The unblinking eye on the sky

From near-Earth asteroids to superluminous supernovae and gravitational wave counterparts, the Zwicky Transient Facility will soon scan for transient phenomena, explain **Eric Bellm** and **Shrinivas Kulkarni**.

The Zwicky Transient Facility (ZTF) is a next-generation optical synoptic survey motivated by the search for rare and fast-evolving optical transients. ZTF succeeds the Palomar Transient Factory (PTF) survey^{1,2} and the intermediate Palomar Transient Factory (iPTF) survey on the 48-inch Samuel Oschin Schmidt Telescope (P48) at Palomar Observatory. The PTF began operations in 2009, emphasizing large area surveys to characterize the optical transient sky. The iPTF has operated for the past four years, emphasizing same-night multicolour follow-up of transient candidates, most recently using a novel ultralow-resolution spectrograph on the robotic Palomar 60-inch telescope (P60). The survey camera on the P48 (CFH12K, originally used on the Canada–France–Hawaii Telescope) had a field of view of eight deg².

ZTF's custom mosaic camera^{3,4} (Fig. 1) will maximize the discovery rate of transients on the P48⁵. It completely fills the available 47-deg² focal plane of the P48 with 16 CCDs of 6,144 × 6,160 pixels each and reduces readout and slew overheads to less than 15 s per exposure. The resulting order-of-magnitude improvement in survey speed relative to PTF will enable ZTF to survey at high cadence over a wide area. The exposure time of 30 s was deliberately chosen to achieve a moderate depth (with magnitude ~20.5; 5σ) so that follow-up could be undertaken by existing telescopes — for example, the P60 for ultralow resolution spectroscopy, 1-m telescopes for multiband photometry, and 3–5-m class telescopes for low-resolution spectroscopy.

ZTF will pursue a broad range of time-domain science, ranging from near-Earth asteroids to the study of distant superluminous supernovae. The 'celestial cinematography' survey undertaken in two bands will cover a large fraction of the observing time over three nights. This survey is expected to detect over five thousand type Ia supernovae per year (thus helping to improve the precision of the Hubble diagram at low redshift), over a hundred superluminous supernovae, and a dozen tidal disruption events. The survey will allow a thorough census of supernovae of all types within 200 Mpc. Typically, the region of the sky least observed by synoptic surveys is the Galactic

plane, where most of the stars in our Galaxy are located. To rectify this lacuna, ZTF will sweep the Galactic equator nightly. This plane survey will find active stars, measure stellar rotation periods, and discover a very large number of variable stars, as well as cataclysmic variables, novae, and other accretion-powered stellar systems.

Another, higher-cadence, survey is designed to study explosions at early times. Early observations of supernovae can place radius and binarity constraints on the supernova progenitor, identify shock interactions, and enable discovery of progenitor emission signatures in the photo-ionized circumstellar wind of core-collapse supernovae through 'flash' spectroscopy. Two models have been suggested for the origin of type Ia supernovae: a coalescence of two white dwarfs, and the explosion of a white dwarf after it accretes sufficient matter from a companion. For the latter, the presence of declining emission in the ultraviolet (observed by the Swift X-ray Observatory) is a certain indication. More intriguingly, ZTF may discover on- and off-axis emission from gamma-ray burst afterglows and constrain the proportion of other types of extragalactic explosions (such as the putative baryon-loaded 'dirty fireballs'). ZTF will be reasonably effective in discovering and following up small streaking near-Earth asteroids⁷, although it is not optimized to study them. Finally, with its fast areal survey speed and rapid response, ZTF can efficiently search for optical counterparts to Advanced LIGO gravitational wave detections.

We are now solidly in the era of bright star and bright transient astronomy. For instance, the limiting magnitude of ZTF is similar to that of the ESA's Gaia mission. While Gaia delivers exquisite astrometric and photometric measurements, ZTF provides a rich trove of time-series observations on a variety of timescales. The combination can be expected to be particularly valuable for stellar astronomy. There will be regular data releases of images, catalogues and light curves for all ZTF data to enable a wide variety of archival studies. The aforementioned celestial cinematography and plane surveys will issue near-real-time transient alerts. Apart from the science returns from the planned surveys,

ROGERSMITH / MICHAEL FEENEY
CALTECH OPTICAL OBSERVATORIES

Figure 1 | The ZTF camera. The CCD mosaic is 560 mm diagonally, which is comparable in size to the Dark Energy Camera (DECam; 525-mm diameter) and the Large Synoptic Survey Telescope (LSST; 640-mm diameter). Due to ZTF's coarser pixel scale, however, its 47-deg² field of view is much larger than that of DECam (3 deg²) and LSST (~10 deg²).

ZTF is expected to provide a valuable platform to develop new methodologies for the burgeoning field of time-domain astronomy.

We expect to achieve first light in July 2017. The primary program will begin after a six-month commissioning period. In the first year priority will be given to building up of co-added reference images of the sky. At the end of the second year there will be review of lessons learnt and science returns, and the survey parameters will be readjusted accordingly. ZTF is expected to serve as a prototype for the Large Synoptic Survey Telescope (survey start 2022), which has a vastly larger data stream. □

ERIC BELLM AND SHRINIVAS KULKARNI are at the California Institute for Technology, 1200 East California Boulevard, Pasadena, California 91125, USA.
e-mail: ebellm@caltech.edu;
srk@astro.caltech.edu

References

1. Law, N. M. *et al.* *Publ. Astron. Soc. Pac.* **121**, 1395–1408 (2009).
2. Rau, A. *et al.* *Publ. Astron. Soc. Pac.* **121**, 1334–1351 (2009).
3. Smith, R. M. *et al.* In *Proc. SPIE* Vol. 9147 (eds Ramsay, S. K. *et al.*) 914779 (SPIE, 2014).
4. Dekany, R. *et al.* In *Proc. SPIE* Vol. 9908 (eds Evans, J. C. *et al.*) 99085M (SPIE, 2016).
5. Bellm, E. C. *Publ. Astron. Soc. Pac.* **128**, 084501 (2016).
6. Cenko, S. B. *et al.* *Astrophys. J.* **769**, 130 (2013).