University of Hawaii • Institute for Astronomy

Research Proposal—Observing Time Request

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Institution/Dept (if not IfA): UH

Proposal Number:

Semester: A **Year:** 2013

PROGRAM TITLE(S) *(one line per program)*

A. Suprime-Cam combined program: Super-TALCS, and a search for ultra-faint cometary activity in asteroids

B.

C.

ABSTRACT(S) *(one single abstract or one abstract per program)*

This program was granted one night in previous semesters, but in 2012A the time was lost to the Suprime–Cam coolant leak. Next, in 2012B, our night was lost to the failure of the Subaru top unit exchanger. It is being resubmitted in the anticipation that Suprime-Cam will be repaired by 2013A. It is expanded to two nights, and is now combined with a Super-TALCS survey, so that the same data will be used for three distinct purposes.

Program A (part 1) - A search for ultra-low activity in asteroids with Subaru Suprime-Cam – Main Belt Comets (MBCs) represent a potential new reservoir of water in the Asteroid Belt, with important implications for the survival of ice and volatiles in the inner solar system and habitable zone. Three such objects (two known) were detected by Hsieh and Jewitt in 2006, one more was discovered in each of 2008 (Garradd) and 2010 (La Sagra) and 2011 (2006 VW139, using PS1 at UH), additionally there have been apparently active objects that are probably collisions. We found suggestions of low levels of cometary activity (and thus water) in the asteroid belt in TALCS (Thousand Asteroid Light Curve Survey) data (Sonnett et al., 2011). These data are of a statistical rather than individual nature, however: we find an excess of low-σ detections, but no high-σ ones. Thus we propose to observe a sample of asteroids for the equivalent of two nights with Subaru Suprime-Cam to probe this unexplored domain of very low activity. Extrapolating from TALCS, ten fields over the equivalent of one night will yield ~ 200 asteroids to a S/N about $4\times$ greater than TALCS, allowing us to determine if the previous statistical hints do indeed arise from ubiquitous low–level activity in the main asteroid belt.

Program A (part 2) - Super-TALCS - an improved Thousand Asteroid Light Curves Survey – TALCS (Masiero et al., 2009) was the Thousand Asteroid Light Curve Survey, which provided a statistical sampling of nearly 1000 asteroid light curves using MegaCam on CFHT. Super-TALCS will use Suprime-Cam to measure the rotation periods of 800 to 1000 Main Belt asteroids and 150+ Trojans. It will improve on TALCS by having greater photometric precision (allowing smaller light curve amplitudes), by more densely sampling light curves, and by sampling far more sub-km asteroids. The distribution of rotation periods is crucial to understanding rotation modification from the YORP effect (angular momentum loss from re–radiation from asymmetrical features). In particular, rotation periods are at present poorly sampled in the sub-km regime, which contains 80% of our sample.

Program A (part 3) - Sweet spot observations at high airmass. - About one hour of evening time will be devoted to the sweet spot program described in the proposal of Richard Wainscoat. This use will contribute to a high overall time utilization fraction, because the targets for the main survey must be in a contiguous field, and will necessarily start and end at a high airmass.

TELESCOPE TIME REQUESTED

Provide a good-faith estimate of the future number of nights per semester and future number of semesters to completion, assuming no weather loss. Specify lunar phase as days about new moon (e.g. ±7 days means dark time).

Run	Program	Telescope	Instrument	Nights (n) or hours (h)	Moon (± xx days)	Observers initials	Future est. number of: nights/semester	semesters
1	A	Subaru	Suprime-Cam	2n	Dark ±5	JK, BB	0	0
2								
3								
4								
5								
6								
7								
8								
9								

Run	Optimum Dates	Acceptable Dates	Unacceptable Dates *(Give reasons)*
1	Feb	Feb-Mar	others (ecliptic in Galactic plane; trojans not in opposition)
2			
3			
4			
5			
6			
7			
8			
9			

COLLABORATORS

Name	Institution	E-mail	Program(s)
Bryce Bolin	UH	bolin@ifa.hawaii.edu	A
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Alan Fitzsimmons	QUB, UH (sabbatical)	a.fitzsimmons@qub.ac.uk	A

TELESCOPE TIME AWARDED TO PI IN THE LAST 2 YEARS

Include upcoming awarded time. Give date, number of nights, telescope, instrument, program title, and briefly list status, results, and publications. Use an additional page if necessary.

Telescope	Semester	Time	Time Used	Comments
Subaru	2012B	1n	0n	night lost to instrument problem; reapplying
CFHT	2012A	3h	$\sim 0.5h$	small amount of MegaCam time has been used to recover PS1 MBC/comet candidates, remainder returned and credited back; dome problem shut CFHT
UH 2.2m	2012A	3n	1n	2n lost to dome problem
Subaru	2011B	1n	0n	completely lost to coolant leak into Suprime-Cam; reapplying
CFHT	2011B	11h	2h	PS1 MBC followup. Some null-candidates observed; most time returned to queue.
UH 2.2m	2011B	3n	1n	1n observed in poor conditions (moon, clouds); 2n lost to technical problems
Gemini	2011A	2h	0h	ToO to observe spectra of bright MBCs from PS1; no opportunity to invoke.
CFHT	2011A	14h	0.5h	PS1 MBC followup. Potential targets did not coincide with Megacam being mounted; some time was used at end of semester; mostly returned and credited back.
UH 2.2m	2011A	6n	3n	PS1 MBC followup. 3n observed and reduced; no MBCs; 3n lost to lightning hit.

LIST OF PUBLICATIONS OF THE PI OVER THE PAST 2 YEARS

Include only refereed and invited papers published or in press within two years prior to due date of application. Do not list papers that have been submitted but are not yet accepted. List facilities used for each paper.

Kleyna, J., Meech, K. J., & Hainaut, O. 2012, 'Faint moving object detection, and the Low Signal-to-Noise recovery of Main Belt comet P/2008 R1 Garradd,' arXiv:1209.3833 (accepted for publication in *PASP*; UH 2.2m, Gemini, and others)

Hainaut, O.R., Kleyna, J., Sarid, G., Hermalyn, B, Zenn A., Meech, K., Schultz, P.H., Hsieh, H., Trancho, G., Pittichova, J., Yang, B., 2012, 'P/2010 A2 Linear I: An impact in the main asteroid belt', 537, 69 *(UH 2.2m, Gemini, and others)*

Meech, K., Kleyna, J., Hainaut, O., et. al, 2012, 'The Demise of 85/P Boethin, the first Epoxi mission target', Icarus, accepted.

Hsieh, H. et al, 2012, 'Discovery of Main Belt Comet P/2006 VW_{139} by Pan-STARRS1', ApJL, 748, L15 (*PS1, UH88)*

Sonnett, S., Kleyna, J., Jedicke, R., & Masiero, J., 2011, 'Limits on the size and orbit distribution of main belt comets', 'Icarus', 215, 534. *(archival CFHT).*

Meech, K., et al., 2011, 'Deep Impact, stardust NExT, and the Behavior of 9P/Tempel1 from 1997 to 2010,' Icarus, accepted *(various incl. UH 2.2m).*

Belton, M. et al, 2011, 'Stardust-NExT, Deep Impact, and the accelerating spin of 9P/Tempel1,' Icarus, accepted. *(various incl. UH 2.2m).*

Stevenson, R.; Kleyna, J.T.; and Jewitt, D., 2010, 'Transient Fragments in Outbursting Comet 17P/Holmes', ApJ, 129, 2230 *(CFHT)*

⋆ **Objective Bonus (first-author paper):** Kleyna, J., Hainaut, O., & Meech, K. 2012, 'P/2010 A2 LINEAR II: dynamical dust modelling,' arXiv:1209.2210 (accepted for publication in *A&A*; UH 2.2m, Gemini, and others)

SCIENTIFIC JUSTIFICATION(S)

On the following pages, give the scientific justification for your program(s). Use any format you choose (e.g., an integrated discussion of closely related programs, separate discussions for each program, or a general introduction with separate detailed discussions). The scientific justification has a **total** *limit of 4 pages of text, 2 pages of figures or tables, plus references (no limit). You may embed figures and tables in the text, and you may substitute figures or tables for text, but not vice versa. Use no less than an 12-point font and half-inch margins. Proposals that exceed these limits will be returned to the submitter.*

1 MBCs: A search for ultra-low activity using Suprime-Cam, and PS1 followup using CFHT and the UH 2.2m

1.1 Introduction

Hsieh & Jewitt (2006), observed three apparent Main Belt Comets (MBCs), or asteroids with comet-like activity, in a set of ~ 300 observations of Main Belt asteroids. Two were known objects, and one was a new discovery. Later, Jewitt *et al.* noted that another comet, P/2008 R1 (Garradd), was in fact a MBC (Garradd et al., 2008; Jewitt et al., 2009), and a third one, P/2010 R2 La Sagra, was discovered very recently (Nomen et al., 2010). Recently, known asteroid (300163) 2006 VW139 was seen to be active, by observing an extended PSF in Pan-STARRS1 photometric data (Hsieh et al., 2012). Another possible candidate with an unknown orbit was found in a survey of $\sim 10^3$ asteroids in shallow CFHT archive data (Gilbert & Wiegert, 2009). Presumably, the activity observed is collisionally excited and short lived, like an excavated icy region, because protracted mass loss is unsustainable. From the survey of Hsieh & Jewitt (2006), one may estimate that up to $\sim 0.3\%$ of all asteroids exhibit some form of cometary activity at any moment. Combining this statistic with our Thousand Asteroid Light Curve Survey (TALCS) survey data (Sonnett et al., 2011), the figure drops to $\sim 0.05\%$, with large variations of observational qualities. The effect of the ongoing PS1 observations on the census is difficult to interpret, because the observations are sparser and of lower quality than the previous two directed surveys.

Together, previous observations suggest that the outer Main Belt contains a significant reservoir of water that may have made it to the Earth in a period of early heavy bombardment. The existence of such a reservoir is likely to be a important part of the puzzle of water acquisition by terrestrial planets, an issue of considerable interest in the subject of planet formation. [1]

Hence we propose deep Suprime-Cam observations of ~ 100 asteroids to probe for very low levels of activity hinted at by previous CFHT and PS1 data.

1.1.1 Preliminary statistical activity results

We have found suggestions of low level cometary activity in the asteroid belt, described in Fig. 1 and its caption (Sonnett et al., 2011). In summary, we compared stars and asteroids in the Thousand Asteroid Light Curve Survey, and found a statistical excess of bright light around the asteroids (Figure 1, left). This statistical significance was concentrated in directions corresponding to the expected antisolar direction (Figure 2, right), after dividing out systematic (telescope optics, chips, and spider) angular variations using the data of the stars. This it appears that there is a statistical case that asteroids may have more extended light stars, suggesting the presence of low–activity MBCs. Currently, these results are for the ensemble rather than for any individual case, however.

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[1] *e.g.* http://www.stsci.edu/institute/conference/volatile

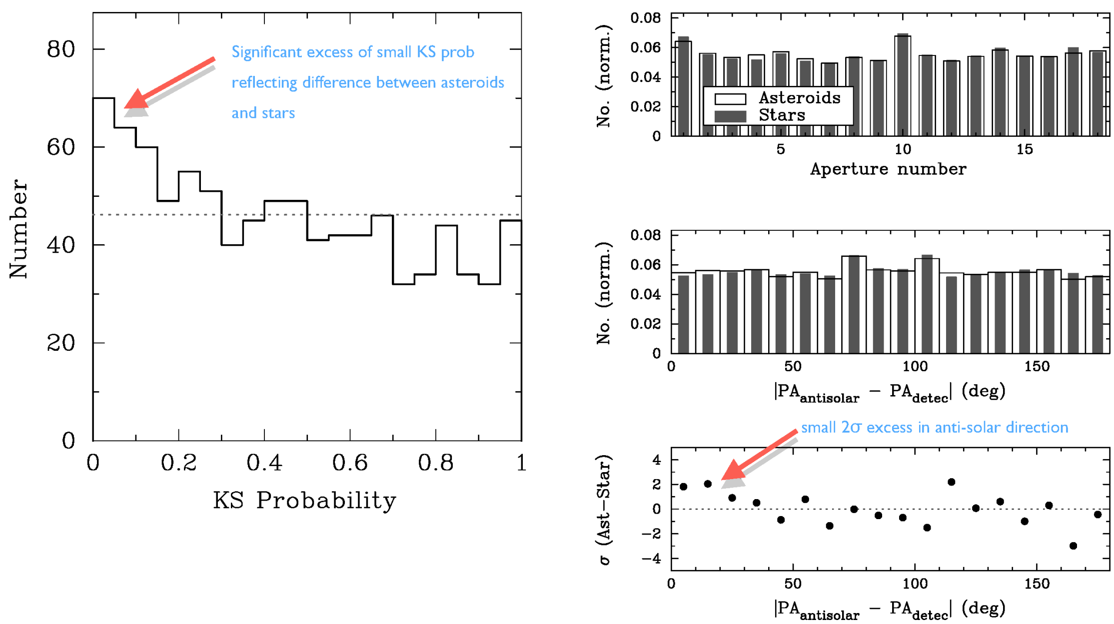

Figure 1: *Detection of excess directional light in CFHT Thousand Asteroid Light Curve Surve (TALCS) data using our tail detection scheme.* **Left:** *The statistical disagreement between the the excess light around TALCS asteroids and stars was expressed as a Kolmogorov-Smirnov probability, with small probabilities representing a disagreement. Under the null hypothesis, this histogram of KS probabilities for asteroids should be flat, indicating that asteroids are no different from stars. In actuality, there is an unexpected surplus of small KS probabilities (at a* $p = 10^{-5}$ *departure from the null hypothesis), showing that asteroids have excess large radius light relative to adjacent stars.* **Right:** *Whenever the directionality of light around an asteroid or comparison star was computed, the position angle (PA) was noted. The top histogram shows the angular distribution of this brightest segment in terms of the "pie slice" aperture on the chip, showing that the distribution is non–uniform. The middle histogram shows the distribution as a function of asteroidal anti–solar direction, with true tails expected to lie at* $PA = 0$. *The bottom panel seeks to remove instrumental effects by computing the* difference *between asteroids and stars in the center panel, on a bin–by–bin basis. In this last panel, a* 2σ *(but over two adjacent points) signature of a tail emerges at the expected* $PA = 0$ *direction. Combined with the KS excess in the left panel, this hints that asteroids, as an ensemble, have weak anti–solar tail activity.*

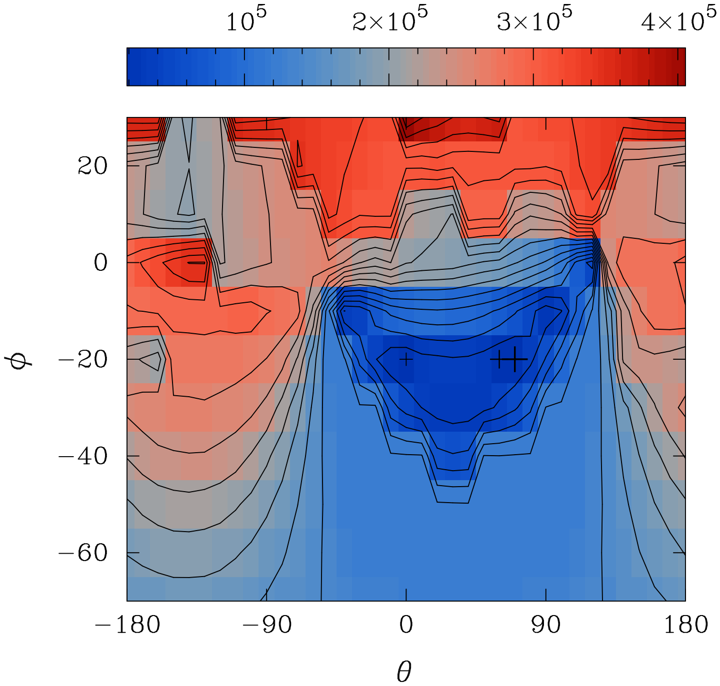

Figure 2: Fitting of the apparent "MBC" P/2010 A2 Linear with an conical ejecta impact model shows that a particular ejection longitude and latitude θ, ϕ fit the observed trail distribution (dark blue region, representing minimum of fit merit function). Combined with the fact that the best fit corresponds to the well–known 80° opening angle of an impact cone, this strongly suggests that P/2010 A2 is actually a trail of impact ejecta. The analysis codes we developed may be applied to other trails/tails to distinguish between sublimation and impact trails (Hainaut et al., 2012; Kleyna et al., 2012).

1.1.2 Levels of Activity, and MBC abundances

The known MBCs are active with mass loss rates of $\dot{M} \sim 0.01$ to $1\,\mathrm{kg\,s^{-1}}$ (e.g. Sonnett et al., 2011). At the lower limit of these levels, our directional tail detection technique can detect activity at the 4σ level in 5000 seconds of UH 2.2m data. Rescaling to the same exposure time on Suprime-Cam, the background limited S/N will scale as the relative mirror diameter (square root of flux), permitting activity four times fainter to be detected, corresponding to $\dot{M} \sim 0.003\,\mathrm{kg\,s^{-1}}$. If we assume that 1) activity is driven by collisions; 2) the excavated impact volume is proportional to the impactor energy, which is proportional to the cube of the impactor size; 3) activity is proportional to the activated area, or the square of the impactor size; then this method has the potential to detect the effect of impactors half the size of those responsible for known MBCs. Because the collisional process of asteroid fragmentation is expected to produce a cumulative impactor power law diameter distribution $N(<D) \propto D^{-2.5}$ (Dohnanyi, 1969), the ability to detect the effects of impactors of half the previous size increases the potential number of impactors (and thus MBCs) by a factor of 6.

From TALCS, we infer that our Suprime-CAM fields should detect about 200 asteroids of TALCS ($r < 23$) brightness, plus another 800 objects in the next 1.5 mags, from the steep powerlaw slope of the size distribution. Thus this method has the potential to observe up to 1000 asteroids, sensitive to impactors 6 time more abundant than those that produce known MBCs.

1.1.3 Distinguishing between impacts and MBCs

MBCs caused by sublimation can be confused with impact trails. Thus we have developed methods for distinguishing between activity driven by sublimation activity from simple debris trails, as for the case of P/2010 A2 Linear (Hainaut et al., 2012; Kleyna et al., 2012). Figure 2 shows how what appears to be an MBC can be fit better with a impact ejecta cone at a specific ejection direction. This will provide us with a tool to distinguish between true sublimation or impacts.

1.2 Objectives of Suprime-Cam observations

Previous searches for MBCs, like Hsieh & Jewitt (2006) and Gilbert & Wiegert (2009), and previous serendipitous discoveries, have employed shallow data to find relatively bright activity. In light of the above suggestions of common but extremely low activity (Fig. 1), we propose to use two nights of Subaru Suprime-Cam time to probe to a final S/N that is $4\times$ greater than that obtained by H&J or TALCS. In ten one hour Suprime-Cam fields (see §2, Figure **??**) , we would expect to see about 200 asteroids to the CFHT limit $g \sim 23$, and many more that are fainter. The bump at small KS probabilities in the top left panel of Fig. 1 suggests that 1 in 20 asteroids might have activity at the ~ 1.5 to 2σ level in CFHT data; hence ten of the 200 we propose here might exhibit activity at the 6 to 8σ level in Suprime-Cam data.

We will try to detect activity using several approaches, including our directional tail detector, an aperture search for symmetrical excess light, and PSF fitting. To eliminate systematics resulting from telescope optics, we will rotate the camera between passes, as described in the technical section. To detect and recover asteroids, we will use either our custom SMoG software, previously used for detecting satellites around giant planets, or PS1 MOPS, as used for TALCS.

Although this is a speculative proposal, it may significantly alter our knowledge of the main belt and of the habitable zone in general, by showing that water might in fact be far more common than previously thought. It also uses the same data as the the relatively low-risk Super-TALCS proposal in §2.

2 Super-TALCS: extending the TALCS survey using Suprime-Cam

2.1 Introduction

The Thousand Asteroid Light Curve Survey (TALCS; Masiero et al., 2009) observed nearly 1000 asteroids using CFHT MegaCam, finding evidence of excesses of both fast and slow rotators, and a possibly bimodel shape distribution. We propose to use the same Suprime-Cam time of the previous section to extend this survey to fainter magnitudes, with better sampling. We will observe in a single filter (wideband VR), and will reach a limiting magnitude of $R \sim 24.2$ rather than ~ 23 for TALCS. We will also observe each asteroid in our survey field 40 times over two nights separated by 24 hours, which will permit denser light curve sampling than in Masiero et al. (2009). We will observe ~ 1000 asteroids, and ~ 150 Jupiter L4 trojans (asteroids on stable Lagrangian co-orbits with parent body).

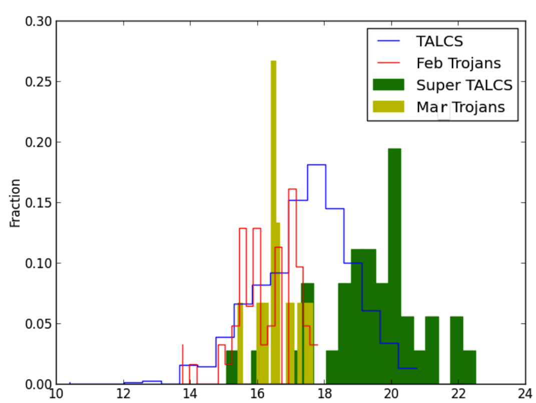

Figure 3: *Relative numbers of asteroids visible in Super-TALCS, compared to TALCS*

We will be observing more sub-km (H=18) main belt asteroids than in Masiero et al. (2009), as seen in Fig. 3. Approximately 80% of asteroids we will observe are smaller than one kilometer. The period distribution of asteroids in the main belt in this size range is not well understood: the previous study of Dermawan et al. (2011) of sub-km asteroids, measuring the periods of only 68 to $R \sim 24.6$, is biased against slow rotating objects because the observations cover only one night.

To assess the sky plane density of main belt asteroids and trojans, we ran a simulation of our survey using the Moving Object Processing System (MOPS) Synthetic Solar System (SSM) on the dates which the L4 Trojan Cloud would be at opposition (early February and March). The results for the sky plane density from our simulations are consistent with the results of Gladman et al. (2009): roughly 357 main belt asteroids and 62 trojans per square degree at opposition in February, and about the same number of main belt asteroids and 15 trojans in March. Our SSM has a limit on H of 18 (1.7 km) for trojans, which is is considerably smaller than the trojans whose rotation periods were studied in Barucci et al. (2002).

The papers of Masiero et al. (2009) and Dermawan et al. (2011) were both criticized by Harris et al. (2012) for having unreliable light curves because of sampling shortcomings. However, another unbiased survey by Polishook et al. (2012) agrees with the Masiero et al. (2009) result. Still, we will design our survey to address the criticism of Harris et al. (2012), taking denser light curves with a higher S/N.

2.2 Science Motivation: YORP

A major motivation of this work is to infer the effect of YORP (radiation induced rotation change from morphological asymmetries) on small asteroids, where it can produce an excess of both ultra–fast and ultra–slow rotators (Bottke et al., 2006). We seek to observe two different populations of asteroids, the main belt asteroids, and asteroids in the L4 trojan cloud, in an un-targeted, unbiased survey. These two populations undergo extensive collisional disruptions (Bottke et al., 2002; Barucci et al., 2002), creating a Maxwellian distribution of orbital periods. The YORP effect will cause this distribution to change for small asteroids. YORP has been measured for individual asteroids Lowry et al. (2007) and Taylor et al. (2007). In this work, we wish to measure the effect of YORP statistically for a large number of asteroids in the two populations by measuring deviations from the Maxwellian distribution. Although this would not rule out other non-Maxwellian effects, we will be able to use the locality and age of the populations of these asteroids in the main belt and trojan cloud as arguments for YORP.

2.3 Observing Strategy

We will design the survey pattern to measure ultra-fast (< 0.1h) and ultra-slow (> 12h) rotators and minimize the loss of asteroid detections due to chip gaps and the scattering of the cloud of asteroids observed on the prior night.

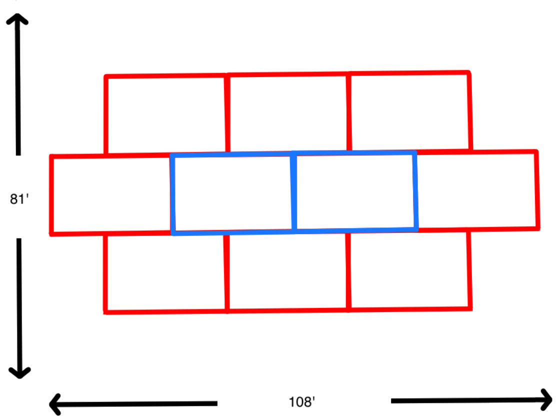

Figure 4: *Field arrangement of Super-TALCS*

To obtain enough asteroid detections to reach our science goals, we will observe a 2.55 deg^2 area in the layout shown in fig. 4. Each $34' \times 27'$ field will be visited at least 20 times each night during the run. We will track at the mean motion of the main belt to minimize trailing losses. The blue rectangles will be alternated in rapid succession for an hour and twenty minutes in order to establish light curves for a subsample of fast rotators. The survey will then expand to the red squares, which will be observed continuously for almost 7 hours and optimized so that light curves for medium (~ 8h) and slow rotators (> 12h) can be measured. Similar observations for the second night will occur 48 hours later so that survey is sensitive to asteroids with rotation periods of 48 hours or more. If we do not get time on two nights separated by a night, we would be sensitive to rotation periods up to 24 hours. The pattern will made to differ from the first night to minimize the effect of aliasing, and to allow for a wide range of rotation period coverage.

Becuse our fields will be at high airmass at the start and end of the night, we intend to devote the last hour to the evening sweet-spot survey described in the proposal of Wainscoat.

References

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Taylor, P. A., et al. 2007, Science, 316, 274

TECHNICAL JUSTIFICATION

Discuss the feasibility of the observations and justify the amount of telescope time requested. The technical justification is limited to one-half page per run. Use an additional page for each run. Proposers are required to describe (fully or partially) acceptable alternatives to the requested combination. Programs without this information may be at a disadvantage, especially for highly subscribed telescopes.

Run No: 1	**Telescope:** Subaru **Alt. telescope:**	**Instrumentation:** Suprime-Cam **Alt. instrumentation:**

We have found evidence of weak comet–like activity in TALCS, in the form of excess light in the expected (dust–integrated) tail direction. We surmise that this may represent a very low level of sublimation driven dust. To test whether this statistical evidence corresponds to real activity, and to extend to TALCS survey to smaller asteroids as Super-TALCS, we propose to take much deeper imaging by repeatedly observing 10 asteroid–filled fields using Suprime-Cam.

The TALCS survey covered a total of 12 $1^\circ \times 1^\circ$ fields, yielding 934 asteroids, or 77 per square degree, with a total exposure time of ~ 20 minutes for each one. Accordingly, ten $34' \times 27'$ Suprime-Cam fields will cover 2.5 square degrees, giving ~ 200 objects of TALCS brightness ($r < 23$), as well as ~ 1000 fainter objects. An exposure time of one hour per field, combined with the larger mirror, will provide an increase of 14.8 in light gathering power, or 3.8 in S/N, or 1.46 magnitudes in depth.

A key part of the observing will be to rotate the camera to symmetrize any optical effects, like spider diffraction spikes.

Our observing strategy will be to 1) observe a field for 120s in VR with non-sidereal tracking at the mean asteroid rate; 2) slew to the next field (~ 1 minute); and 3) rotate the camera (2 minutes) after each two such rounds. Hence 16 hours of telescope time will give the desired depth of almost one hour per field. The observing pattern is described and illustrated in §2 of the science case.

Object detection will be performed either using our custom SMoG software previously used to find moons of Jupiter and Saturn, or PS1's MOPS software may be used in a special case as it was in TALCS. Objects will be stacked using existing automated software (used for PS1), and individual and stacked detection techniques will be used to search for both tails and comae in the form of extended PSFs, as described in the science text.

Our ideal telescope allocation would consist of two nights with one intervening night (as described in §2) to allow detection of slow rotation. February time is optimal for the trojan cloud.

LIST OF PRINCIPAL OBJECTS *(to be studied in run justified above)*

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
A	10 fields on ecliptic			