European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **93A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title

Category: **D–8**

The Transient Sky with Gaia

2. Abstract / Total Time Requested

Total Amount of Time: 5 nights VM, 0 hours SM

We propose to start spectroscopic follow-up of the first Gaia transients to: **1.** Determine the contents, completeness and contamination of the Alerts Stream within the first year. **2.** Validate the classification system, focusing on Galactic transients (e.g. Novae, 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 e.g. magnitude, colour, amplitude, event duration, and environment. This validation programme will help optimize the Gaia Science Alerts pipeline, allowing the assured stream of classfied alerts to the wide astronomical 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.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	93	EFOSC2	5n	aug	n	1.4	THN	v	

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:	NTT	45h

5. Special remarks:

These observations are targeted to follow up Science Alerts from the Gaia satellite, which will be published typically 1–2 days after observation.

6. Principal Investigator:

S. Hodgkin, sth@ast.cam.ac.uk, UK, Institute of Astronomy, University of Cambridge

6a. Co-investigators:

See bit.ly 19Q4vjC Institute of Astronomy, University of Cambridge,UK

7. Description of the proposed programme

A – Scientific Rationale:

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 the NTT 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 build a large homogenous spectral library to enable machine-learning discovery and classification methods.
3. To identify rare or previously unknown transient phenomena and trigger their detailed study.
4. To investigate large samples of especially Galactic transients (Novae, CVs, Symbiotic stars, R CrB stars, and YSOs in outburst).
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.

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$\sim$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.

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

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

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.

B – Immediate Objective:

We are applying for an initial allocation of 5 NTT nights to be used in late Period 93 to measure $\sim$ 90 classification spectra. By the end of the 1-year campaign, we aim to have measured a total of $\sim$1000 spectra, and to have triggered follow-up of the most exciting events. 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. The remainder of the follow-up will take place in Periods 94 and 95, and will be applied for in the subsequent *CfPs*. 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 $\sim$200 of each broad class of transient phenomena (AGN/cnSN/TDE, SN/Novae, VarStar-CV, VarStar-Misc, VarStar-Periodic) for a total of $\sim$ 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.

Attachments (Figures)

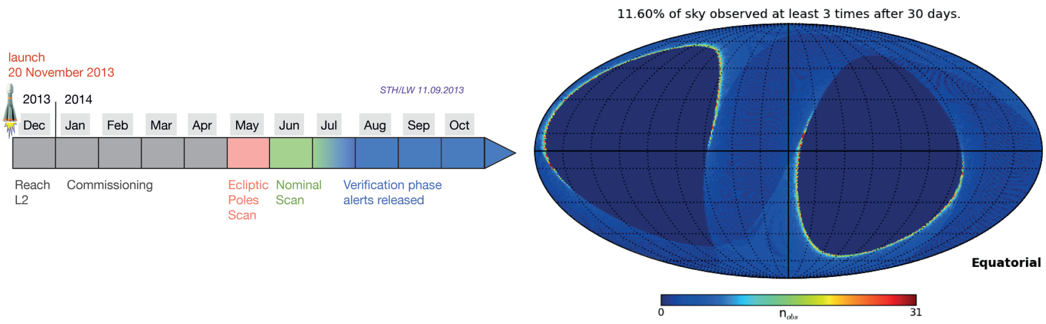

Fig. 1: **Left:** Current timeline for Gaia operations and data accumulation. **Right:** by 30 days, 11% of the sky has been observed at least 3 times by Gaia.

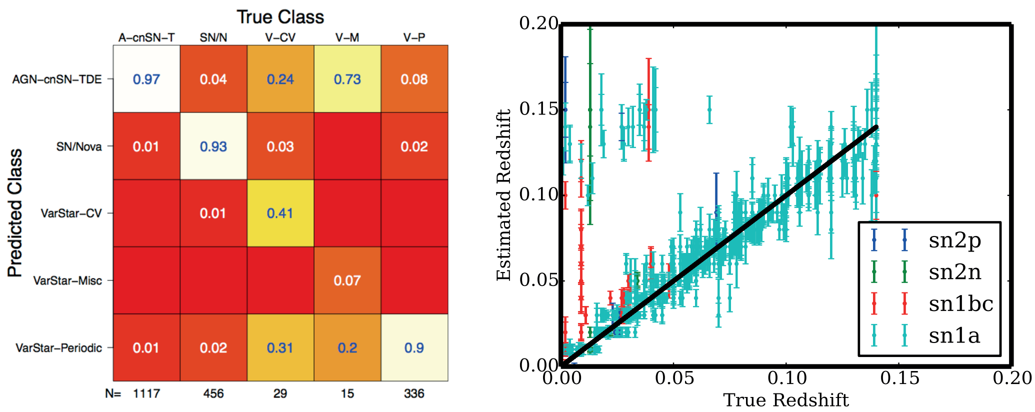

Fig. 2: **Left:** Confusion matrix from Bloom et al. (2011) random forest classification. Entries along the diagonal corresponds to correct classification. Recovery rates are$\geq$ 90%, with very high purity, for the three dominant classes. Classification accuracy suffers for the two classes with small amounts of data (class size is written along the bottom of the figure). **Right:** 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.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: We accept and can use a wide range of lunar phases, and will observe brighter targets when the sky is bright.

Time Justification: (including seeing overhead)

This proposal represents the beginning of the spectroscopic classification programme for Gaia Alerts. We aim to measure in total ∼1000 homogenous high-quality spectra in the first year of the mission. Half of these spectra will come from the NTT, while the other half will come from complementary northern hemisphere facilities: The INT and the WHT. Our targets will range in brightness from naked-eye objects to objects as faint as 20th magnitude, dominated by sources around r=18–20. We will measure classification spectra and release the data and results promptly (next day) to the community (following the PESSTO model) for detailed follow-up.

Classification spectra will use one standard setting : Gr13, covering 3685-9315Å (with a 1.0" slit producing 17.7Å resolution). The typical classification exposure time will be 1200s (OBs of 1800s duration). This will provide a SNR∼ 20 for r = 19.5 (3 days from new moon, airmass=1.5, seeing=1.0), ideal for building a classification training set.

500 spectra will take 250 hours of observing time. In this proposal we will focus on the first two months of Gaia Science Alerts and therefore request 45 hours or 5 nights. Future proposals will ensure full right ascension coverage and probe the diversity of Galactic and extra-Galactic environments.

Photometric Follow-up Campaigns: We are also coordinating a large programme of photometric follow-up to improve the lightcurve sampling of Gaia transients. A list of 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). LCOGT are expected to play a key role in the follow-up especially of μlensing and young star transients. We point out the strong synergies with external facilities operating at different wavelengths. We will be able to confirm and characterise e.g. LOFAR transients, and we may also trigger prompt SWIFT follow-up for particularly interesting events.

Follow-up Data Release: One of the most critical aspects of any transient survey is the release of discoveries in a timely fashion. The Catalina Real Time Transient Survey, the Palomar Transient Survey, and the Public ESO Spectroscopic Survey of Transient Objects (PESSTO) have all shown the power of not only making discoveries, but classifying them and releasing them rapidly to the community. Therefore we intend to archive and release our spectoscopic classifications from NTT+EFOSC2 promptly after processing each night's observing (collaborating and sharing PESSTO software).

8a. Telescope Justification:

NTT+EFOSC2 is a proven transient classification machine (PESSTO collaboration). It offers the perfect balance of efficiency, reliability, thoughput and site-quality, and guarantees that we can produce a homogenous sample of spectra. There is significant overlap between the PESSTO and the Gaia Alerts communities, which ensures that much of the PESSTO knowledge, practices and software (pipelines and transient broker/marshall) can be shared. Further, this proposal is complementary to PESSTO, and will provide coverage for times when PESSTO is not observing, focussing largely on classes which PESSTO does not pre-select for, especially in the Galactic plane.

We note here the planned used of complementary resources in the Northern hemisphere to ensure all-sky coverage (Liverpool Telescope, INT and WHT). The Liverpool Telescope in particular offers us alternative observing modes, and very rapid follow-up if required, e.g. fast SN followup of PTF discoveries (Nugent et al. 2011, Nature, 480, 344).

8b. Observing Mode Justification (visitor or service):

For this initial phase of classification, we require visitor-mode access to the telescope, to ensure real-time analysis and classification. This will also enable publication of transient classifications (via ATELs and on the Gaia Science Alerts webpages) and pipeline-reduced spectra within 24 hours of the end of the Chilean night (via a public archive).

8c. Calibration Request:

Standard Calibration

9. Report on the use of ESO facilities during the last 2 years

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

The data requested here are for transients not yet discovered by Gaia and are therefore not in the ESO Archive.

9b. GTO/Public Survey Duplications:

Gaia transients are public and some will also be discovered independently (PTF, CRTS, Skymapper, LaSilla-QUEST, PanSTARRS). There is a significant ongoing classification and follow-up programme running at the NTT: PESSTO (unusual supernovae). This GSA proposal will complement PESSTO target selection by focussing on Galactic transients, and longer-duration events to which Gaia is best suited and offers unique sensitivity. We expect many SNe will be classified as part of routine PESSTO classification observations, hence that is not the primary goal of this proposal. However we can and will observe SNe when PESSTO is unable to, and contribute to the PESSTO science goals, and the hunt for extreme and rare events.

10. Applicant's publications related to the subject of this application during the last 2 years

Bloom J. et al. 2012, ApJ, 744, 17

Campbell H. et al., 2013, ApJ, 763, 88

Elias-Rosa N. et al. 2013, MNRAS, tmpL, 166

Feat M.W., Menzies J.W., Whiteloxk P.A., 2013, MNRAS, 428, 36

Fender R.P., Maccarone T.J., Heywood I., 2013, MNRAS, 430, 1538

Fraser M. et al. 2013, MNRAS, 433, 1312

Hodgkin S.T. et al. 2013, PhilTransA, 371, 20239

Jonker P. et al. 2012, MNRAS, 423, 3308

Kains N. et al. 2013, A&A, 552, 70

Ofek E.O. et al. 2013, ApJ, 763, 42

Scholz, Froebrich, Wood, 2013, MNRAS, 430, 2910, "A systematic survey for eruptive young stellar objects using mid-infrared photometry"

van Vezen S. & Falcke H., 2013, A&A, 557, 7

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	90 Gaia Transients	22	-30	45	5-19	point sources		

Target Notes: Targets will be selected from the Gaia Alerts data stream which will be published by the Gaia DPAC (`http://www.rssd.esa.int/gaia/dpac`) photometric processing centre in Cambridge, expected from late-July 2014.

12. Scheduling requirements

3. Unsuitable period(s) of time

Run	from	to	reason
A	1-apr-14	31-jul-14	Gaia Alerts release timescale.

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
93	EFOSC2	A	Spectro-long-slit	Grism#13:369-932