole mass, star mass and radius, impact parameter, etc). The ZTF partnership survey is the only survey capable of accomplishing this goal, since we require well-sampled light curves with data points on the rise to peak in order to determine the ***rise-time*** of the events, which is related to the fallback timescale:

$$\Delta t = 41\ d\ (M_{BH}/10^6\ M_{sun})^{1/2} (M_{star}/M_{sun})^{-1} (R_{star}/R_{sun})^{3/2}$$

an important probe of the central black hole mass (M_{BH}), and the ***shape of the rise to peak***, which is sensitive to the density profile of the disrupted star, and can distinguish between stars of different masses (fully convective vs. radiative) (Lodato et al. 2009; Guillochon et al. 2013). Note, that <u>only 3 out of the dozen optical TDEs in the literature have well-sampled pre-peak light curves for which such an analysis is possible</u>: PS1-10jh (Gezari et al. 2012), PTF 09ge (Arcavi et al. 2014), and iPTF 16fnl (Blagorodnova et al. 2017).

An important obstacle to overcome in creating this sample will be efficient filtering out of more common interlopers (nuclear SNe and flaring AGN). This will be necessary in ***real time***, if we want to enable prompt spectroscopy of bonafide TDEs in order to catch transient emission lines powered by the events, and confirm their classification as TDEs.

Private Partnership Survey Design Requirements:

TDEs have observed rise-times (from 1 magnitude below peak) of 10 days (iPTF 16fnl) to 30 days (PS1-10jh and PTF 09ge), and so to get good sampling (> 5 points) we require a 2 day cadence. However, accounting for weather losses (40% of the time) this translates to a 1 day cadence requirement. We have other requirements that are critical regarding filter choice (to enable culling of SN interlopers from color information) and area (to ensure a large enough number of detections). To summarize, our requirements are:

1) ***Cadence: A 1 day cadence.***
2) ***Filters: We require g+R observations on the same night.***

3) ***Area: We would like to maximize the area covered per night (3750 deg^2).***

IPAC Pipeline/Marshal Requirements:

1) We require the ***positional offset information*** (delta_ra and delta_dec in arcsec) between the nearest source in the registered reference image and the detection in the registered difference image.
2) We require ***real-time catalog matching*** with SDSS and PS1 for star/galaxy separation and optical colors of the host.
3) We require the ability for the IPAC pipeline to ***coadd*** all the exposures in a given filter on a given night, and perform real-time image subtraction on the nightly coadd.

Simulations:

Our simulation parameters:

40% private collaboration time
Average length of night: 10 hours
Area survey speed: 3760 deg^2 hr^{-1}
Planning for 4 hours a night = 15,000 deg^2 / night

Option A: g+R every night over **7500** deg^2, mlim=**20.5** per epoch
Option B: g+R x 2 every night, coadded, over **3750** deg^2, mlim=**20.9** per epoch
Option C: g+R x 4 every night, coadded, over **1875** deg^2, mlim=**21.25** per epoch

Simulation:

We use **Uli's simulation tool** and the following assumptions:

1) volume rate of 5e-8 Mpc^{-3} yr^{-1} (van Velzen et al. 2014)
2) peak absolute mag ranging from Mg = -19 to -21 mag (Arcavi et al. 2014), and a light curve that follows the fallback model fitted to PS-10jh (Gezari et al. 2015)
3) multiply by 0.6 to account for 40% of time due to weather losses

In the table below we list the **area**, limiting magnitude (**mlim**) per night (from coadding the exposures during the night in each filter), **cadence**, **total** number of TDEs detected, number of **bright** TDEs (g < 19 mag at peak), and number of TDEs detected **early** (at least 30 days before peak). We assume both g+R are observed on each night. We also show the expected detection rates scaled from the SDSS search by van Velzen et al. (2011). These are close to our simulated **early** detection rates, and consistent with the fact that the SDSS TDEs were detected with a peak at least 1 mag brighter than the detection limit of the survey. Note, that our **total** TDE detection rates require only a 5 sigma detection in one epoch.

	area	**mlim**	**cad**	**total**	**bright**	**early**	**van Velzen et al. (2011)**
Option A:	7500	20.5	1d	32	2	5	6
Option B:	3750	20.9	1d	34	2	7	5
Option C:	1875	21.25	1d	17	0	7	4
MSIP:	15000	20.5	3d	48	4	6	12

We find that the optimal survey for well-sampled pre-peak TDE light curves and a large total sample of TDEs is Option B. ***While MSIP will detect a similar number of early TDEs, the 3-day cadence will not be sufficient to sample the early rise of the TDEs well-enough to extract physical parameters.***

End-to-End Planning:

SEDM spectroscopy:
The partnership survey will yield at most 2 bright (g<19 mag at peak) TDEs per year. Assuming a contamination rate of 9:1 from non-TDE blue nuclear transients determined from our iPTF experiments, this yields a manageable load of 2 SEDM triggers per month.

Other optical spectroscopy: DCT, Gemini, Palomar, Keck
We will propose for spectroscopy on DCT, Gemini, Palomar, and Keck to get spectroscopy of the 5 fainter (20 < g < 19) early TDEs each year.

UV/X-ray follow-up: Swift, HST, Chandra, XMM
We will propose for intensive Swift follow-up of the 7 TDEs with early light curves.
We will propose for Chandra/XMM X-ray imaging and HST UV imaging and spectroscopy observations of the 2 bright TDEs.

Radio Follow-up:
Radio observations are instrumental for completing the study of TDE physical properties, such as their energetics and shock physics, as well as for probing the interstellar medium (ISM) near the SMBH. In case of a relativistic TDE, such as SwiftJ1644+57, the radio observations provided the calorimetry of the event. For non-relativistic TDEs, radio observations probe the presence of off-axis jets and non-relativistic outflows.
We will propose for JVLA and AMI follow-up of the 2 bright TDEs in order to determine the presence of an outflow or jet.

Host Galaxy Follow-up:
We will propose for high-spatial resolution K-band imaging and high-resolution optical spectroscopy of the confirmed TDE's host galaxies to estimate M_{BH}.

Science Questions:

Tiara's Thesis: Systematic selection of TDEs from ZTF. Year 1-2 sample of ~14 early ZTF TDEs. Comparison of the energetics, temperatures, line ratios, and timescales of the events. Are there different populations? Create a classification scheme. Try to make the selection as unbiased as possible, so can find new classes of TDEs.

Other Science Goals:

- How light curve rise-times correlate with host galaxy black hole mass. M_{BH} will be determined from velocity dispersion, host galaxy luminosity, and host galaxy bulge mass.
- Rate as a function of host galaxy type, nuclear stellar density profile, MBH, SF history, recent merger history.
- Faint and fast TDEs: Potential detection of TDEs from IMBHs.
- Rare TDEs: Potential detection of TDEs from spinning SMBHs and binary SMBHs.