First results of the SkyMapper Transient Survey

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Abstract. The SkyMapper Transient (SMT) survey is exploring variability in the southern sky by performing both a rolling search to discover and study supernovae and a Target of Opportunity program utilizing the robotic SkyMapper Telescope at Siding Spring Observatory. The supernova survey is obtaining a non-targeted sample of type Ia supernovae (SNe Ia) at low redshifts, $z < 0.1$ and studying other interesting transients found with our search strategy. We have a Target of Opportunity program with an automatic response mechanism to search for optical counterparts to gravitational-wave and fast radio burst events, which benefits from SkyMapper's large field-of-view of 5.7 square degrees and rapid data reduction of our pipeline.

In this work we present first results of the SMT survey. The SMT pipeline can process and obtain potential candidates within 12 hours of observation. It disentangles real transients from processing artefacts using a machine learning algorithm. To date SMT has discovered over 60 spectroscopically confirmed supernovae, several peculiar objects and over 40 SNe Ia, including one SNIa 2016hhd was found within the first few days of explosion. We have also participated in searches for optical counterparts of gravitational waves, fast radio bursts and other transients, and have successfully published observations on the optical counterpart of gravitational wave event GW170817. We also participate in coordinated observations with the Deeper Wider Faster program and the Kepler K2 cosmology project.

Keywords. supernovae: general, surveys, gravitational waves, cosmology: observations

1. Introduction

The SkyMapper 1.3 m telescope at Siding Spring Observatory is a robotic telescope with a wide field of view of 5.7 square degrees (Keller et al. 2007). In March 2014 it started the SkyMapper Southern Sky Survey (SMSS)†, a comprehensive digital survey of the entire southern sky. Further details about the SkyMapper instrument and its eponymous survey can be found in Wolf et al. (2018), which also describes the first SMSS data release.

Alongside the Southern Survey, SkyMapper is carrying out a search for supernovae and other transients with the SkyMapper Transient Survey (SMT). The search strategy is optimized for discovery and follow-up of low-redshift type Ia supernovae by searching ∼2000 square degrees with a cadence of $\leqslant$ 5 days, (Scalzo et al. 2017). SkyMapper aims to address the limitations of the current sample of nearby SNe Ia by searching a wide sky area uniformly with a short ($\leqslant$ 5 days) cadence, in multiple well-determined bandpasses (Bessell et al. 2011). Thus the resultant low-redshift ($z < 0.1$) SN Ia sample will be magnitude-limited, with a more similar selection function to the high-z sample. More information on the infrastructure and operations of the SMT, and first results including performance during an early Science Verification period can be found in Scalzo et al. (2017).

2. Transient Survey Strategy

Although SMT and SMSS both use the SkyMapper telescope, SMT has its own data reduction pipeline infrastructure, maintained and run separately from the SMSS's SDP. The goal of our pipeline is to have rapid (< 12 h) turnaround for discovery of new transient candidates. Our pipeline performs image subtraction to detect transients and provides additional data to support situational awareness of active transient candidates, such as historical light curves.

The transient detection procedure can be described in the following simplified steps (for more details, see Scalzo et al. (2017)):

- Image subtraction: This requires a pre-existing template image of the sky ("REF") to remove host galaxy light and non-variable sources from each new exposure ("NEW"). The REF is convolved by a suitable kernel to match its point-spread function (PSF) to that of the NEW. References must be taken at least two weeks prior to the NEW image (the rise time of a typical SN Ia to maximum light is about 17 days).
- Source detection: This is done in the subtracted image ("SUB") using Source Extractor (Bertin et al. 2002).

† http://skymapper.anu.edu.au

- Classification: All detections on the SUB are run through an automated classification routine to determine the likelihood that they are real astrophysical sources rather than artifacts from an imperfect subtraction process. This classification is done using machine learning with a Random Forest algorithm implemented in Pedregosa et al. (2011).
- Candidate detection: All high-quality detections in the SUB image are astrometrically matched to previous detections. For sources passing a threshold number of high-quality detections in one or more subtractions, a historical light curve is compiled using all detections of the transient at that position.
- Transient selection: selected candidates are now visually inspected to discard possible bogus detections. Bogus detections are mostly due to processing artifacts in SUB images. Until May 2017, the inspection was done by members of the SMT team. Currently inspections are done by citizen scientists. In partnership with the Zooniverse, we launched in May 2017 a citizen science project called "Supernova Sighting" †. In this project, volunteers inspect the NEW, REF, SUB images of possible candidates and select those which are promising Real candidates. Through an API we both upload images and download classifications ‡ and the selection of promising candidates is passed to our SMT team.
- Public transients: candidates that are consistent with astrophysical sources are publicly communicated using the Transient Name Server (TNS ¶).
- Spectroscopic follow-up: supernova candidates are sent to PESSTO and our Target of Opportunity program at the ANU's 2.3 m to get spectroscopic classification and redshift. Since candidates are public, other spectroscopic surveys are also able to classify our targets.

For the Target-of-Opportunity programs, including Gravitational Waves and Fast Radio Bursts electromagnetic counterparts searches as well as simultaneous observations with Deeper Wider Faster and Kepler K2 cosmology project, the pipeline is identical until "Transient Selection", where events go to the SMT team and collaborators.

This SkyMapper pipeline and early survey data have been used to develop the pipeline for the MeerLICHT and BlackGEM projects (K. Paterson in prep.).

3. First Results

3.1. *Supernovae*

Since December 2016, when automation of the TNS reporting was implemented, we have reported over 70 transients. To date SMT has discovered more than 60 spectroscopically confirmed supernovae. In this sample, over 40 non-targeted SNe Ia have been discovered within the redshift range $0.02 < z < 0.16$. In addition, a type Ia supernova discovered by our team, SNIa 2016hhd, was found within the first few days of explosion and may present evidence of shock interaction with SN Ia companion (Möller et al. in prep.).

In May 2017 we launched the Supernova Sighting Project in collaboration with the Zooniverse project. Within the first 24 hours over 18,000 volunteers had classified 30,000 transient candidates into real and bogus. Soon after, the first spectroscopically confirmed type Ia supernova found by volunteers was announced in Tucker et al. (2017). Overall, volunteers have discovered 45 astrophysical transients that include supernovae, flares, AGNs and unclassified transients. Their contributions can be found on the SMT webpage‖.

Although the SMT search cadence is optimized for normal SNe Ia, we devote a small fraction (5%–10%) of our follow-up resources to individual objects of interest that are likely to generate high-impact single-object papers. Exotic transients discovered so far include SN 2015J, a possible supernova impostor or magnetar-powered type Ic supernova (Tucker et al. in prep), and an object similar to Arcavi et al. (2016) in the so-called superluminous gap.

Our survey may be sensitive to other non-supernova transients. We have found that our past survey data is not expected to have any kilonovae using realistic simulations based on the light-curve of GW170817 electromagnetic counterpart (Scolnic et al. 2017).

3.2. *Target-of-Opportunity and Collaborations*

Since 2015, the ToO program has observed the following triggers: four Fast Radio Burst (FRBs), four Gravitational Waves (GWs) and one high-energy neutrino event.

In particular, we participated in the follow-up of the gravitational wave event GW170817, observing the first electromagnetic counterpart to a GW event (Andreoni et al. 2017; LIGO-Virgo collaborations 2017). We searched in the SMT supernova survey for possible transients at the location of GW170817 before the GW trigger but found none (A. Möller et al. 2017).

We also actively participate in coordinated observations with the Deeper Wider Faster program and the Kepler K2 cosmology project. These programs are based on scheduled observations to provide multi-color light-curves of interesting events.

The Kepler Extra-Galactic Survey (KEGS) is using the Kepler K2 mission to monitor supernova fields at a very high-cadence of 30 minutes. K2 fields 1, 3, 4, 5, 6, 8, 10, 12, 14, 16, and 17 have been KEGS-focused fields, discovering

† *https://www.zooniverse.org/projects/skymap/supernova-sighting*
‡ implemented by P. Armstrong
¶ *https://wis-tns.weizmann.ac.il*
‖ *https://www.mso.anu.edu.au/skymapper/smt/supernovasighting*

to date 23 supernovae of all types, several of which been observed by SkyMapper (Rest et al. (in prep), Tucker et al. (in prep), Zenteno et al. (in prep)).

The Deeper Wider Faster collaboration coordinates simultaneous observations with over 40 observatories at all wavelengths (radio to gamma-ray) and multi-messenger detectors. Events currently being analyzed include SNe Ia DWF17a5068 and DWF17a23 with SkyMapper data (Kuhn et al. in prep).

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