Science and Technology Facilities Council
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PATT2
Version 02/2013

APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *(AAT, UKST, WHT, INT or UKIRT)*	INT	Reference:	Date stamp:
2 SEMESTER	2022A	3 SCIENTIFIC CATEGORY	1

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

5 PRINCIPAL APPLICANT

Surname: Rożek Title: Dr First name: Agata

Post held: Postdoctoral Research Associate

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6 COLLABORATORS

Name:	Institute:	Observer?
Abbie Donaldson	Institute for Astronomy, University of Edinburgh	Yes
Dr Colin Snodgrass	Institute for Astronomy, University of Edinburgh	Yes
Dr Rosita Kokotanekova	European Southern Observatory, Garching	Yes

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

Exploring the morphological links of bilobed near-Earth asteroids to comets

8 SUMMARY OF PROPOSED OBSERVATIONS

Spacecraft imaging suggest majority of comets to be ‘contact binaries’. Meanwhile, amongst the near-Earth asteroids only a small fraction show a bilobed morphology. Despite the small sample this prompts us to ask whether the contact-binary shapes of NEAs be indicative of a common formation mechanism with comets? We want to use optical photometry of selected contact-binary asteroids (identified from radar observations) to develop new shape models. While radar observations are an abundant source of shape information they are not sufficient to develop accurate shape models and light curve information is needed to constrain spin-state. We will use the new shape models to investigate possible formation scenarios and explore whether we can use morphology to identify extinct comets in the NEA population, which could provide accessible targets to study the end state of comet evolution.

9 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
prime	WFC	EEV 4Kx2K	Sloan R

10 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester		5		Nights
Minimum useful allocation this semester		3		

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: 1 night 19 Feb - 11 Mar; Run 2: 4 nights 20-31 July
Impossible dates:	1-18 Feb, 12-31 Mar, Apr, May, 1-21 Jun, 15-19 Jul
Give justification for impossible dates	Our targets are either not visible for sufficient time at night, drop in brightness during that time, or appear too close to the Moon
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*	Observations around new moon are preferred. If both proposals are awarded time observing Run 1 could be linked with a coordinated proposal by AD for optimal telescope time use otherwise this run could be performed in service mode.

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:
388188 (2006 DP14)	09:55 (19 Feb)	-04 (19 Feb)	16.8(V)	0.4(V-R)	6s (8h in Run 1)
	08:59 (11 Mar)	+04 (11 Mar)	19.4(V)		42s
398188 (Agni)	17:05 (20 Jul)	+18 (20 Jul)	17.1 (V)		6s (14h in Run 2)
	16:23 (31 Jul)	+01 (31 Jul)	17.4 (V)		7s
3752 (Camillo)	23:27 (20 Jul)	+08 (20 Jul)	17.4 (V)		24s (8h in Run 2)
	23:27 (31 Jul)	+01 (31 Jul)	16.8 (V)		15s

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:
CAHA 3.5m / OPTICON	Morphological links between asteroids and comets / Programme with similar science goals, but a complementary set of targets
INT	PI Donaldson: The shapes of comet nuclei / Related but independent student-led programme on comet nucleus shapes. Coordinated scheduling with this programme would be beneficial if both are awarded time.

17 SCIENTIFIC JUSTIFICATION

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

Asteroids are markers of the turbulent formation of our Solar System: their shapes record a history of collisions, mergers or distortion, which depend on how asteroids first formed and the changing Solar System environment over time. Comets are their less processed cousins, spending most of their lifetimes at large distances from the Sun. The defining difference between asteroids and comets is composition: comets, unlike asteroids, harbour volatile materials that evaporate in a spectacular display of activity as their orbital paths change and bring them closer to the Sun. Generally, asteroids have more circular and less inclined paths around the Sun than comets. However, recent studies show the distinctions between asteroids and comets blur: bodies on typically asteroid-like orbits display activity; and bodies on comet-like trajectories are found dormant, possibly depleted of their volatiles. We are particularly interested in the near-Earth asteroids (NEAs) which can originate from both asteroid and comet populations, and whose orbits are complicated by frequent perturbations from planets. Study of links between comets and asteroids normally focus on objects on orbits with the Tisserand Jupiter parameter $T_J \leq 3$ (classic criterion for distinguishing cometary orbit) and searches for comet-like activity, however we want to take a different approach. We want to **investigate possible links between comets and NEAs** through their shapes.

Contact binary shapes. A fascinating case of small-body morphology is the contact binary shape, which resemble two bodies stuck together (Fig. 1). Six short period (with orbital periods on the order of years) comets have been imaged by spacecraft, most recently the 'rubber-duck' comet 67P/Churyumov-Gerasimenko by the European Space Agency's *Rosetta* mission [1]. Of these, four are bilobate in shape, and radar images of one additional comet 8P/Tuttle also indicate a bilobed structure [2]. The contact binary morphology is also found among the NEAs, usually by radar observations, though it is not as abundant as amongst the comets – it is estimated that 20% of ∼1000 radar-detected NEAs could be in this configuration, while shape models exist for only a few. Despite the small sample size, this compels us to ask: **Are there physical characteristics or formation processes unique to cometary orbits that result in the preferential formation of bilobate shapes?**

Formation scenarios. Possibilities for the formation of bilobate shapes have been explored at various dynamical stages for comets e.g. hierarchical agglomeration in the primordial disk [3], re-accretion following catastrophic collisional disruption [4], or rotational disruption of the nucleus by its sublimative activity in the Centaur region, the supposed precursor population of the Jupiter-family comets (JFCs) [5]. Scenarios developed for contact binary NEAs include formation through gentle collision of two bodies in a mutual orbit aided by thermal torques [6], as a direct result of gravitational accumulation of fragments left by an asteroid collision [7], and deformation by fast rotation of an initially symmetrical body of a specific internal structure [8]. While a study of morphological similarities should be done at population level, developing detailed shape models of individual targets is important as they provide necessary context to the formation models. Characteristics like shape and relative sizes of the apparent contact binary components can be used to consider the feasibility of the formation scenarios, however detailed shape models exist for only 8 contact-binary asteroids. We propose to collect the optical lightcurves essential to constraining radar shape models for an additional 3 contact-binary NEAs that are well placed for observation in 2022A.

Radar shape modelling. Radar observations are an active astronomical experiment in which we illuminate asteroid surfaces with a narrow-band radio beam and then measure the Doppler shift of the reflected signal. It is also possible to measure the delay of the signal obtaining information on distance between the observer and the asteroid's surface. Two-dimensional Doppler-delay 'images' created this way contain a wealth of information about the asteroids' shapes as we are able to resolve surface detail down to a few metres. Indeed, radar observations, while possible only for specific objects that come close to Earth, are the best ground-based source of information about non-convex shape features. However, due to the snap-shot nature of radar observations they are not sufficient to produce reliable shape models. For the best results, radar observations need to be supported by high quality optical lightcurve observations to determine rotational state of the body. Radar data for the targets selected in this proposal were collected previously using Arecibo and Goldstone planetary radars; we will use them to develop detailed shape models when combined with the proposed optical lightcurves.

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

Target selection: We have selected three near-Earth asteroids: 388188 (2016 DP14), 398188 (Agni), and 3752 (Camillo) for which radar observations reveal bilobed extended objects (Fig. 1). There are no shape models available for any of them. The orbital and physical parameters of the objects are summarised below:

Name	ecc.	incl.	a	T_J	spec.	P
388188	0.78	11.8	1.36	4.4	*N/A*	5.8
398188	0.27	13.2	0.86	6.8	Sq [9]	22
3752	0.30	55.6	1.41	4.2	Ld [10]	38

Table 1: Properties of the 3 NEAs. The columns include: *ecc.* - orbital eccentricity, *incl.* - orbital inclination in degrees, a - the orbital semimajor axis in au, T_J - the Tisserand Jupiter parameter, *spec.* - spectral class along with reference, and P - rotational period in hours.

Insufficient lightcurve data exists in the archive at present for a shape reconstruction of the selected NEAs. They were selected as previous radar observations show an elongated objects with two lobes. However, radar observations convolve the size of the object with its rotation rate and rotational axis orientation. High quality photometry is necessary for shape reconstruction, which can be obtained with WFC. At the time of observations the targets will be quite bright (table in Section 15), but moving fast across the sky (1-5 arcs/min depending on the target and exact timing of the observing run). To avoid trailing we need short exposure times, and using a telescope with a large aperture allows us to do this without compromising the SNR. Additionally, the wide field of view of WFC is beneficial for our proposed observations of all 3 targets, as we can keep the same stellar background for the extraction of relative lightcurves across extended periods of time.

Observing plan at the INT: We request 5 nights of optical lightcurve observations with the **INT WFC** in semester 2022A. These would be split into two runs:

- **Run 1:** 1 night to be scheduled end of February/beginning of March to observe **388188**
- **Run 2:** 4 nights to be scheduled in June/July to observe **398188** and **3752**.

Those runs are to observe bright targets and could be executed in either grey or dark time provided the targets are at least 30 degrees away from the Moon.

The chosen asteroids are slow rotators (see **P** in the table above) meaning several hours each night are needed to cover a different lightcurve segments. The shortest rotation period, that of asteroid 388188, is 5.8 hours. This asteroid is visible for up to 8h/night which is why we only apply for a single night in Run 1. For the remaining two asteroids we need more time to cover lightcurve segments at different rotational phases. We therefore request 4 nights (minimum useful: 3) for Run 2 where we can spend several hours on each of the two targets each night, to populate large fractions of the rotational lightcurves.

Observations of fast-moving objects, particularly the NEAs require striking balance for exposure times which need to be short enough to avoid object trailing when using sidereal tracking and long enough to obtain sufficient SNR. Use of **INT** with **WFC** is optimal in that respect for the observations of targets listed in this proposal. The table in Section 15 lists position and brightness of each target at either end of each observing window. The listed exposure times refer to object moving by less than 0.5", well below median seeing conditions of 0.8" for ING, so they will not trail beyond the seeing disc. The targets are also bright, meaning we will obtain SNR on the order of 100, ideal for high quality lightcurve observations, even for the shortest exposure times listed.

This proposal is based on postdoctoral research project by AR; we are submitting a linked proposal led by AD focusing on cometary nuclei. While those proposals should be considered separate there is a clear synergy between them in our interest in asteroid and comet morphology. The favourable observing geometry for the comets selected by AD and asteroid **388188** included in this proposal would make it possible to combine the comet observations with Run 1, were the time awarded to both proposals, making efficient use of telescope time.

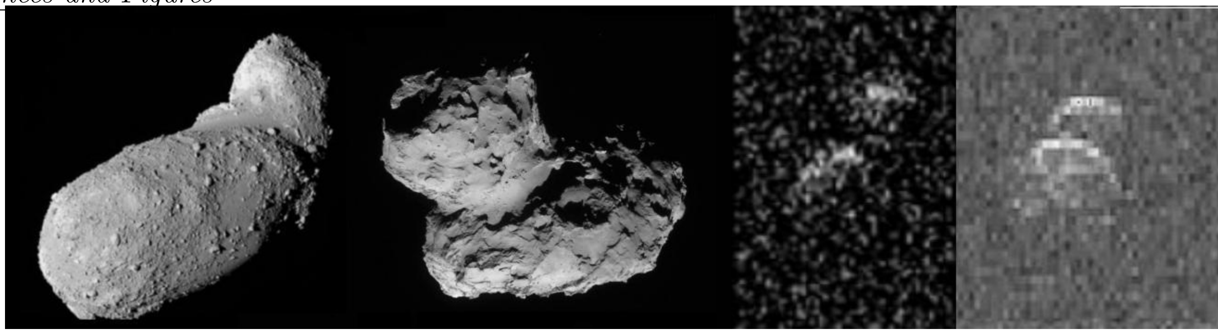

Figure 1: A mosaic of spacecraft and radar images showing different contact binaries (objects not to scale). From left to right: asteroid Itokawa from Hayabusa (JAXA), comet 67P from Rosetta (ESA), an Arecibo radar image of 8P/Tuttle, and a Goldstone radar images of 388188 (2016 DP14). While the radar images are produced in a different way to optical images they clearly reveal contact binary natures of comet 8P and asteroid 388188.

References: [1] L. Jorda et al. Icarus 277 (2016), 257. [2] J.K. Harmon et al. Icarus 207 (2010), 499. [3] B. J. R. Davidsson et al. A&A 592, (2016), A63. [4] S. R. Schwartz et al. Nature Astronomy, 2 (2018), 379. [5] T. K. Safrit et al. Planetary Science Journal, 2.1, (2021), 14. [6] M. Ćuk and J. A. Burns. Icarus, 176, (2005), 418. [7] A. Campo Bagatin et al. Icarus, 339, (2020), 113603. [8] P. Sánchez and D. J. Scheeres Planet. Space Sci., 157, (2018), 39. [9] M. Popescu et al. A&A, 627, (2019), A124. [10] R.P. Binzel et al, Icarus, 324, (2019), 41-76.

19 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS

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

Targets are bright enough to do in any conditions that allow us to open the dome.

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)*

Zegmott T.J., Lowry S.C., Rożek A., Rozitis B., Nolan M.C., Howell E.S., Green S.F., Snodgrass C., Fitzsimmons A., Weissman P.R., Detection of the YORP Effect on the contact-binary (68346) 2001 KZ66 from combined radar and optical observations, 2021, MNRAS (accepted, stab2476)

Rożek A., Lowry S. C., Nolan M. C., Taylor P. A., Benner L. A. M., Fitzsimmons A., Zegmott T. J., Weissman P. R., Green S. F., Rozitis B., Snodgrass C., et al., Shape model and spin-state analysis of PHA contact binary (85990) 1999 JV6 from combined radar and optical observations, 2019, A&A, 631, A149

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

AR is an experienced observer at other telescopes; AD is a student who would be accompanied by another observer; CS and RK are experienced observers with the INT

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

Name of student:	Abbie Donaldson
Project title:	Comet evolution: JFC nuclei

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):