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Optical & NIR Transient Surveys

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Abstract. A workshop on *Optical & Near Infrared Transients* took place during the first afternoon of the Symposium. It ran for two sessions. The first was given over to talks about various current optical and near-infrared transient surveys, focussing on the Vista surveys, the Catalina Real-Time Transient Survey, Pan-STARRS, Gaia, TAOS and TAOS2. The second session was a panel-led discussion about coordinating multi-wavelength surveys and associated follow-ups.

1. Introduction

The objective of the *Optical & Near Infrared Transient Surveys* Workshop was to address some of the key issues facing the current and forthcoming ground-based, optical and near-infrared synoptic sky surveys. The issues covered included key lessons learned from the current surveys, what the principal bottlenecks are (especially regarding follow-up observations), the scientific opportunities, the technological challenges, and how coordination between different surveys at all wavelengths might be improved.

The workshop was allocated two sessions, one of 90 minutes and one of 60 minutes. The first session set the scene and initiated discussions by arranging five short talks, each of about 15 minutes, which highlighted some of the current or imminent transient surveys, their scientific goals and the key outstanding challenges that they are encountering. The second session was a panel-led discussion that focused mainly on the issues of effective follow-up and coordination between different surveys, community engagement, and the cyber-infrastructure needs.

2. NIR Transient Surveys – Nicholas Cross

Near-infrared telescopes, instruments and surveys are very similar in their design to optical telescopes, instruments and surveys. However, current infra-red detectors are both smaller and significantly more expensive than their optical counterparts and the sky is brighter and more variable from the ground. Near-infrared transient surveys are therefore designed to probe areas where equivalent optical surveys are insufficient, such as finding planets around low mass stars (Sipőcz *et al.* 2011), looking for pulsating stars through the dust and nebulæ in the Galactic plane (Minniti *et al.* 2010), or studying Young Stellar Objects in star-forming clouds (Alves de Oliveira & Casali 2008), rather than more general transient searches that are better performed in the optical.

The two fastest current near-infrared survey instruments are the United Kingdom Infrared Telescope with the Wide Field CAMera (UKIRT-WFCAM; Casali et al. 2007) and the Visible and Infrared Survey Telescope for Astronomy (Vista; Emerson *et al.* 2004). The data from both of these instruments are processed by the Vista Data Flow System (VDFS), whose components are the Cambridge Astronomy Survey Unit (CASU) and the Wide Field Astronomy Unit (WFAU) in Edinburgh. CASU is responsible for daily data reduction and processing of individual data blocks and the astrometric and photometric calibration. WFAU is responsible for putting together data from different data blocks (deep stacks, multi-band catalogues, multi-epoch catalogues and variability statistics) as well as producing a queriable database (Hambly *et al.* 2008; Cross *et al.* 2009).

The most ambitious current NIR transient survey is the VISTA Variables in Via Lactea (VVV; Minniti *et al.* 2010). It covers 520 square degrees of the Galactic plane and bulge, and when complete will observe 1 billion objects over 100 epochs in the Ks band. The main science driver is to derive distances to different structures within the Milky Way using the period-luminosity relationships of RR Lyræ and Cepheid stars, so accurate post-calibration light curves are more important than real-time transient selection and follow-up. Most of the processing of light curves takes place during archive curation at least 6 weeks after the observations (Cross *et al.* 2009).

The main difficulties facing the VVV stem from the extreme source density of $> 10^6$ sources per deg^2, leading to difficulties in sky subtraction, deblending and occasional astrometric errors. The focal plane contains 16 2k×2k non-buttable Raytheon detectors that are laid out in a 4×4 pawprint. The design has 90% spacing in the X-direction and 45% spacing in the Y-direction, requiring half-detector overlaps to produce a 1.5 sq. deg. image tile. With highly variability both in the skies and in the PSFs within the duration of a data block significant processing is needed to remove the skies. The processing of a single tile is time consuming, requiring catalogue extraction on 6 pawprints as well as on the final tile.

The combination of dense fields and complex processing means that these fields are the ones that are most likely to need reprocessing. That adds large overheads to archive curation, especially when the processing is split between two data centres: data have to be re-transferred and re-ingested into the archive. However, using the VVV to deal with database tables containing $10^{10} - 10^{11}$ rows while also enabling users to have queries returned in sensible times is stretching the Microsoft SQL Server 2008 to its limits.

3. Catalina Real-Time Transient Survey – Andrew Drake

The Catalina Real-Time Transient Survey (CRTS; `http://crts.caltech.edu`) is a synoptic sky survey which uses data streams from 3 wide-field telescopes in Arizona and Australia. The data result from a NEO asteroid search led by Ed Beshore and Steve Larson of UAz LPL (`http://www.lpl.arizona.edu/css`). CRTS searches for highly variable and transient sources outside the Solar system. The collaboration illustrates how the same synoptic sky survey data stream can feed many different scientific projects in a highly efficient manner.

The survey covers the total area of $\sim$ 33,000 deg^2, down to limiting magnitudes ∼19–21 mag per exposure (depending on the telescope and the seeing), with time base-lines from 10 min to ∼7 years (and growing). There are now typically ∼300–400 exposures per pointing, and coadded images reach deeper than 23 mag. The basic goal of CRTS is a systematic exploration and characterization of the faint, variable sky. The survey has detected ∼4,000 high-amplitude transients to date, including $> 1,000$ supernovæ, many of them unusual (in both 2009 and 2010, CRTS published more SNe than any other survey), nearly 1,000 CVs and dwarf novæ (the majority of them previously uncatalogued), hundreds of blazars and other AGN, highly variable and flare stars, etc.

CRTS has a completely "open data" philosophy: all transients are published electronically immediately, with no proprietary period at all, and all of the data (images, light curves) will be publicly available, thus benefiting the entire astronomical community. The events are published in real time using a variety of electronic mechanisms, as described on

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the survey website. Annotated events with links to data from other surveys and archives are also provided at the CRTS website, and at `http://skyalert.org`. About 10^8 light curves are now in process of being released through a web server.

In many ways, CRTS is a scientific and technological testbed and precursor for the grander synoptic sky surveys to come. More details and references are given in Drake *et al.* (2008), Djorgovski *et al.* (2011), Mahabal *et al.* (2011), and elsewhere in these Proceedings (page 306).

4. Pan-STARRS – Stephen Smartt

The survey is operating and producing transients. Details can be found at `http://pan-starrs.ifa.hawaii.edu/public/home.html`, and elsewhere in these Proceedings (page 71).

5. TAOS & TAOS2 – Matt Lehner

The Taiwanese-American Occultation Survey (TAOS) searches for occultations of stars by distant small bodies in the outer Solar system. Details can be found at `http://taos.asiaa.sinica.edu.tw`.

6. The GAIA Satellite as a Transient Survey – Simon Hodkin

GAIA is a European Space Agency (ESA) astrometry space mission, and a successor to the ESA HIPPARCOS mission. GAIA's main goal is to collect high-precision astrometric data (positions, parallaxes, and proper motions) for the brightest 1 billion objects in the sky. Those data, complemented with multi-band, multi-epoch photometric and spectroscopic data collected from the same observing platform, will allow astronomers to reconstruct the formation history, structure, and evolution of the Galaxy.

GAIA will observe the whole sky for 5 years with an average of 80 times per source, providing a unique opportunity for the discovery of large numbers of transient and anomalous events such as supernovæ, novæ and microlensing events, GRB afterglows, fallback supernovæ and other theoretical or unexpected phenomena. GAIA's focal plane is comprised of 106 CCDs with almost 1 billion pixels that are read out every 4.5 seconds. The Astrometric field G-band CCDs will sample the sky with 0.06×0.18-arcsecond pixels. The BP/RP spectrographs provide blue and red low-dispersion (R$\sim$10–100) spectra for all GAIA sources. The Radial Velocity Spectrograph will provide velocities for stars with $V \leqslant 16$ to a precision $\leqslant 10$ km s^{-1}.

The Photometric Science Alerts team has been tasked with the early detection, classification and prompt release of anomalous sources in the GAIA data stream. Transient phenomena will be identified either via the discovery of new sources (new to GAIA), or through the detection of significant changes in magnitude and/or the spectrum. Precise astrometry, spatial morphology, photometry and spectroscopy will be combined with a history of the transient's environment to provide initial event classifications and associated probabilities. Ground- and space-based archival data will be cross-matched against each transient to refine its classification before publication of the event to the community at large via email, skyalert.org and other agreed mechanisms, within 24–48 hours of the observation. The aim is to publish all the data which have contributed to the discovery and classification of the event, including the transient's light curve, coordinates, morphology, thumbnail cutouts from the onboard SM and AF windows, BP/RP spectroscopy, and the cross-match results. Even though GAIA is primarily an astrometric mission, it provides real power for the early discovery and accurate classification of alerts, thanks to the unique combination of high sensitivity, high spatial resolution, and near-simultaneous low-dispersion spectroscopy.

7. Panel Discussion on Multi-wavelength Transient Programmes: Surveys and Follow-ups

The panel consisted of Peter Nugent, Neil Gehrels, Joseph Lazio, George Djorgovski and Nicholas Cross. Nugent, Gehrels and Lazio each gave a short introduction before questions were invited from the floor.

Discussion

Peter Nugent (to Cross): Have you tried using parallel databases?

Cross: Our tests so far show that Microsoft SQL should be sufficient for the VVV. We have not had the manpower to test other DBs like sciDB or MonetDB thoroughly enough, nor work out how we would have to change our curation software.

Nugent: The expensive parts are the computing and follow-up. People try to get the most out of their own pipelines, but there is a lot of useful historical data ("historical follow-up").

Lazio: There is a range of radio data from sub-millimeter to decametre. Radio wavelengths are important for astrometry in X-ray/gamma ray follow-ups and provide constraints on the physics.

Gehrels: The good news is that gamma-ray transients get followed up, especially with telescopes with NIR spectroscopy for high-z events. The bad news is that everyone does the interesting GRBs and ignores the rest. For X-ray follow-ups, Swift started with 100 ToO requests per year and now receives 1000. It cannot handle any more. Also, it will not last forever; what will replace it?

Hanisch: We can now do a 1,000,000-row cross-match in a couple of seconds, but the difficulty is getting the data to the server. Real-time follow-ups are constrained by cross-matching to external data. We still need humans.

Mundell: The Liverpool GRB team have GRBs to 24 mag but no redshifts. The support amongst TACs for follow-ups of GRB detections is dropping just as the physics is getting better defined.

Schmidt: We have the wrong hardware for follow-ups. Multi-object spectrographs are not useful for following up a single bright object. Long-slit spectrographs are not useful for most transients either. We need dedicated hardware.

Kulkarni: The Palomar Transient Factory has follow-up telescopes too. A generous time allocation to collaboration investigators is not enough. Any idiot can discover a supernova, but following it up is more difficult and the follow-up telescope has to be bigger than the survey telescope.

Mundell: The Liverpool Telescope has spectroscopy and polarimity and a 10s changeover time between instruments.

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Djorgovski: Large surveys should be designed or organised to compliment each other by following each other up simultaneously.

Lazio: There is also the need for robust archives since the radio often turns on much later.

Djorgovski: We use layers of follow-up, gradually reducing the candidates until we have the ones that are interesting enough for spectra.

Kulkarni: This is the golden age of transient astronomy. It will be over by LSST.

Djorgovski: I agree.

Schmidt: The main phase space of transients will be covered soon, perhaps in the next 12 months, and then we will move into a dour regime. But we cannot do the high-redshift universe well. We have the wrong hardware.

Djorgovski: QSOs were spotted in the optical in the 1920s, but they were thought to be variable stars. They were only noticed as something special when they were matched to the radio.

Schmidt: Gravity waves will open up new studies.

Participant: With GRBs detected by EXIST we will need NIR photometric follow-up from space to answer the dedicated science questions. This will not be possible in the present funding climate, but a 2-m to 3-m-class telescope in Antartica would cover half the sky for five months of the year.

Ridgway: What can we expect from LSST follow-up? No-one is doing the simulations to test this, they are too busy.

Djorgovski: On the contrary, we have the opposite problem. Too many good people are wasting their time simulating data, instead of learning from the real data and event streams.

Kulkarni: We cannot extrapolate across 10 years. This is the decade of discovery: PTF, Pan-STARRS, Swift, HST, Chandra. Dark Energy Camera will also be around soon. LSST will be like Kepler: people will use time-series analysis on the light curves rather than following up detections. It will be a physics machine, not a discovery machine: lots of chi-squared tests.

Lazio: The precursors to the SKA will be interesting, and the metre and centimetre wavelengths. There will be new incoherent and coherent sources, and fast transients. We are still exploring the discovery space. What about high-speed optical surveys? There is TAOS, but it is not wide-field.

Djorgovski: We have to think about the cadences as well as the wide field.

Vestrand: We need to understand the whole system and have real-time knowledge of what is available. Sometimes it is like second graders playing soccer: everyone kicks at the ball. Everyone observes the same GRB at the same time and doesn't know that it is already being observed.

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Djorgovski: VOEvent was designed with problems like this in mind.

Gehrels: Lots of small telescopes that are useful for follow-up are getting closed down.

Kulkarni: Lots of small telescopes need to be refurbished.

Djorgovski: We need to use computers to observe archives as a historical follow-up.

Djorgovski: This will be the first and last meeting dedicated to time-domain astronomy. The field will be too big for one meeting and there will be more specialised meetings.

8. Summary

The take-away messages from this workshop can be summarized as follows:

• There is not enough awareness in the community of all of the tools and facilities available, such as *SkyAlert*, or the various Virtual Observatory services, so the follow-up of transients is not as efficient as it could be.

• The main bottleneck in extracting science from existing synoptic surveys is the follow-up spectroscopy. The problem will get worse by orders of magnitude as we move towards the LSST. Dedicated spectroscopic facilities may be necessary. A lot of spectrographs developed for large telescopes are designed for many faint objects over a small FOV, whereas transients are observed one at a time.

• There should be more coordination between surveys at different wavelengths to maximise the scientific returns. The cadences and pointings need to be coordinated, sometimes with offsets as emission at some wavelengths (e.g. radio) can be delayed. Given such a variety of different technologies and science requirements, this is an extremely complex task.

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