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PATT2
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APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *(AAT, UKST, WHT, INT or UKIRT)*	INT	Reference:	Date stamp:
2 SEMESTER	2023A	3 SCIENTIFIC CATEGORY	1

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

5 PRINCIPAL APPLICANT

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6 COLLABORATORS

Name:	Institute:	Observer?
Abbie Donaldson	Institute for Astronomy, University of Edinburgh	Yes
Dr Agata Rożek	Institute for Astronomy, University of Edinburgh	Yes
Dr Cyrielle Opitom	Institute for Astronomy, University of Edinburgh	Yes
Professor Alan Fitzsimmons	Astrophysics Research Centre, Queen's University Belfast	No

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

Lightcurves of Asteroids with Strong Apparition Effects

8 SUMMARY OF PROPOSED OBSERVATIONS

One must characterise the phase curve of an asteroid in order to obtain essential physical properties such as the absolute magnitude, which is related to size. Rotational brightness variation and long term changes in the aspect angle complicate measurement of the phase curve. We have developed a method to identify a list of asteroids observed by the low cadence, long baseline ATLAS survey that exhibit large shifts in absolute magnitude between apparitions due to these effects. Lightcurve inversion methods can be used to remove these effects but this generally requires an apriori rotation period to work effectively. We propose to observe 5 asteroids from our list and obtain rotational periods that will allow us to invert the sparse ATLAS data. This will highlight the benefit of identifying apparition effect objects in large surveys in order to obtain more accurate absolute magnitudes and sizes.

9 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
prime	WFC	EEV 4Kx2K	Sloan g, Sloan r, Sloan i, RGO Z

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester		6		Nights
Minimum useful allocation this semester		4		

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				

12 SCHEDULING INFORMATION

Preferred dates:	Run 1: 3 consecutive nights in the period 11-28th February. Run 2: 3 consecutive nights ~ 1 month after run 1, up to 28th March.
Impossible dates: *Give justification for impossible dates*	For the 5 selected targets dates before 11th February and after 28th March are not ideal. Outside of our requested date range not all objects are visible in the sky on the same night. However we have a large list of backup targets.
If observations are to be simultaneous with other telescopes or satellites, give details:	N/A
Any other scheduling constraints: *Include likely clashes with other time applications, constraints on lunar position or quarter, instrument preparation requirements, etc*	For the requested dates all 5 targets are observable during the same night.

13 SERVICE OBSERVING

yes: [ ] no: [ ] maybe: [X]

14 SUPPORT ASTRONOMER REQUESTED AT TELESCOPE

every night: [ ] no: [ ] first night only: [X]

15 LIST OF PRINCIPAL TARGETS

Object(s):	RA(h,m):	Dec(degs):	Mag(type):	Colour:	Exp. Time:
7891 (Fuchie)	08:52 (22nd Feb)	+16 (22nd Feb)	17.2(V)	0.30 (V-R)	55s
	08:40 (17th Mar)	+17 (17th Mar)	17.8 (V)		212s
10902 (1997 WB22)	12:16 (22nd Feb)	+14 (22nd Feb)	16.4 (V)	0.40* (V-R)	57s
	11:58 (17th Mar)	+18 (17th Mar)	16.1 (V)		45s
26286 (1998 SV65)	10:48 (22nd Feb)	-03 (22nd Feb)	16.1 (V)	0.26 (V-R)	46s
	10:31 (17th Mar)	+01 (17th Mar)	16.1 (V)		44s
32443 (2000 RD101)	09:23 (22nd Feb)	+02 (22nd Feb)	17.0 (V)	0.40* (V-R)	44s
	09:04 (17th Mar)	+02 (17th Mar)	17.5 (V)		97s
37824 (1998 BU14)	09:30 (22nd Feb)	+17 (22nd Feb)	17.3 (V)	0.29 (V-R)	47s
	09:16 (17th Mar)	+19 (17th Mar)	18.0 (V)		126s

* Assumed colour [1]

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:

17 SCIENTIFIC JUSTIFICATION

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

Asteroids are the leftovers of the process of planetary formation; they are the evolved building blocks of the planets. Their physical properties such as size, shape and composition are a product of their formation in a particular region of the protoplanetary disk and their subsequent dynamical and physical evolution from processes such as collisions and space weathering. Therefore the physical properties of asteroids, and where they are found in the modern Solar System, provide valuable constraints on the early formation of the planets and their subsequent dynamical interactions. **We propose to obtain dense lightcurve observations for selected asteroid targets that show strong brightness variations** due to shape and spin in low cadence ATLAS [2] survey data. Obtaining an accurate rotational period from these lightcurves will **enhance the ATLAS data and provide improved measurements of the size, shape and spin state of these asteroids.**

The phase curve of an asteroid describes how its brightness changes with the Sun-asteroid-Earth phase angle of the observation. Determination of the phase curve is required in order to accurately measure two important asteroid parameters: absolute magnitude and phase curve slope. The absolute magnitude of an asteroid is related to its size through albedo. **Accurate asteroid sizes are essential for assessing the size distribution of different asteroid populations**, which is a function of planetesimal formation and collisional evolution [3]. The slope parameter(s) describes the shape of the phase curve, which depends on the composition of the asteroid surface and its roughness [4,5,6]. They are important for tracing different compositions/families amongst the asteroid populations [7], which provides constraint on where asteroids formed and how they have since been dispersed.

Observing phase curves is complicated by brightness variations caused by changes in the geometric scattering cross-section of an asteroid due to its non-spherical shape and spin state. This leads to an additional scatter around the aforementioned phase curve, or even deviations from the expected phase curve [8], and **if not accounted for these effects can hinder the accurate determination of absolute magnitude and slope parameter**. Furthermore, if the asteroid rotation axis is tilted with respect to the observer's line of sight then the angle between these vectors (the aspect angle) will change on long timescales between apparitions of the asteroid [9]. During each apparition the asteroid presents a different cross-sectional surface area which leads to shifts in its measured absolute magnitude. Thus the true size of an asteroid can only be determined after accounting for these effects. Fortunately, when observations are obtained over a range of viewing geometries it is possible to use methods such as lightcurve inversion to retrieve a shape and spin model for the unresolved body [10], allowing us to correct for these brightness variations. Generally low cadence observations from wide field surveys are utilised to assess the phase curve behaviour of asteroids over a long baseline, but from this data alone it is difficult to obtain a unique solution for the rotation period of an asteroid. **If the rotation period of an asteroid is known apriori from high cadence targeted lightcurve observations this significantly reduces the lightcurve inversion parameter space to be searched** [11].

We have analysed a large database of sparse asteroid photometry from the wide field ATLAS survey and we have assessed the phase curve properties of nearly 400,000 asteroids [12] (paper in prep). We have developed a method which quickly identifies asteroids in this dataset exhibiting strong apparition effects; i.e. shifts in absolute magnitude between different apparitions. We fit a phase curve to each apparition separately and search for variation in absolute magnitude over the ~ 6 years of ATLAS data. Fig. 1 clearly shows these shifts as well as the rotational brightness variation on top of each phase curve. We identify > 2000 such objects without periods in the ALCDEF/LCDB databases [13]. We select 5 targets from our list that have the brightest estimates for absolute magnitude, the most ATLAS observations, and optimum visibility during semester 2023A. We propose to measure their rotational periods to enable lightcurve inversion of the sparse ATLAS data, similar to studies which instead made use of published rotational periods [11].

This study is particularly relevant given upcoming wide field surveys such as the Rubin Observatory Legacy Survey of Space and Time (LSST). LSST will discover $> 5 \times 10^6$ asteroids over the 10 years of its operation [14] however rotational brightness variation and the apparition effect described above will need to be accounted for. **This proposal will allow us to verify our method for identifying the apparition effect in sparse survey data and demonstrate how targeted lightcurve observations will allow us to obtain the true absolute magnitude and size of these objects**.

18 TECHNICAL INFORMATION (I)

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

Target Selection

From our list of > 2000 objects with strong apparition effects we have a large number of possible targets. None of these objects have rotation periods reported in the ALCDEF/LCDB database but they are all well observed by the ATLAS survey with ∼1000-1400 detections for each object (Fig. 1). Objects from this list are prime targets for dense lightcurve observations to complement the sparse, long baseline ATLAS observations and obtain a shape/spin model and improved absolute magnitude. From this list we select the objects with the brightest absolute magnitudes (larger physical size). By observing these larger, brighter objects we will achieve accurate, high S/N photometry (S/R of order 100 is ecpected for all targets) which will give us high quality lightcurves. Bright objects can be observed with lower exposure times which will reduce motion trailing effects, although all our targets have a maximum motion of 0.7 arcsec/min. Our targets are bright enough to allow us to make use of dark to grey sky conditions. Lightcurve amplitude varies with aspect angle [9] and by observing brighter targets we are more sensitive to smaller brightness variations. This minimises the risk of selecting a target that is in a low amplitude season with a difficult to measure lightcurve. Furthermore, larger asteroids are less affected by processes that cause spin state evolution, e.g. collisions and YORP [15]. This means that the lightcurve periods measured during semester 2023A will be more applicable to the long baseline ATLAS data. However, larger asteroids can have longer spin periods so we will need to do an initial assessment of the lightcurves after night 1 as described below. We prioritised targets from our list with a greater number of ATLAS detections. This gives us a larger dataset of photometry to work with for subsequent lightcurve inversion.

Our 5 selected targets are most visible from 11th February to 28th March, when all objects are visible in the same night and brighter than magnitude 18.5. Target visibility is >7hrs for all targets, with targets spread throughout the night. There is at least one target with airmass<1.4 throughout most of the night (Fig. 2). For these 5 objects we have attempted to find a rotational period in the ATLAS data alone using a Lomb-Scargle periodogram [16]. This search identifies only alias periods associated with the ATLAS survey cadence (e.g. 24, 12hrs etc.). Thus targeted lightcurve observations are required to get a rotational period and improved size, shape and spin models for these objects.

Time requested and observing strategy

The use of **INT WFC** is ideal for these observations, its large aperture will allow us to obtain high S/N photometry with low exposure times and no trailing. Our observing strategy is to spend run 1, night 1 switching between targets in order to sample the lightcurves of all 5 targets throughout the night. The data will be reduced during the day by the listed collaborators to assess the initial lightcurves. For asteroids like our targets which are around 10km in size the typical rotation is approximately 3-4 cycles/day [17]. However, if the initial analysis shows a target to have a long period that would require more than one full night of observing it can be swapped out for a backup target. Subsequent nights in run 1 (ideally 2 nights, but 1 extra night minimum) will be used to fill in missing lightcurve phases for each target. We will occasionally intersperse lightcurve measurements in Sloan r with frames in g, i, z filters to get the colour index for each asteroid, to better establish asteroid taxonomy and merge this data with ATLAS data in o and c filters.

By run 2 we will have rotational periods for each target and thus can dedicate sufficient time on each night to observe 1-1.5 rotational periods of the targets. By conducting run 2 roughly 1 month after run 1 we will measure the lightcurve of each object at a different phase angle (change in phase angle ∼15 degrees for most targets). Sampling more viewing geometries will improve the analysis of shape and spin via lightcurve inversion.

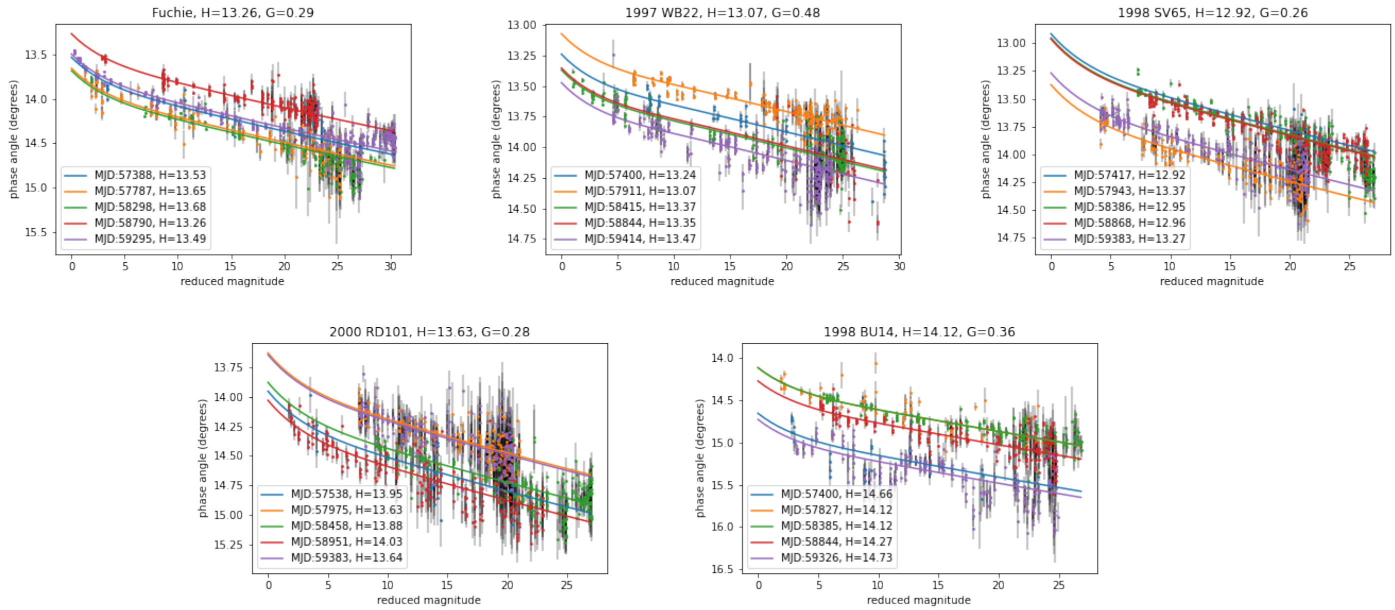

Figure 1: *HG* phase curve models [4] fitted to ATLAS photometry for the 5 target asteroids. The legend for each plot provides the start date of the apparition in MJD and the absolute magnitude H at that epoch. The observations and phase curve for each apparition are indicated by marker/line colour. We show only the ATLAS data in the o filter which is most frequently used in the survey; each object has similar but fewer observations in the c filter. There are clear shifts in absolute magnitude between apparitions and the scatter around each phase curve is driven by rotational variation.

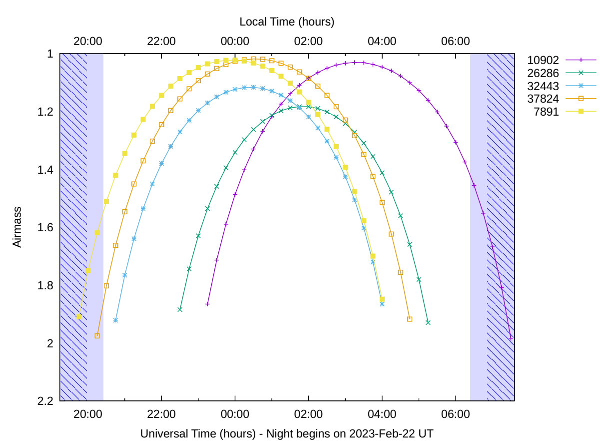

Figure 2: Airmass of the 5 targets on the night of 22nd February 2023.

References:

[1] B. J. Gladman et al., Icarus 202 (2009): 104–18. [2] J. L. Tonry et al., PASP 130 (2018): 064505. [3] W. F. Bottke et al., Icarus 175 (2005): 111–40. [4] E. Bowell et al., in Asteroids II (1989). [5] K. Muinonen et al., Icarus 209 (2010): 542–55. [6] A. Penttilä et al., P&SS 123 (2016): 117–25. [7] M. Mahlke et al., Icarus 354 (2021): 114094. [8] S. L. Jackson et al., MNRAS 513 (2022): 3076–89. [9] E. Fernández-Valenzuela, Front. Astron. Space Sci. 9 (2022): 796004. [10] M. Kaasalainen et al., Icarus 153 (2001): 37–51. [11] J. Ďurech et al., A&A 643 (2020): A59. [12] J. E. Robinson et al., EPSC2021-706 (2021). [13] B. D. Warner et al., Icarus 202 (2009): 134–46. [14] R. L. Jones et al., LSST Science Book: The Solar System. 97–136. [15] K. J. Walsh, Annu. Rev. Astron. Astrophys. 56 (2018): 593–624. [16] J. T. VanderPlas, ApJS 236(1) (2018), 16. [17] P. Pravec et al.,in Asteroids III (2002).

19 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS

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

We started target selection with a list of $>$2000 possible targets demonstrating strong apparition effects in ATLAS data and selected the 100 objects with the brightest absolute magnitude and most detections. We therefore have no shortage of backup targets over the whole semester. In the period of 1st Feb to 28th Mar we have $\sim$40-50 out of the 100 targets brighter than magnitude 20 and $>$30 degrees from the moon available as backup targets.

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

All collaborators have experience using the INT and/or other telescopes.

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

Name of student:	
Project title:	

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

Name of principal investigator:	
Grant title:	
Grant number:	

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

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

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