TAG: JMU

LIVERPOOL TELESCOPE
APPLICATION FOR TELESCOPE TIME

Ref: PL/14A/xxx

Semester: 14A **Duration (Semesters):** 1 **PROGID:**

Applicants (PI First)	**Institution**	**email**
Hodgkin	**IoA, Cambridge, UK**	**sth@ast.cam.ac.uk**
Chris Davis	Liverpool JMU	c.j.davis@ljmu.ac.uk
David Bersier	Liverpool JMU	D.F.Bersier@ljmu.ac.uk¿
Heather Campbell	IoA, Cambridge, UK	hcc@ast.cam.ac.uk
Morgan Fraser	IoA, Cambridge, UK	mfraser.astro@gmail.com
Full list of Co-I's	www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/Working_group	

Title: The Transient Sky with Gaia

Abstract:
We propose to begin spectroscopic and photometric follow-up of the first Gaia transients to: **1.** Determine the contents, completeness and contamination of the Alerts Stream **2.** Validate the classification system for transients (SNe, TDEs, GRB afterglows, novae, BHBs, CVs, symbiotic stars, R CrB stars, and YSOs in outburst). **3.** Build a large homogenous library of spectra to enable machine-learning discovery and classification methods. **4.** Identify rare or previously unknown transient phenomena and trigger detailed study. **5.** Study the transient sky as a function of magnitude, colour, amplitude, duration, and environment. This validation programme will optimize the Science Alerts pipeline, allowing the assured stream of classfied alerts to the community for the remainder of the mission. At the same time, it will provide a significant sample of characterised galactic transients, of use in e.g. probing the AN CVn to SN Ia pathway.

TIME REQUESTED
This semester (hours): 15
Total (hours):
Min. Useable %: 10
Sky Brightness: any
Photometric: N
Seeing (arcsec): any
Constraints: FLEXIBLE,MONITOR **Group Cadence (days):** 1.0
ToO: Y **ToO Likelihood (%):** 100

Which month(s) of the year would you ideally like your observations taken?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Y	Y				

Instrument(s)		**Details**	
IO:O	Y	**Filters**	ugriz
IO:I*	Y	**Filters**	H
IO:THOR		**Filters**	
RINGO3			
RISE			
FRODOSpec	Y	**Gratings**	blue and red gratings (low dispersion)
Other*			

* *You must consult with LT Support before selecting this option*

Summary of Progress on previous related LT Programmes:

List of previous related and unrelated LT Publications:

Related Proposals: LCO: WHT:**Y** INT:**Y** ESO:**Y** UKIRT: JCMT: GEMINI: eMERLIN:

Details of related/complimentary proposals to this or other facilities:

We have applied for the following:

- INT+IDS: Scheduled observations spanning 10 nights in Aug 2014 to take classification spectra for $\sim$100 Gaia transient candidates with r<18.
- WHT+ISIS/AUXCAM: Scheduled observations spanning 4 nights in Aug 2014 to take classification spectra for transients fainter than r=18.
- NTT+EFOSC2: To focus on southern hemisphere transient candidates - especially Galactic Plane events.
- **LT: Note that a proposal has also been submitted to the PATT TAG for a similar allocation of time in support of our GAIA follow-up programme.**

TARGET LIST:

Targets for the LT proposal will be automatically detected and initially classified by the Gaia Science Alerts pipeline, operated by DPAC at the Institute of Astronomy, Cambridge. Because this is in the early phases of the Gaia transient science program, the classifications will initially be simple, and will not have had the benefit of a Gaia-data-based training set. The goal of this proposal is to help build the classification training set with spectroscopy and lightcurves for the remainder of the Gaia mission.

Initially, human *Alert Brokers* will (scientifically) select high-priority transients that require rapid follow-up from the Liverpool Telescope. **However, we (Bersier et al.) are developing a system that will allow us to trigger the LT using VOEvents. Our goal is to develop this tool so that it can eventually be used for the distribution of Gaia alerts. This system will be tested by this proposal. The goal is to facilitate an immediate response to any trigger without human intervention.**

The LT is unique because it can react so quickly and does not depend on waiting for a specifically scheduled allocation of time.

If the objects are bright enough (r<18) and require spectral classification, we will request a ToO to use FRODOSPEC and/or imaging observations (for monitoring) with IO:O, or even IO:I if warranted.

If the images are too faint for FRODOSPEC, and imaging is warranted, then we will request a ToO for IO:O/IO:I.

Targets will span suitable hours of RA for coverage from the ground.

SCIENTIFIC CASE:

Gaia is an excellent transient discovery instrument, covering the whole sky (including the Galactic plane) an average of 70 times over 5 years at high spatial resolution with precise photometry (1% at G=19) and sub-milliarcsecond astrometry. The detection, classification and publication of the Gaia photometric Science Alerts (GSA) is one of the core activities undertaken in Cambridge, and is described in Hodgkin et al. (2013:PhilTransA, 371, 20239). Gaia will uncover many examples of known (and sometimes rare) transient behaviour, and almost certainly new classes. We are submitting this proposal to begin early spectroscopic follow-up of the first alerts from Gaia, and to start to tackle the following overarching goals:

1. To determine the contents, completeness and contamination of the GSA within the first year.

2. To investigate large samples of Galactic and Extra-Galactic transients (SNe, TDEs, GRB afterglows, novae, BHBs, CVs, symbiotic stars, R CrB stars, and YSOs in outburst).

3. To build a large homogenous spectral library to enable machine-learning discovery and classification methods.

4. To identify rare or previously unknown transient phenomena and trigger their detailed study.

5. To produce a detailed study of the transient sky as a function of properties such as: magnitude, colour, amplitude, event duration, Galactic and extra-Galactic environment.

6. To develop VOevents-triggering of the LT based on GAIA alerts (effort led by JMU staff).

Classification. Gaia has a unique feature: every transient will be observed with the onboard BP/RP spectrograph (R$\sim$20–100, S/N$\sim$10 at G=19). We will ultimately classify the Gaia Alerts with a Random Forest machine learning algorithm, but this requires a training-set of well-exposed (S/N$\sim$20–50), medium-dispersion (R$\sim$500–1000) spectra to be reliable. **This proposal will provide that training set for transients detected by Gaia**. The spectroscopic observations proposed here will be complemented by a large photometric follow-up programme coordinated by the same team (see `http://bit.ly/1bdjJDI`). An investment of time now will greatly increase the value and efficiency of the survey in subsequent years.

Discovery Space. The Gaia observing and processing strategy is suited to the discovery of variability on timescales of days–years. The Gaia Alert stream should be almost completely free from moving objects (asteroids, NEOs) thanks to two closely-separated exposures (Δt = 2hrs) and the dedicated Solar-System Object pipeline. We expect Gaia to make significant contributions in some of the following fields, especially in the Galactic plane which is essentially unsurveyed in the optical by ongoing transient surveys. There are many other classes of transient that we expect to discover and alert on, e.g. R CrB stars, Symbiotic stars, Helium-shell flash events, Novae, μlensing events (see: `http://bit.ly/1e8QUcI` for more details).

Cataclysmic Variables: Gaia will find $\sim$ 200 new CVs per year, making significant contributions to studies of Galactic populations and period distributions, as well as searching for new rare double degenerate AM CVn systems (Carter et al. 2013, MNRAS, 429, 214), the favoured pathway for SN Ia progenitors.

Black Hole Binaries: Using Gaia, there will be a step-change in our ability to detect **all** objects with d<few kpc in quiescence, as they are known to show strong variations and flickering in their optical LCs in quiescence (Cantrell et al. 2010, ApJ, 710, 1127). BHBs permit detailed dynamical studies to establish periods, companion nature and NS/BH masses, but only for a few dozen systems to date (Fender & Belloni, 2012, Sci, 337, 540).

Young Stellar Objects: Spectacular eruptions (3–6 mag, timescales $>$ 1 yr) have been measured in a dozen FU Orionis stars. Recently, a small handful of YSOs have shown eclipses that are not obviously arising from simple binary occultations, but most likely are long-lasting eclipses by disk material (Herbst et al. 2010, AJ, 140, 2025; Plavchan et al. 2013, A&A, 554, 110; Rodriguez et al. 2013, AJ in press). We need to discover and trigger on more of these objects to understand the origins and mechanisms for the outbursts and eclipses.

Tidal Disruption Events: Flares from the tidal disruption of a star are currently the only tool to study dormant, non-interacting black holes at intermediate–high redshift (z>0.01). Simulations (Blagorodnova et al. in prep) show that Gaia should discover 30 TDE events per year to G=20 with an amplitude $>$ 0.3 mags. We expect to find 20 AGN/yr with similar amplitudes. Spectroscopic and photometric follow-up will help us discriminate between SN, AGN and TDE hypotheses.

Supernovae: Gaia will detect about 6000 SNe (3 per day, e.g. Belokurov & Evans 2003, MNRAS, 341, 569), with $\sim$70% SNe Ia, below z = 0.1 to G=19. Each object will have a colour and a BP/RP spectrum, which will ultimately enable rapid classification (Blagorodnova et al. 2013 in prep). This large homogenous sample will improve our understanding of SN explosions and enable a wide variety of science aims.

TECHNICAL CASE:

Overview

We are applying for an initial allocation of 15 LT hours from JMU which will be combined with a similar allocation from the PATT TAC to be used in July/Aug 2014 to measure approximately 30 classification spectra (see below) and lightcurve data for 30 targets. We plan to request extra time in the following semester. By the end of the 1-year verification campaign, we aim to have measured a total of ∼1000 classification spectra, and to have triggered follow-up of the most exciting events. Approximately one quarter of these will come from the LT.

Gaia has a nominal launch date of 2013-11-20. Routine operations (and accumulation of flux histories) will begin in May 2014 (Fig. 1, we also show the expected coverage of Gaia by mid-August 2014). Any slip in the Gaia launch-date will be communicated immediately to the TAC. We need to build large training sets over a wide range of classes in order for our machine learning algorithms to perform well, and for our classifications to be useful. To gather a sufficient sample of classification labels (e.g. Bloom et al. 2011) we aim to observe ∼200 of each broad class of transient phenomena (AGN/cnSN/TDE, SN/Novae, VarStar-CV, VarStar-Misc, VarStar-Periodic) for a total of ∼ 1000 classifications. After the first year, we expect the transient communities to submit their own more detailed observing programmes with much more specific science cases

Gaia Operations

Gaia data will be downlinked from the spacecraft in an 8 hr daily window. Initial processing is completed before the GSA detection, classification and publication pipeline is run in Cambridge. We expect to publish alerts typically within 24–48 hours of their observation with Gaia. We will spend the first months (during the Ecliptic Pole Scanning phase) internally verifying the data, and learning how to identify large amplitude variable stars (potential contaminants of the GSA stream).

Initially, transient discovery will be conducted down to G∼18–19, and is based on either detection of a new source, or a significant deviation in brightness of a known source compared to previous Gaia measurements. The amplitude and threshold are tunable (by us) parameters, and will start off conservative to avoid swamping the community, while at the same time ensuring that we sample all objects types in this early phase. The Alert Stream will go live once Gaia has mapped at least 10% of the sky at least 3 times, which takes one month (see Fig 1). With the Alert Stream public (and not before), we are free to follow-up and publish exciting transient candidates discovered by Gaia. However it is important to invest time at the beginning to understand and characterize the transients that we discover with Gaia, so that we can optimize the process, and ensure that the rest of the mission is as productive as possible.

Transient Rates

Transient rates for Gaia are difficult to predict without detailed simulations, and whilst there is still discussion on the sensitivity limits that GAIA will be operating within (either G=20 or 21, which will be discussed at the October Gaia Science Team meeting).

Simulations (Belokurov & Evans 2003, MNRAS, 341, 569) predict Gaia will see 6000 SNe down to G=19 (3/day), and twice this to G=20. One SN per day will be birgther than 18th magnitude. For CVs the rate will be approximately similar (Breedt, priv. comm) predicts Gaia should find 1000 new CVs. Blagorodnova et al. (in prep) predict that Gaia will find of order 20 TDE's per year. YSO outbursts will be less common and we will probably only find a few per year.

Spectroscopy with FRODOSPEC

The LT+FRODOSPEC is a good system for prompt (timescale 1-day) spectroscopic classification of brighter Gaia transients. We will save the fainter objects for 4m class follow-up. Without an ETC it's hard to make predictions, but experienced FRODOSPEC users suggest that we should restrict the spectroscopic sample to $r < 17$ and aim for 30 min classification spectra with S:N∼ 20. Ultimately, the more sensitive SPRAT spectrometer (under development in Liverpool and not offered in 14A) will revolutionize classification of GAIA alerts at the LT.

Photometry

We are coordinating a large programme of photometric follow-up to improve the lightcurve sampling of Gaia transients. The LT is expected to make an important contribution and will be the largest dedicated telescope at the best observing site, so particularly suited to the fainter transients. In addition, the NIR capabilities offered by IO:I are unique. A list of smaller currently active observatories which are already testing followup procedures can be found here (`http://bit.ly/1aHNXzy`), while some early lightcurves are shown here (`http://bit.ly/17ViW7s`). All make use of our photometric calibration survey to place the disparate data onto the same system (Wyrzykowski et al. 2013 ATEL#5245).

FIGURES AND TABLES:

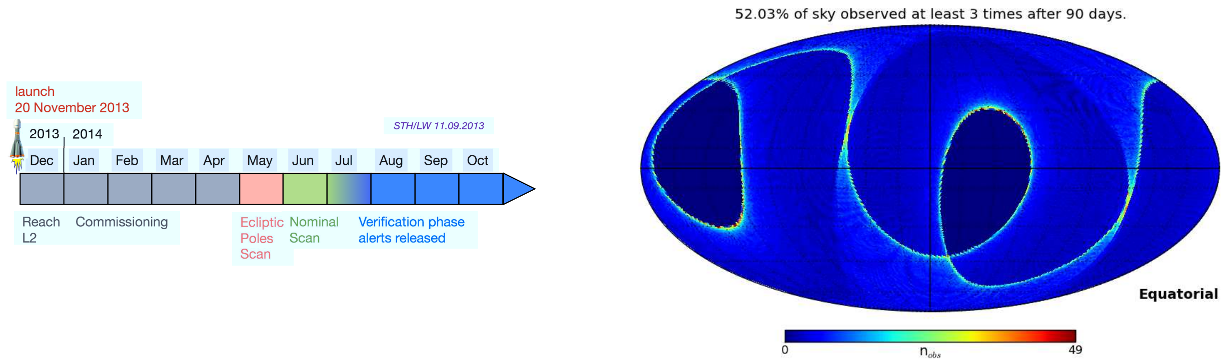

Fig 1 L: *Current timeline for Gaia operations and data accumulation.* **R:** *by 90 days, 50% of the sky has been observed at least 3 times by Gaia.*

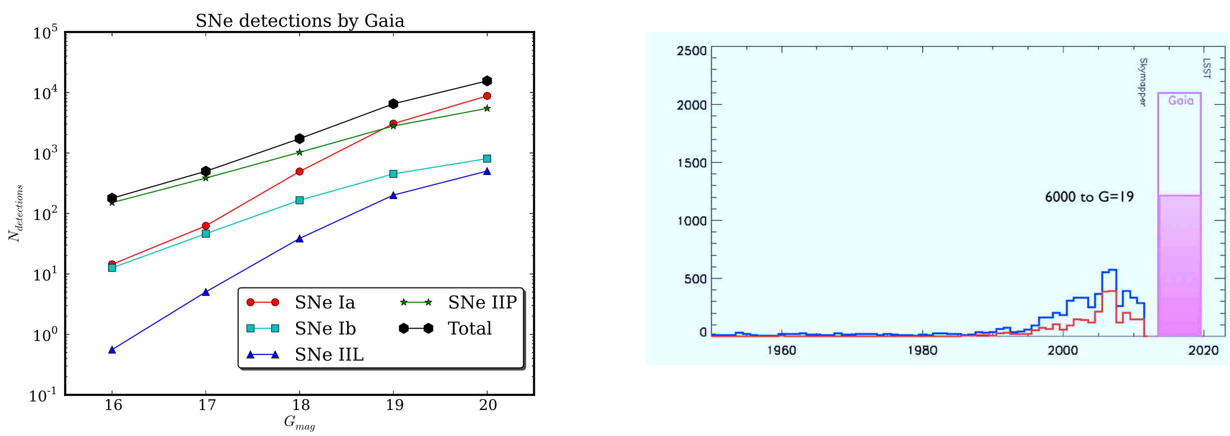

Fig 2 L: *Predicted SN detections with Gaia as a function of G-band magnitude.* **R:** *Comparison between the Gaia SNe discovery rate (SN/yr) and current surveys. The solid histogram is the number expected to 19th magnitude (1200/yr), while the open histogram (*> 2000*/yr) is for G=20.*

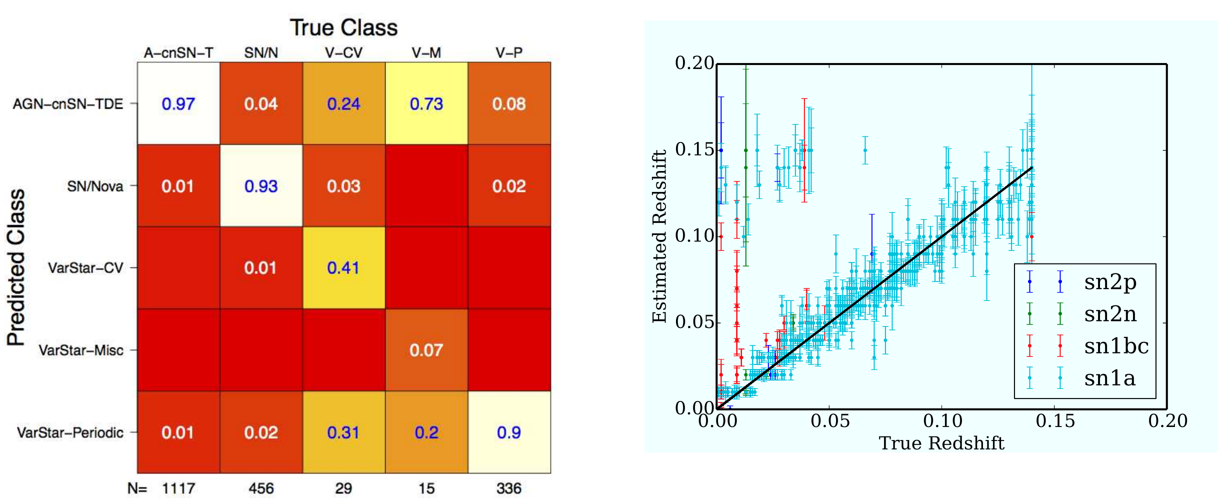

Fig 3 L: *Confusion matrix from Bloom et al. (2011) random forest classification. Entries along the diagonal corresponds to correct classification. Recovery rates are 90%, with very high purity, for the three dominant classes. Classification accuracy suffers for the two classes with small amounts of data (class size is written along the bottom of the figure.* **R:** *Redshift estimation for simulated Gaia SNe observations with G=18. Only well typed objects are selected for this test. Redshift estimation is done by comparing individual spectra to a template library. We will need to build a real template library of SNe actually observed by Gaia.*