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The SALT Transient Programme

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Abstract. The SALT transient follow-up programme began in 2016 and will continue for 5 semesters (until 31 Oct 2018), with an expectation of renewal thereafter. It is currently the only SALT Large Science Programme, and was awarded ∼250 ksec. per semester, with a significant fraction (60%) given for the highest priority target-of-opportunity time. The aim is to characterise and study transients across a wide range of classes, currently including (from closest to most distant) cataclysmic variables, novæ and other associated eruptive variables, low- and high-mass X-ray binaries, OGLE and Gaia transients (including tidal disruption events), super-luminous and unusual core-collapse supernovæ, kilonovæ and other candidate optical counterparts to gravitational-wave events, flaring blazars and AGN, and gamma-ray bursts. This programme currently involves four SALT partners, of which South Africa is the major contributor of time (74%) and resources and includes five institutions with over 30 co-investigators. This talk reviewed the nature of the programme and highlighted some of the results to date.

Keywords. Gravitational waves, (stars:) binaries: general, stars: dwarf novæ, novæ, cataclysmic variables, galaxies: active, gamma rays: bursts, X-rays: binaries

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1. Introduction

There has been growing interest amongst South African astronomers and their collaborators to study astrophysical transients occurring in a variety of classes. Follow-up observations with SALT are playing a key part in that endeavour, both to identify rapidly the type of object (e.g. classification spectroscopy) and, where appropriate, to conduct more intensive studies (e.g., time-resolved spectroscopy or photometry). This SALT Large Science programme takes advantage of one of SALT's competitive advantages in that it can respond rapidly to transient alerts using a range of appropriate instruments. It brings together astronomers from a variety of institutions in South Africa and in three other SALT partner countries (India, UK & USA), combining experience that covers a breadth of transient objects and potentially utilising a range of other multi-wavelength facilities in support of the programme.

Many detections of transients require either rapid follow-up after the initial alert, or on-going observations with cadences as short as a day. The only way to achieve that is if a significant fraction of the observing time is given at the highest priority (P0) and reserved for target-of-opportunity override. That category has been recognised by the respective SALT partner Time Assignment Committees (TACs, one for each partner); the programme receives typically ∼60% of the ∼250 ksec awarded each semester in the P0 class. 74% of the observing time for the programme has been contributed by South Africa.

The different transient-object classes which have been observed so far in this programme (arranged in order of the fraction of time allocated during two recent semesters) is as follows:

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• Low-mass X-ray binaries: 23.3%
• OGLE/ASAS-SN transients: 17.5%
• Cataclysmic variables & super soft sources: 16.5%
• Gaia transients: 12.8%
• Blazars/AGN: 12.2%
• Novæ: 9.6%
• GRBs/SNe: 5%

2. The SALT Transient Observation Process

As SALT is a 100% queue-scheduled and service-observing telescope (Buckley 2013), it is much easier in principle to arrange target-of-opportunity (ToO) follow-up observations of transients with it than with conventionally scheduled telescopes. The major issues in conducting SALT follow-up observations are target availability, and the time-scale over which such observations can be attempted. Because of SALT's design, namely the fixed altitude angle of the telescope structure, the instantaneous viewing window is a 12°-wide annulus offset from the zenith by 37°. Thus only ∼15% of the instantaneously visible sky (above an altitude of 20°) is available to SALT at any given time, implying that observations have to be scheduled carefully to match when a transient is accessible to SALT. For prompt follow-up observations (e.g., within a few 1000 secs of an alert), as might apply to GRBs, that requirement is clearly a challenge. Nonetheless, several successful ToO programmes involving fast transients have been conducted with SALT, particularly for GRBs and also for the gravitational-wave event, GW170817 (Buckley *et al.* 2018).

The instrumentation available on SALT is well suited to a variety of follow-up observations of transients, particularly spectroscopy for the characterisation of objects and time-resolved studies. The four science instruments on SALT (Buckley 2006) which have various modes well suited for transient observations are

• SALTICAM; broad-band UV–visible imaging camera, for time-resolved photometry,
• RSS (Robert Stobie Spectrograph), a versatile prime-focus instrument for low- and medium-resolution spectroscopy (R ∼ 500–6000) and spectropolarimetry,
• SALT HRS: stable fibre-fed high-resolution échelle spectrograph, and
• BVIT: Berkeley Visible Image Tube photon-counting camera (visitor instrument; see Welsh, p. 7)

Transient alerts for the programme have come in from a variety of ground-based and space-based observatories. To date those include:

• MASTER, ASAS-SN, OGLE, ATLAS, Gaia: general optical transients
• Watcher, MASTER: γ-ray burst optical counterparts
• Fermi, Swift, MAXI, INTEGRAL, NuSTAR, XMM: γ-ray and X-ray transients
• Spitzer: infrared transients
• HESS: TeV γ-ray sources
• LIGO, Virgo: gravitational-wave sources
• IceCube, ANTARES: neutrino sources

Newer facilities, and those coming on-line in the near future, will add to the pool of sources of alerts. Contributors will include MeerKAT/MeerLICHT (radio), NICER (X-ray) and ASTROSAT (X-ray), as well as other ground-based optical networks.

Table 1 outlines the potential types of transient follow-up observations that have been undertaken with SALT and the corresponding instruments and observing modes. The faintness limits for such observations are very dependent on observing conditions.

Various Co-Investigators take the lead for different source classes of transients, assuming responsibility for looking out for likely targets (e.g., from ATel and GCN alerts) and preparing the information needed to define the required observations (instrument set-ups, exposure times, cadences, finding charts, etc.). After the observing, an initial

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Table 1. SALT instrument capabilities used for transient follow-ups

Type of observations	Instrument	Mode	Types of objects
Classification spectroscopy	RSS	Longslit; R 350−1000	SNe; XRTs; GRBs; CVs; AGN; TDE
Spectral line diagnostics	RSS HRS	Longslit; R = 3000−6200 R = 15,000−70,000	CVs; Novæ; AGN V < 16; Novæ; some AGN
Radial velocities	RSS HRS	Longslit; R > 2000 R = 15,000−70,000	CVs; SSSs; LMXBs; HMXBs V < 14; HMXBs, Novæ
Time res. Spectroscopy	RSS	Frame transfer/Slot	2 s/0.1 s resolution; CVs; XRTs
Spectropolarimetry	RSS	Linear, circular, all-Stokes	GRBs; SNe; CVs; Novæ; Blazars
High speed photometry	SALTICAM BVIT	Frame transfer/Slot Photon counting	2 s/0.06 s resolution; CVs; XRTs 50 ns time tagging; CVs; XRTs

assessment of the data is performed, followed by a full data reduction and analysis. This is a dynamic process that is coordinated by the Principal Investigator (i.e., myself).

The programme began in semester 1 of 2016 (1 May – 31 Oct) and was due to run until 2018 31 Oct†. 2018 will also see the start of MeerKAT science operations – and with it the radio transient programme, ThunderKAT (www.thunderkat.uct.ac.za). In support of the latter, the 0.65-m optical telescope, MeerLICHT (www.meerlicht.uct.ac.za), with its wide-field optics (1°.2), will observe the MeerKAT fields simultaneously to search for optical counterparts of commensally detected radio transients.

3. A Sample of Results

Some results over the period 2016–2017 are presented here; results for some X-ray transients are mentioned by Charles (page 127). Earlier results on MASTER-detected optical transients were presented by Buckley (2015). Five refereed papers had been published by late 2017, and a similar number was nearing completion even then.

3.1. *Nuclear transients from OGLE IV, Gaia and ASAS-SN*

Over 50 transients, mostly detected by the Gaia or OGLE surveys, were identified as nuclear transient candidates for tidal disruption events (TDEs). SALT spectroscopy, including some observations at repeat epochs, have led to some interesting results. One example is Gaia17dbg, which coincides with the centre of the galaxy GALEXASC J225413.32-214100.1. The colour temperature is around 27,000 K, suggesting that Gaia17dbg is unlikely to be a supernova and is more likely to be an AGN flare or a TDE (see Fig. 1).

3.2. *Novæ*

Nova SMCN 2016-10a was observed by SALT following its discovery by MASTER–SAAO until 65 days post-eruption. Spectroscopy of this He/N nova was carried out with both the RSS and HRS instruments (see Fig. 2). Spectropolarimetry observations obtained on day 15 showed 0.2–0.6% linear polarisation that was most likely caused by interstellar extinction. Analysis of the SALT spectra and data from the 2-m Faulkes telescope (LCO), plus SMARTS optical and IR photometric observations and *Swift* UV and X-ray observations, were published by Aydi *et al.* 2018, who concluded that this fast nova is perhaps the most luminous ever observed. Four other novæ had also been observed

† It has now been extended for a further 6 semesters, until 2021 April 30.–*Ed.*

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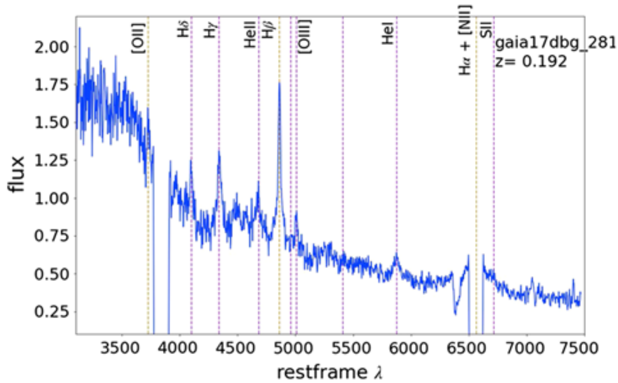

Figure 1. SALT spectrum of Gaia17dbg

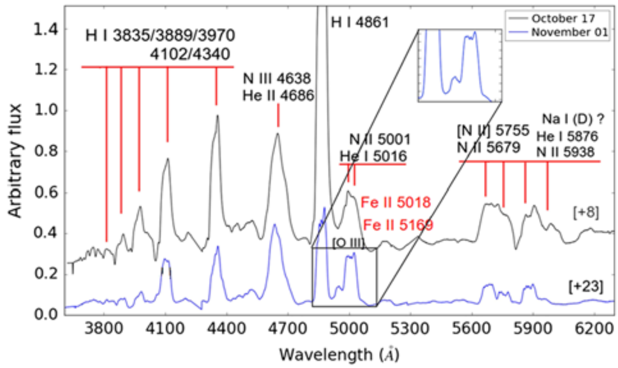

Figure 2. SALT spectrum of nova SMCN 20161-10a

recently as part of the programme: V407 Lup (Nova Lup 2016), PNV J11261220-6531086, PNV J13532700-6725110 and PNV J16484962-4457032.

3.3. *Blazars*

Spectropolarimetric observations by SALT of blazars at different states of their flaring activity have been used to probe the variability of the polarisation for a sample of sources spread over a wide range of redshift, in order to provide constraints on the contributions of different radiation mechanisms over a broad range of emitted wavelengths (e.g., Böttcher *et al.* 2017). For example, repeated observations of 4C +01.02 confirmed that the synchrotron component was very weak for this source during the quiescent state, but was stronger, and polarised at between 6 and 11%, during the flaring periods.

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