Science and Technology Facilities Council
Polaris House, North Star Avenue, Swindon, SN2 1SZ
Telephone 01793 442000 Fax 01793 442002

PATT2
Version 02/2013

APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *(AAT, UKST, WHT, INT or UKIRT)* WHT

Reference: Date stamp:

2 SEMESTER 2014A

3 SCIENTIFIC CATEGORY 2,3,4

4 COORDINATED PATT PROPOSALS *AAT:*☐ *UKST:*☐ *WHT:*☐ *INT:*☒ *UKIRT:*☐ *JCMT:*☐ *GEMINI:*☐ *LT:*☒ *MERLIN:*☐

5 PRINCIPAL APPLICANT

Surname: Hodgkin
Title: Dr
First name: Simon
Post held: Senior Research Associate
Address:
Institute of Astronomy
Madingley Rd
Cambridge
Telephone: +44 (0)1223 766657
Fax: +44 (0)1223 337523
E-mail: sth@ast.cam.ac.uk
Is the applicant a possible observer? Yes

6 COLLABORATORS

Name:	Institute:	Observer?
Full List of Co-I's at:	www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/ Working_groups	Yes

7 SHORT TITLE OF PROPOSAL *(maximum 12 words)*

The Transient Sky with Gaia

8 SUMMARY OF PROPOSED OBSERVATIONS

We propose a large collaborative programme of spectroscopic follow-up of the first year of Gaia transients to: **1.** Identify rare or previously unknown transient phenomena and trigger their detailed study. **2.** Provide input into the completeness and contamination of the Gaia Alerts Stream within the first year of data release and aid with the tuning of discovery and classification parameters. **3.** Classify large samples of nearby extragalactic transients (including Novae, Supernovae and Tidal Disruption Events), and Galactic transients (e.g. Novae, CVs, Symbiotic stars, R CrB stars, and YSOs in outburst). **4.** Produce a study of the transient sky as a function of properties such as: magnitude, colour, amplitude, event duration, Galactic and extra-Galactic environment. The WHT component of the proposal is principally targeted at fainter and rarer transients.

9 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
Cass	ACAM+ISIS	AUXCAM, EEV12, RED+	VPH disperser, R300B, R600B, R316R, R600R

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester	2			nights
Minimum useful allocation this semester			2	

UKIRT applicants requiring dark time must justify this in section 18

11 COMPLETE THIS SECTION ONLY IF THIS IS A LONG TERM PROPOSAL

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Total time requested	6	6	6	N

12 SCHEDULING INFORMATION

Preferred dates:	Jul–Aug
Impossible dates:	Feb–May
Give justification for impossible dates	Gaia Launch date is Nov 20 2013, commissioning nominally ends April 19th 2014
If observations are to be simultaneous with other telescopes or satellites, give details:	Alerts will be fed from the Gaia Photometric Alerts Team based at the IoA, Cambridge. Alerts are expected to be discovered and published to the world within $\sim$24-48 hours of observation by the satellite.
Any other scheduling constraints: *Include likely clashes with other time applications, constraints on lunar position or quarter, instrument preparation requirements, etc*	

13 SERVICE OBSERVING

yes: ☐ no: ☒ maybe: ☐

14 SUPPORT ASTRONOMER REQUESTED AT TELESCOPE

every night: ☐ no: ☐ first night only: ☒

15 LIST OF PRINCIPAL TARGETS

Object(s):	RA(h,m):	Dec(degs):	Mag(type):	Colour:	Exp. Time:
All	13h-03h	-20–+90	$r \geq 18$	wide range	$t \sim 1800$s

16 LIST ALL SIMILAR/SUPPORTING APPLICATIONS TO ANY PATT OR OTHER TIME ASSIGNMENT COMMITTEE

You must include a brief description of any other applications whose targets or science goals are similar to those requested here

Telescope/satellite:	Title/Description of programme:
INT/PATT	The Transient Sky with Gaia (Bright target spectroscopy)
INT/NL	The Transient Sky with Gaia (Dutch share of above)
WHT/NL	The Transient Sky with Gaia (Dutch share of this proposal)
Liverpool/PATT	The Transient Sky with Gaia (ToO follow-up and photometric/spectroscopic monitoring)

17 SCIENTIFIC JUSTIFICATION

Case not to exceed this A4 page. Figures and/or references can be included on page 4a

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 alerts 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 one large proposal to the INT for spectroscopic follow-up over one year to tackle the following overarching goals:

1. To identify new examples of rare or unknown transient phenomena and trigger their detailed study.
2. To provide input into the completeness and contamination of the Alerts Stream within the first year and improve discovery and classification algorithms.
3. To classify large samples of nearby extragalactic transients (SNe Ia, core-collapse SNe, SLSNe, and TDEs), and Galactic transients, (CVs and young stellar objects in outburst).
4. To produce an unbiased study of the transient sky as a function of magnitude, colour, amplitude, duration, population, and Galactic and extra-Galactic environments.

The Gaia Alert stream should be almost completely free from moving objects (asteroids, NEOs) thanks to two closely separated exposures ($\Delta t = 2$hrs) and the dedicated Solar-System Object pipeline. Gaia has a unique feature: every transient will be classified using the onboard BP/RP spectrograph (R∼20–100, S/N∼10 at G=19). This classification needs a training set of well-exposed (S/N∼20–50), medium-dispersion (R∼500–1000) spectra to be reliable. This proposal will provide that training set for the fainter and rarer 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. Some of the key science areas we will explore are:

Supernovae

SNe Ia are proven cosmological probes. They provide convincing evidence for an accelerating Universe (Riess et al. 1998, ApJ, 504, 935; Perlmutter et al. 1999, ApJ, 517, 565), and can be used to map its geometry to high precision. **Core collapse SNe** (CCSNe, from $> 8\mathrm{M}_\odot$ stars) are a major source of metals in the Universe. They (with SNe Ia) shape and influence galaxy structure and star formation. They provide critical insights into the first stars, and test the predictions of stellar evolutionary codes.

Gaia is expected to detect about 6000 SNe (3 per day, e.g. Belokurov & Evans 2003, MNRAS, 341, 569), with ∼70% SNe Ia, below z = 0.1 to G=19 (the white-light Gaia passband). Each object will have a colour and a BP/RP spectrum, which will ultimately help prompt classification (Blagorodnova et al. 2013 in prep). This large homogenous sample will improve our understanding of SN explosions and enable unbiased investigations of the following science aims: **A.** Studying SNe Ia as a function of host-galaxy type, rate differences between passive and star-forming galaxies (Smith et al. 2012, ApJ, 755, 61), *prompt* and *delayed* paths to explosion (Sullivan et al. 2006a, AJ, 131, 960; Mannucci et al. 2006, MNRAS, 370, 733), and the role of host-galaxy mass (Sullivan et al. 2010, MNRAS, 406, 782). **B.** Gaia provides extremely accurate positions and spatial resolution, which will allow for the detailed study of the SN Ia and CCSNe spatial distribution (and progenitors pre-imaged with e.g. HST or even Gaia itself) within different galaxy types and environments. E.g. luminous Infrared Galaxies (LIRGs) which have very high star formation rates, should produce prodigious numbers of CCSNe particularly close to their bright nuclei, but which are difficult to resolve from the ground (Kankare et al. 2012, ApJ, 744, 19). **C.** Studying the discrepancy (at 2σ: could be from systematics or from evolution) between the local measurement of the Hubble constant from SNe Ia measurements (Riess et al. 2011, ApJ, 730, 119) and the high redshift H0 measurements from CMB (Planck collaboration 2013). **D.** Detection of the shock breakout and early optical emission of CCSNe (Soderberg et al. 2008, Nat, 453, 469; Arcavi et al. 2011, ApJ, 742, 18), which constrains the radius of the progenitor star (extended red supergiant progenitors of Type II SNe should have a shock breakout lasting a day). **E.** Gaia is well suited to finding and studying slowly evolving Super-Luminous SNe (SLSNe; Gal-Yam et al. 2012, Sci, 337, 927). SLSNe are 10–100 times more luminous than traditional SNe and are not yet understood (Inserra et al. 2013, ApJ, 770, 128). SLSNe are intrinsically rare (∼10^{-4} of the CCSNe rate) and Gaia can detect SLSNe out to z=0.4. We will confirm their nature, and make the first systematic measurement of their intrinsic rates.

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 ($z>0.01$). Since the frequency of disruptions depends strongly on the evolution of stellar orbits, a measurement of the TDE rate allows us to constrain the phase space distribution of stars in Milky Way-like galaxies. Furthermore, tidal disruptions provide a new way for testing our understanding of accretion physics. While AGN vary on a 10^6 yr timescale, the fallback rate of the disrupted stellar debris can change from super-Eddington to sub-Eddington in a few years. Hence modeling the optical to X-ray emission from tidal disruption flares is extremely challenging. Only by observing a robust set of example light curves we will be able to make progress.

New simulations (Blagorodnova et al. in prep) suggest that Gaia should discover 10 TDE events per year to $G=19$ with an amplitude > 0.3 magnitudes (30/yr to $G=20$) in galaxies detected by Gaia. Only 0.1% of AGN show variability with such large amplitudes on a 10–100 day timescale (McCleod et al. 2012, ApJ, 753, 106). We expect to find 20 AGN/yr with similar amplitudes (fewer as we build up LC history). Spectroscopic and photometric follow-up will help us discriminate between SN, AGN and TDE hypotheses. Spectroscopic observations of AGN flares will allow us to calibrate a color “locus” of these events for the Gaia BP/RP. This will help us to reject AGN flares in future searches for TDEs and SNe. Yet the highest amplitude AGN flares themselves are of great interest, as they may come with a spectroscopic type change (Sy2–Sy1), providing us with new key information on the nature, formation and stability of the AGN broad-line region.

Galactic Transients: Interacting Binaries

Dwarf novae, a main subclass of **CVs**, show semi-regular (accretion disk instability) outbursts of typically a few magnitudes. **Classical nova** outbursts are thought to occur when the surface layers of the white dwarf undergo a thermo-nuclear runaway. Discovery of a new dwarf nova in outburst, and rapid follow-up (Thorstensen & Skinner 2012, AJ, 144, 81) enables us to measure the binary period (typically a few hours, spanning from mins to days: e.g. Gaensicke et al. 2009, MNRAS, 397, 2170). Gaia astrometry and parallaxes will make a key contribution to determine the true Galactic population of these sources which is shaped by ill-constrained angular momentum loss mechanisms. Double degenerate white dwarf binaries (**AM CVn systems**, Carter et al. 2013, MNRAS 429, 2143) are the favoured pathway for Type Ia progenitors, and the principal source of low-frequency gravitational waves. But samples of these systems are still very small, and an all-sky search with Gaia has the scope to make a real difference. After training, spectral information from BP/RP will be used to separate these from normal CVs, thanks to hydrogen-deficient spectra dominated by He emission lines.

All Galactic stellar mass black hole binaries have been discovered via their transient outbursts (in all-sky X-ray monitors). They permit detailed dynamical studies to establish binary periods, companion nature and NS/BH masses, but only for a few dozen systems (Fender & Belloni, 2012, Sci, 337, 540). Using Gaia, there will be a step-change in our capability to detect **all** the objects with d<few kpc in quiescence, as they are known to show strong variations and flickering in their optical light-curves in quiescence (Cantrell et al. 2010, ApJ, 710, 1127). Spectroscopic follow-up will allow us to differentiate the accreting neutron star and black hole systems from accreting white dwarfs.

There are many other classes of Galactic transient that we expect to see, e.g. R CrB stars, Symbiotic stars, Helium-shell flash events, Novae, μlensing events (see: `http://bit.ly/1e8QUcI`).

Young Stellar Objects: outbursts and eclipses

Some young pre-main sequence stars (EX Lup, DR Tau) have exhibited drastic episodic outbursts (1–3 mag). Spectacular eruptions (3–6 mag, timescales < 1 yr) have been measured in a dozen FU Orionis stars. V1515 Cyg is the only example to require a decade to rise to visual maximum;, although historical light curves for many of these systems are poorly documented. Prompt follow-up is needed to study the impact of such accretion bursts on the properties of the dust and gas in the disks. High cadence monitoring immediately after the event is useful for modeling the source. 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 eclipses.

18 TECHNICAL INFORMATION (I)

Give details of the technical feasibility of the proposal (S/N,etc) AND any non-standard technical requirements

Observing Strategy

We are applying to the UK TAC for a total of 18 WHT nights, spread over three semesters (2+9+7). The WHT+ISIS/ACAM will be used to measure classification spectra for the fainter and rarer transients which we canot reach with the INT. We will measure ∼300 homogenous high-quality spectra in the first year of the mission, and will begin early science with the Gaia Alert Stream. Gaia has a nominal launch date of 20/11/2013. Routine operations (and accumulation of flux histories) will begin in April 2013 (Fig 1), after a month of intense scanning of the Ecliptic Poles. In Fig 1 we show the expected coverage of Gaia by mid-August 2014. We propose to begin Gaia Alerts Spectroscopic Follow-up in the last weeks of July and the first week of August with an allocation of time (4 nights total split between UK and NL TACs). Any slip in the Gaia launch-date will be communicated immediately to the TACs.

The bulk of the follow-up will take place in 2014B and early 2015A. The majority of spectroscopic classification will be performed using the WHT in classical observing mode with runs lasting ∼3 nights per month (half of these from the UK). WHT+ACAM/ISIS gives us an ideal mix of sensitivity and flexibility, depending on the early (photometric) classification of the source. For example, with an R=19.5 transient, we can reach S/N∼20 in 1800s (seeing:*1.2*as, airmass:*1.2*, sky:*Grey*) with the V400 grating on ACAM, excellent for classification. WHT+ACAM/ISIS is an extremely efficient observing system, and allowing for overheads, and calibration, we can observe ∼10 targets per summer night. ISIS is preferred for the bluest sources, or if a high dispersion is warranted.

All Gaia alerts will ultimately be classified on the basis of photometry (lightcurves) and BP/RP spectroscopy. We need to build large training sets over a wide range of classes in order for our (Random Forest) machine learning algorithms to perform well. For the rarest, and most interesting classes, the logN–logS for transients shows that a component of our follow-up programme will need to classify fainter sources. We will also request additional ToO observations with the Liverpool Telescope for following exciting transients, and to allow for quick reactions when our INT/WHT observations are not scheduled. **We request 1.5 nights per month of time from the UK TAC spread over one year**, which when combined with a similar allocation from the NL TAC will enabe us to classify a sample of some 300 fainter transients (allowing for 20% time lost to weather). We apply for long term status now, although we understand that the TAC will probably prefer an additionall application to be made in March 2014, following a successful Gaia launch and commissioning phase. **Therefore in this proposal we request an initial allocation of 2 nights.**

In the long term, we expect the Gaia community to submit their own more detailed observing programmes with much more specific science cases. This proposal is focused solely on the first year of Gaia Alerts.

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

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 the WHT promptly after processing each night's observing. To this end, we will develop a fast, largely automated pipeline (as was done for PESSTO) for the (real-time, and day-after) reduction of WHT+ACAM/ISIS data. To facilitate the pipeline reduction of data, we will be using a small range of set-ups.

18 TECHNICAL INFORMATION (II)

References and Figures

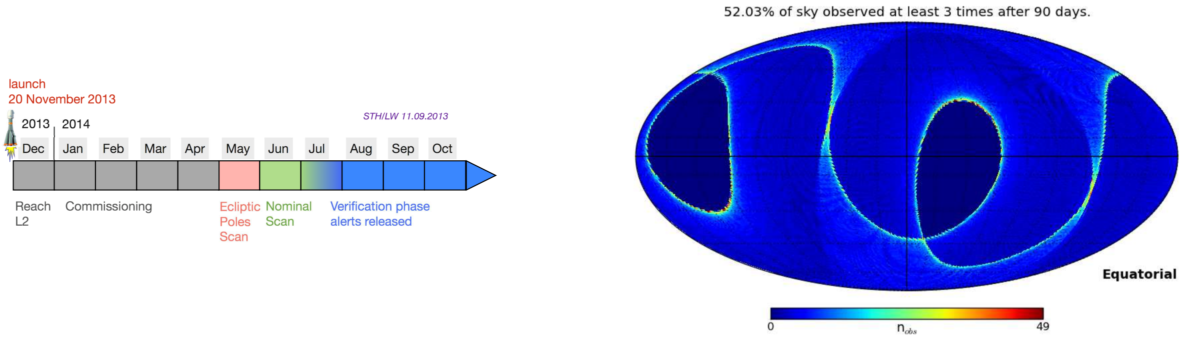

Fig 1 **[Left]:** Current timeline for Gaia operations and data accumulation. **[Right]:** by 90 days, 50% of the sky has been observed at least 3 times by Gaia.

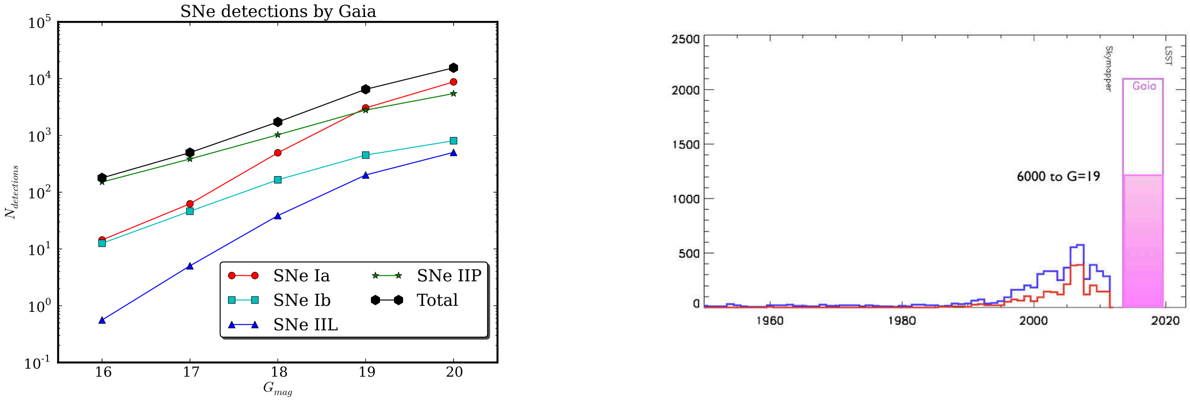

Fig 2 **[Left]:** *Predicted SN detections with Gaia as a function of G-band magnitude.* **[Right]:** *Comparison between the Gaia SNe discovery rate (SN/yr) and current surveys. The solid histogram is the number expected to 19th magnitude (1200/yr), while the open histogram (> 2000/yr) is for G=20.*

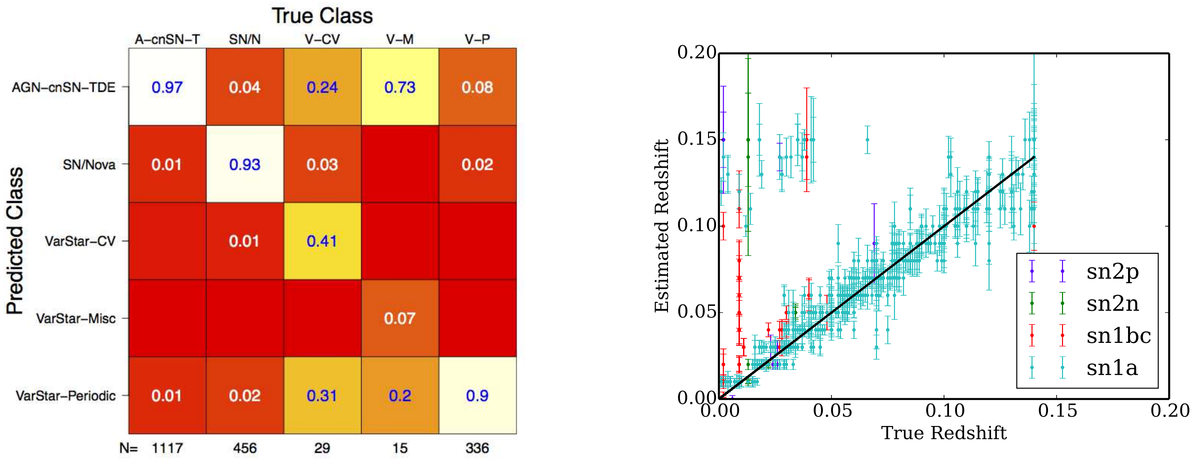

Fig 3 **[Left]:** *Confusion matrix from Bloom et al. (2011) random forest classification. Entries along the diagonal corresponds to correct classification. Recovery rates are 90%, with very high purity, for the three dominant classes. Classification accuracy suffers for the two classes with small amounts of data (class size is written along the bottom of the figure.* **[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.*

19 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS

If instrumentation or setup differs from main programme, give full details

In poor observing conditions we will observe brighter targets, or integrate longer to maintain signal-to-noise. If there are problems with the Gaia data flow (which occur too late in the cycle to communicate to the TAC) we will observe transient events as part of the PESSTO survey but which are too far North for the NTT. We note that the PESSTO survey target unusual SNe and targets the Southern Hemisphere.

20 RELATED PATT APPLICATIONS OVER THE LAST FOUR SEMESTERS *(including unsuccesful applications)*

PATT reference:	Award:	Clear nights:	Comments:

21 PUBLICATIONS BASED ON PATT TIME PUBLISHED DURING THE LAST FOUR SEMESTERS *(maximum 6)*

22 EXPERIENCE OF INTENDED OBSERVERS WHO HAVE NOT PREVIOUSLY USED THIS TELESCOPE

There are many experienced WHT observers in the proposal, including Hodgkin, Littlefair, Gaensicke, Naylor, Sullivan, Smartt

23 COMPLETE IF THE OBSERVATIONS ARE PRIMARILY FOR A STUDENT RESEARCH TRAINING PROGRAMME

Name of student:	Grad students are indicated on the co-I webpage
Project title:	

24 COMPLETE IF THE OBSERVATIONS ARE ASSOCIATED WITH A CURRENT STFC RESEARCH GRANT

Name of principal investigator:	Professor P C Hewett
Grant title:	STFC Grant for IoA 2011-13
Grant number:	Grant Number:ST/J000647/1

25 NON-STANDARD TRAVEL AND SUBSISTENCE REQUIREMENTS *(UK observers only)*

Justify requests for travel and subsistence for more than one person:

We will run a real-time pipeline reduction of the data. For most efficient use of the telescopes, two observers will be needed.

Details of any other expenditure (eg freight, remote observing):