Finding transients in Kepler fields for transient and calibration studies

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Abstract

The Kepler satellite will for four months, starting Dec 2017, monitor more than 20 000 galaxies well suited for ground-based follow-up, with a 30 min cadence. Kepler single-band photometry provides unique data for studies of variability in general and the early rise-time of supernovae in particular, but requires complementary multi-color and spectroscopic observations. ZTF will be ideally positioned to find and follow SNe for which Kepler data will eventually be down-linked. Through matching the Kepler lightcurves with multi-band P48 photometry we can create a critical dataset for studies of CC SN shock-breakout and SNIa progenitors while improving ZTF calibration and determining the transient detection efficiency.

1 Scientific Motivation

1.1 Outline of the goals and competitiveness of ZTF for the project

Kepler summary The Kepler satellite repeatedly scans a pre-selected set of targets, for which well-calibrated lightcurves with (typically) a $30min$ cadence and 20.5 mag depth are downloaded after each campaign. The K2-C16 campaign, commencing Dec 2017, is oriented to allow simultaneous ground-based observations.[1] Kepler data, by itself, consists of photometry in only one broad filter. To properly interpret these lightcurves requires transients to be detected while still active, in order for follow-up observations to be triggered. Main science drivers for the mission includes observations of shock-breakout in Core Collapse SNe (CC SNe), interaction with a companion for Type Ia supernovae (SNe Ia) and creating a large, uniform sample of high-cadence observations of AGN variability. Kepler will continue targeting ground-observable fields through the C17 campaign, which ends April 2018. This constitutes a unique opportunity to obtain high-frequency optical observations of transients from space.[2]

Opportunities for ZTF The C16 and C17 fields will be targeted by virtually all ground-based observatories (including e.g. high cadence monitoring by ASAS-SN and ATLAS). However – *weather permitting* – no survey has better capabilities for detecting transients in Kepler targets than ZTF. Each K2 campaign is limited to an area corresponding to four ZTF pointings, making a high cadence search feasible. While other surveys will find these supernovae, the depth of ZTF allows early detection and we have good experience with scheduling rapid follow-up observations. *We propose for ZTF to publish the position of confirmed transients in Kepler targets.*

[1]https://keplerscience.arc.nasa.gov/supernova-experiment

[2]The K2 SN program will be further developed during a workshop Feb 2017, after which more details will be available.

Data requirements, based on search for SN Ia progenitors Kepler lightcurve deviations will be hard to interpret, in itself, as these can be caused by (a combination) of progenitor star interactions, circumstellar dust and ejecta (Ni) distribution. However, having color information at these phases can provide exactly the added information to distinguish these scenarios (Fig. 1) Progenitor differences are at the $\Delta B - V = 0.1$ level a day or two after explosion. Unfortunately, SNe Ia are at this phase ~ 4 mag below peak and only observable by ZTF to $z = 0.01$ – it is unlikely that K2-SN will find transients within this small volume. Instead, obtaining the sample of objects required to constrain SN Ia progenitors[3] requires the use of the complete $z < 0.05$ sample observed by Kepler. Assuming a 20.5 mag ZTF depth, unreddened SNe Ia will here typically be found 5 days after explosion (~ 1 mag below peak). At this phase, the difference between progenitor scenarios are limited to $\Delta B - V = 0.05$. *Project goal is to provide daily color measurements of Kepler targets with this sensitivity.* This will provide a unique ZTF data-set to complement Kepler lightcurves.

1.2 Figures of merit

Based on our suggested Kepler target list (see Fig. 1), we expect 2 to 5 SNe Ia below $z = 0.05$ each campaign, and a similar number of CC SNe. In this range, ZTF can discover SNe Ia within one week of explosion while Kepler lightcurves are sufficiently deep to monitor the early lightcurve. Many times more SNe will be discovered beyond $z \sim 0.05$, too distant to directly monitor the explosion.

Success of this program can be divided into three tiers:

- Detecting candidates in nearby Kepler targets sufficiently early to trigger spectroscopy that probes the outer SN environments. We expect this to be feasible to $z \sim 0.02$, and we thus expect 1 to 3 such candidates each campaign. These warrant full spectroscopic follow-up, initially at large facilities, combined with multi-color photometry. A successful project means these are first discovered by ZTF.
- Provide sufficient early color measurements, as described above, for all K2 SNe at $z < 0.05$. With cadenced observations in multiple filters, this does not amount to as strong requirements on real-time detections. We can reconstruct the early color lightcurve, prior to detection, of all candidates, also those not first detected by ZTF. These objects warrant a few high signal-to-noise spectra to characterize the SN sub-type accurately.
- The K2 variability data allows us to test the ZTF calibration and detection efficiency – the pipeline detection and photometry can be directly compared with downloaded K2 lightcurves. This final tier requires no real-time observations.

1.3 Real-time discovery

This project will require human scanning, but only for the ~ 10000 galaxies that are followed by Kepler. As C16 starts early in ZTF, where machine learning might still be in training, we suggest these targets to be scanned with relatively low Real/Bogus values. If necessary we will appoint a dedicated scanner to inspect candidates in Kepler galaxies. We will require two detections (possibly in different filters).

2 Proposed Observations

2.1 Pointings, cadence, filters

Scanning the full Kepler field in one band requires four pointings, i.e. three minutes including overhead. Assuming the target ZTF calibration (see below), color uncertainties will be limited

[3] Complementing individual objects, like SN2011fe, SN2014J and SN2016abc previously studied by PTF

by statistical uncertainties. Based on PTF data, four exposures in each filter are sufficient to produce a color uncertainty of 0.05 to $z = 0.04$. With improvement both in calibration (pixel sensitivity) and matching to the PS catalogue, we expect this to be feasible to $z = 0.05$. We suggest these visits to be distributed throughout the night to be sensitive to the continuous brightness increase. These observations would sum to 24 min each night, and thus 48 $hours$ for four months. As these observations can be used by multiple other projects, the effective cost will be lower.

Ideally, four exposures would be made using the g-band as early SN variations are predominantly blue. The other observations are more flexible – these could be r or i, or even a combination thereof.

We are currently working with the Kepler team in target selection, including data from the PTF Census of the Local Universe catalog (see sample overlaps in Fig. 1). We have suggested placing targets such that they are conveniently matched to ZTF fields, and avoid ZTF chip gaps, but the final target list is not yet available. Covering all targets might thus require distributing observations also using the alternate (offset) grid pattern. This might also be necessary if subtraction/photometry is severely limited in the vignetted ZTF area (to be evaluated during commissioning).

2.2 Sensitivity to calibration and variations in cadence and filters.

A reduced cadence would limit the sample where progenitor models can be distinguished to the nearby region, where few SNe are expected. As mentioned above, the g-band is most sensitive to early SN variations. Calibration uncertainties beyond 2% would further limit the constraints obtained.

2.3 Specify suitable periods for the observations, if applicable.

The C16 and C17 campaigns run from (mid) Dec 2017 to April 2018.

3 Supporting Observations

3.1 Photometric follow-up at other facilities

In principle, the cadenced observations in secondary filter (beyond g) could be exchanged for rapid multi-color follow-up with other facilities (eg. Rainbow camera). However, as color variations are expected to rapidly grow close to explosion, having even low signal-to-noise photometry (i.e. prior to a confirmed detection) can provide strong model constraints. Only continuous color coverage can provide this data.

3.2 Spectroscopic follow-up

Transients at $z < 0.05$ in K2 targets will require rapid, early spectroscopy from large facilities. Smaller facilities, such as NOT, will be used for observations closer to peak. Besides regular ZTF spectroscopy programs, we will propose for dedicated ESO time. There will also be general K2-SN programs in the community. The SEDM and NOT will be used for classification of transients in K2 galaxies in the $0.05 < z < 0.1$ range. We expect ~ 10 such during each campaign.

3.3 Other external resources

We will rely on the Kepler data to be obtained and reduced using their pipeline.

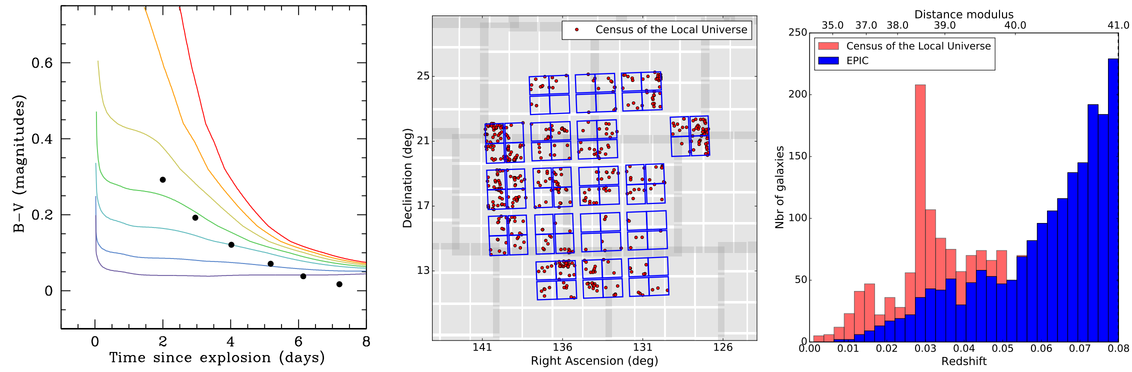

Figure 1: *Left:* Color effects from mixing of radioactive material (Ni), e.g. due to violent WD mergers. From Piro & Morozova (2016, ApJ, 826:96). *Mid:* The K2 C16 CCD positions (blue lines), the ZTF field grid (grey) and new CLU $H\alpha$ galaxies (points). *Right:* z-distribution of targets: EPIC sample with reliable SDSS photometric redshifts (blue/dark bars), additional galaxies from the CLU $H\alpha$ survey (red/light).

4 Expertise to Undertake the Project

4.1 Expertise and external collaborators

We will rely on the Kepler team for producing the final Kepler lightcurves. We will work together with the Pipeline/Marshal groups in incorporating Kepler targets.

4.2 Specify tools required to deliver science products.

We would look for methods to only monitor the K2 targets in the marshal, potentially with other (less strict) selection criteria. If the requested depth in secondary filters will not be available, we will strive to have automatic Rainbow-camera observations of new transients in Kepler fields (prior to human scanning).

Other tools would be useful, but not strictly required: (i) Bad weather at Palomar can be mitigate through cross-matching with other surveys, such that we could use their photometric limits when searching for new candidates. (ii) Stacking the nightly ZTF observations could allow earlier detections.

5 Manpower and Time-line

5.1 People and publication plan

This project will be coordinated by Jakob Nordin, who will also communicate with the Kepler team. Observations of individual SNe will mainly be carried out by the respective science working groups. These are expected to be completed during 2018. Brad Cenko will lead efforts in creating a joint Kepler-ZTF sample for studies of AGN variability.

5.2 Is this a thesis project? If so provide name(s) of student(s).