University of Hawaii • Institute for Astronomy

Research Proposal—Observing Time Request

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Institution/Dept (if not IfA): **Institute for Astronomy**

Proposal Number:

Semester: **A** **Year:** **2016**

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

A. The Manx Comets–Testing Solar System Formation Models

B. Mapping CO_2 Abundances with NEOWISE

C. Main Belt Comet 238P/Read Activity

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

A – Small primitive bodies were witness to the solar system's formative processes. Ground- and space-based observations of comets have played a key role in mapping out our early solar system chemistry, and ALMA observations of protoplanetary disks are now generating chemical maps of other forming solar systems to use as constraints of disk chemical models. On the dynamical side, there are now several models that are able to reproduce much of our solar system's current architecture, although they are not unique. Recent Pan-STARRS 1 discoveries of objects on long-period comet orbits that are inactive or minimally active at perihelion (the "Manx comets") have suggested the intriguing possibility that these could represent inner solar system material that was ejected into the Oort cloud during planet migration. One of these objects has surface properties similar to S-type asteroids and exhibits activity, possibly representing fresh inner solar system material. Of the 123 Manx comets identified, there are only 18 that are still observable. We request 6.9 hrs with GMOS to obtain *grizY* photometry to characterize the surface of 6 northern targets that are still observable during 2016A from Hawaii. Additionally, we request 10.2 hr with WFCAM on UKIRT to obtain *YJHK* photometry of 2 of the targets. We also request 5.8 hrs on MegaCam to follow up new Pan-STARRS 1 Manx discoveries to assess the level of dust production, and to obtain sufficient astrometry so that the orbits are not lost. The data will be used to test predictions of several dynamical models.

B – We request 9.6 hrs using Megacam on CFHT to obtain *gri*-band observations of active comets to be observed in the *WISE* IR survey. The *NEOWISE* W2 bandpass is sensitive to emission from both the 4.26 μm band of CO_2 and the 4.67 μm band of CO. Combined with optical wavelength photometry, we can estimate the abundance of these volatiles in all the comets detected by the all-sky survey in W2. Earth's atmosphere is opaque at at the wavelength of the W2 bandpass, so this will provide the first comprehensive large survey exploring CO_2 abundances in comets. The observations include both known, active Jupiter-family and long-period comets, and new discoveries. Comets for which we have long-term observations will be modeled, using the estimates of CO/CO_2 production rates as constraints for sublimation models. This is a continuation of a successful program started in 2014A and is being funded by the PI's new "Early Solar System Volatile Distribution" NSF Proposal (2014-7). The *NEOWISE* program is expected to end in 2017.

C – Main belt comet 238P/Read has been characterized for a potential Discovery mission. The previous two apparitions showed a possible secular decrease in activity. Observing Read on a third perihelion passage will be important for understanding the longevity of the ice reservoirs and duration of activity. Read comes out of solar conjunction in July and will be at a similar distance to where it turned on in 2010. This is the best apparition since it's discovery. This is a unique chance to compare the activity across three apparitions. We request 1.2 hrs on Gemini GMOS and 3.9 hrs on UKIRT with WFCAM to characterize its surface composition.

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)	PWV (τ_{183})
1	A	Gemini	GMOS	6.9 h	±7-11	
2	A	CFHT	Megacam	5.8 h	±7	
3	A	UKIRT	WFCAM	10.2 h	Any	
4	B	CFHT	MegaCam	9.6 h	±7	
5	C	Gemini	GMOS	1.2 h	±7	
6	C	UKIRT	WFCAM	3.9 h	Any	
7						
8						
9						

Future est. number of: nights/semester	semesters
4 h	6
6 h	6
3 h	6
6 h	3
0	0
0	0

Run	Optimum Dates	Acceptable Dates	Unacceptable Dates *(Give reasons)*
1	Queue	Queue	
2	Queue	Queue	
3	Queue	Queue	
4	Any	Any	
5	Jul	Jul	Other-not vis
6	Jul	Jul	Other-not vis
7			
8			
9			

COLLABORATORS

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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.

Run		Tel	Nts	Dates	Instr	Stat	Red	Program Title
1	PI	Keck2 10m	1.0	Aug. 7, 2013	LGS/NIRC2	1	y	Centaur densities
2	PI	Keck1 10m	0.5	Oct. 21, 2013	HIRES	1	p	133P Gas
3	PI	Keck1 10m	0.5	Jan. 16, 2014	HIRES	1	p	Ceres Gas
4	PI	GeminiN	6.3h	Queue-Sp14	GMOS/GNIRS	1	y	Manx Comet
5	PI	CFHT	12h	Queue-Sp14	MPrime	1	y	NEOWISE comets
6	PI	Low1.8m	2.0	Mar. 27-28,2014	PRISM	0	y	MBC 176P Rotation
7	PI	HCT2m	2.0	Apr. 21-22,2014	CCD	0	p	MBC 176P Rotation
8	PI	UH2.2m	6.0	Feb-Jul, 2014	Tek2K	-1	–	NEOWISE; Tel. failed
9	PI	HCT2m	2.0	Jun. 23-24, 2014	CCD	1	n	Centaurs
10	PI	CFHT	12h	Queue Fall14	MPrime	1	y	NEOWISE comets
11	PI	GemN-DDT	0.2h	Sep, 2014	GMOS	1	y	Manx C/2013 P2
12	PI	VLT-DDT	1.5h	Queue Nov, 2014	FORS2	1	y	Manx C/2014 S3
13	PI	Low1.8m	5.0	Nov. 21-25, 2014	PRISM	1	y	Main Belt Comets
14	PI	HCT2m	2.0	Dec. 3-4, 2014	CCD	-1	–	NEOWISE Followup
15	PI	CFHT3.6m	14h	Queue-Sp15	MPrime	1	y	NEOWISE/Volatiles
16	PI	UH2.2m	6.0	Feb-Jul, 2015	Tek2K	1,0	y	NEOWISE (2 nts lost)
17	PI	GemN	5.5h	May-Jul, 2015	GMOS	-1*	p	Read phase function
18	PI	GemN	1.7h	FT May, 2015	GMOS	1	y	Manx comet spectrum
19	PI	GemN	1.3h	FT Jun, 2015	GMOS	1	y	Manx comet colors
20	PI	GemN	2.6h	Aug-Sep, 2015	GMOS	-1**	n	Read Activity
21	PI	GemN	4.8h	Sep-Dec, 2015	GMOS	TBD	–	SS Formation Models
22	PI	CFHT	11h	Queue-F15	MPrime	TBD	–	NEOWISE/Volatiles

Key to Status — **1** - photometric, **0** - observed, but not photometric - requires calibration, **-1** - run mostly lost (weather / instruments). Reduction key: **y** - reduced, **p** - in progress, **n** - not yet done, – - N/A, no data. *Most of our critical dates were lost to weather and scheduling issues. We will get science out of the data, but likely the phase function aspect will be not met. **Only one window obtained (poor weather).

The PI is currently at ESO during Sep. 2015 working with collaborator B. Yang on new Manx data from FT proposals and working on the first Manx paper. Major effort put into proposals to get funds for this project. Paper to be presented at DPS 2015. FT runs are now reduced and being added to the data set. Paper to include PS1 data, CFHT, Gemini, VLT and other observatory photometry and modeling. Everything is fully reduced, we writing the manuscript. Meech, K.J., Yang, B., Kleyna, J., Keane, J., Hainaut, O., Micheli, M., Morbidelli, A. S. Berdyugina, Hsieh, H., Bauer, J., Wainscoat, R.J., Veres, P., Park, R.

The first *NEOWISE* manuscript has been accepted for publication. It outlines the cryogenic mission CO_2 observations; subsequent papers will combine the ground data with the spacecraft data. Bauer, J.M., Stevenson, R., Kramer, E., Grav, T., Mainzer, A., Masiero, J., Lisse, C., Meech, K.J., Nugent, C., Sonnett, S., Cutri, J., Dailey, M., Kleyna, J., Walker, R., Weissman, P., MacMillan, R., Lucas, A., Wright, E. (2015). "The *NEOWISE*-Discovered Comet Population and the CO/CO_2 Production Rates". The UH team will be co-authors on all the NEOWISE papers combining optical/IR data. NEOWISE postdoc, E. Kramer will lead the large paper combining optical/IR data to get the CO_2 distribution, J. Kleyna will be 2nd author. UH will lead several papers on specific targets: (1) J. Keane on comets C/2013 R1 Lovejoy and C/2014 E2 Jacques (submitting in Oct., used Keck, optical, WISE and sublimation models as part of E. Toller's 699), (2) J. Keane to lead comet 2013 US10 Catalina (Jan 2016-Keck, WISE, CFHT), (3) E. Toller leading a sublimation model paper for her 699 (WISE, CFHT, UH2.2m)-target TBD, (4) Meech - Manx paper (incl. WISE). We have 4 other comets that use WISE data that our team will take the lead on the papers.

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.

[1] ⋆**Ansdell, M.**, **Meech, K.J.**, Hainaut, O., Buie, M.W., Kaluna, H., Bauer, J., Dundon, L. (2014). "Refined Rotational Period, Pole Solution, and Shape Model for (3200) Phaethon", *ApJ* **793**, 50. [*UH2.2m (88%); Lowell 1.8m (12%)*]

[2] Bauer, J. M. *et al.* (2013). "Centaurs and Scattered Disk Objects in the Thermal Infrared: Analysis of WISE/NEOWISE Observations", *ApJ* **773**, 22. [*WISE s/c (100%)*].

[3] Bauer, J.M., Stevenson, R., Kramer, E., Mainzer, A., Grav, T., Masiero, J., Fernandez, Y., Lisse, C., **Meech, K.J.**, *et al.* (2015). "The NEOWISE-Discovered Comet Population and the CO/CO_2 Production Rates", *ApJ*, in press. [*WISE s/c (100%)*].

[4] Belton, M.J.S., *et. al* (2013). "The Complex Spin State of 103P/Hartley 2: Kinematics and Orientation in Space", *Icarus* **222**, 595. [*DI Spacecraft (80%), GeminiN-S (10%), Other ground (10%)*].

[5] Bonev, B.P., Villanueva, G.L., Paganini, L., DiSanti, M.A., Gibb, E.L., Keane, J.V., **Meech, K.J.**, Mumma, M.J. (2013). "Evidence for two modes of water release in Comet 103P/Hartley 2: Distributions of column density, rotational temperature, and ortho-para ratio", *Icarus* **222**, 740. [*Keck I (100%)*.

[6] DiSanti, M., Villanueva, G., Paganini, L., Bonev, B., Keane, J., **Meech, K.**, Mumma, M., (2014). "Pre-and post-perihelion observations of C/2009 P1: Evidence for an oxygen-rich heritage?" *Icarus* **228**, 167. [*Keck (100%)*]

[7] Fernández, *et al.* (2013). "Thermal properties, sizes, and size distribution of Jupiter-family cometary nuclei", *Icarus* **226**, 1138. [*Spitzer (100%)*]

[8] Fong, W., Berger, E., Metzger, B.D., Margutti, R., Chornock, R., Migliori, G., Foley, R.J., Zauderer, B.A., Lunnan, R., Laskar, T., Desch, S.J., **Meech, K.J.**, **Sonnett, S.**, Dickey, C., Hedlund, A., Harding, P. (2014). "Short GRB 130603B: Discovery of a Jet Break in the Optical and Radio Afterglows, and a Mysterious Late-time X-Ray Excess", *ApJ* **780**, 118. [*Magellan 6.5m (UH contribution)*]

[9] Hainaut, O.R., Boehnhardt, H., Snodgrass, C., **Meech, K.J.**, Deller, J., Kuehrt, E., Lowry, S.C., Micheli, M., Mottola, S., Vincent, J.-B., Wainscoat, R. (2014). "Continued activity in P/2013 P5 PANSTARRS. Unexpected comet, rotational break-up, or rubbing binary asteroid?" *A&A* **563**, 75. [*CFHT (60%), NTT (20%), CA1.2m (20%)*]

[10] Hermalyn, B., *et al.* (2013). "The Detection, Localization, and Dynamics of Large Icy Particles Surrounding Comet 103P/Hartley 2", *Icarus*, **222**, 625. [*EPOXI s/c (100%)*].

[11] Hsieh, H. H. *et al.* (2013). "Main-belt Comet P/2012 T1 (PANSTARRS)", *ApJ* **771**, L1. [*UH2.2m (48%), Lowell 1.8m (14%), Keck (10%), Magellan (10%), PS1, SOAR, FTS (18%)*].

[12] Hsieh, H.H. *et al.* (2014). "Search for the Return of Activity in Active Asteroid 176P/LINEAR", *AstronJ* **147**, 89. [*UH2.2 (33%), NTT (20%), GeminiN (16%), duPont (13%), Keck (7%), VLT, Subaru (4% each), PS1 (3%)*]

[13] Hsieh, H. H., *et al.* (2015). "Sublimation-Driven Activity in Main-Belt Comet 313P/Gibbs" *AstronJ* **800**, 16. [*PS1 (25%), Subaru (8%), Palomar 5m (8%), FTN (8%), DCT (16%), NTT (16%), UH2.2 (8%), SDSS (11%)*]

[14] ⋆**Kaluna, H.M.**, Masiero, J.R., **Meech, K.J.** (2016). "Space Weathering Trends Among Carbonaceous Asteroids", *Icarus* **264**, 62-71. [*Subaru (100%)*]

⋆ **Objective Bonus (first-author paper):** Meech *et al.* (2013). *Icarus* **222**, 662. Meech *et al.* (2013). *ApJL* **776**, 20; Ansdell *et al.* (2014). *ApJ* **793**, 50; Sonnett *et al.* (2013). *PASP* **125**, 456, Kaluna *et al.* (2016), *Icarus* **264**, 62.

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.*

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.

[1] Kelley, M., *et al.* (2013). "The persistent activity of Jupiter-family comets at 3-7 AU", *Icarus*, **225**, 475. [*Spitzer (100%)*]

[2] Kleyna, J., Hainaut, O.R., **Meech, K.J.** (2013). "P/2010 A2 LINEAR II: Dynamical Dust Modelling", *A&A*, **549**, 13, arXiv:1209.2210. [*UH2.2 (40%), ESO NTT (40%), Gemini N (20%)*].

[3] Li, J.-Y., *et al.* (2013). "Photometric properties of the nucleus of Comet 103P/Hartley 2", *Icarus* **222**, 559. [*DI spacecraft (90%), GeminiN-S (10%)*].

[4] ⋆**Meech, K. J.**, *et al.* (2013). "Outgassing Behavior of C/2012 S1 (ISON) From September 2011 to June 2013", *ApJ* **776**, 20. [*GeminiN (13%), JCMT (13%), PS1 (22%), Lowell (8%), CalarAlto (8%), HCT (2%), VYSOS (17%), CARA (17%)*].

[5] ⋆**Meech, K. J.**, *et al.* (2013). "The Demise of Comet 85P/Boethin, The First EPOXI Mission Target", *Icarus*, **222**, 662. [*VLT (15%), Subaru (15%), Gemini (15%), Magellan (10%), SOAR (5%), CTIO4m (5%), CFHT (15%), NTT (10%), Spitzer (10%)*].

[6] Paganini, L., DiSanti, M.A., Mumma, M.J., Villanueva, G.L., Bonev, B.P., Keane, J.V., Gibb, E.L., Boehnhardt, H., **Meech, K.J.** (2014). "The Unexpectedly Bright Comet C/2012 F6 (Lemmon) Unveiled at Near-infrared Wavelengths", *AstronJ* **147**, 15. [*Keck I (100%)*].

[7] Paganini, L., Mumma, M.J., Villanueva, G.L., Keane, J.V., Blake, G.A., Bonev, B.P., DiSanti, M.A., Gibb, E.L., **Meech, K.J.** (2014). "C/2013 R1 (Lovejoy) at IR Wavelengths and the Variability of CO Abundances among Oort Cloud Comets", *Astrophys. J.* **791**, 122. [*Keck (100%)*]

[8] Snodgrass, C., Tubiana, C., Bramich, D.M., **Meech, K.**, Boehnhardt, H., Barrera, L. (2013). "Beginning of activity in 67P/Churyumov-Gerasimenko and predictions for 2014-2015", *A&A* **557**, 33. [*VLT (30%), NTT (7%), UH (5%)*]

[9] ⋆**Sonnett, S., Meech, K.**, Jedicke, R., Bus, S., Tonry, J. (2013). "Testing Accuracy and Precision of Existing Photometry Algorithms on Moving Targets", *PASP* **125**, 456. *UH2.2m (100%)*].

[10] Thomas, P.; *et al.* (2013). "Shape, density, and geology of the nucleus of Comet 103P/Hartley 2", *Icarus*, **222**, 550. [*Deep Impact & StardustNExT s/c 100%*].

[11] Thomas, P.; *et al.* (2013). "The Nucleus of Comet 9P/Tempel 1: Shape and Geology from Two Flybys". *Icarus*, **222**, 453. [*Deep Impact & StardustNExT s/c 100%*].

[12] Tozzi, G.P. *et al.* (2013). "Activity of Comet 103P/Hartley 2 at the Time of the EPOXI Mission Fly-by", *A&A*, *Icarus* **222**, 766, arXiv:1206.1185. [*TNG (100%)*].

[13] Veverka, J., Klaasen, K., A'Hearn, M.F., Belton, M., Brownlee, D., Chesley, S., Clark, B., Economou, T., Farquhar, R., Green, S.F., Groussin, O., Harris, A., Kissel, J., Li, J.-Y., **Meech, K.J.**, *et al.* (2013). "Return to Comet Tempel 1: Overview of Stardust-NExT Results", *Icarus*, **222**, 424. [*NExT spacecraft (100%)*].

[14] Yang, B., Keane, J., **Meech, K.**, Owen, T., Wainscoat, R. (2014). "Multi-wavelength Observations of Comet C/2011 L4 (Pan-STARRS)", *ApJ* **784**, 23. [*Gemini (55%), JCMT (27%), IRTF (18%)*]

⋆ **Objective Bonus (first-author paper):** See previous page.

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.*

Understanding the primordial sources of terrestrial planet organics and volatiles, and where in the disk they originated, is a key priority for both the Planetary Decadal Survey and the NASA Astrobiology Roadmap[1]. There is widespread evidence for aqueous alteration throughout primitive asteroids originating in the outer asteroid belt[2−3], and there is evidence that water may still be present in the outer belt and observable as outgassing from main belt comets[4]. The ultimate goal of the observations of small icy objects is to tie observations of the distribution and composition of volatiles in these bodies to an understanding of the distribution of volatiles in the protoplanetary disk, and to link this through disk observations to other forming planetary systems to understand how habitable worlds acquired the volatiles needed for life[5]. To make these connections, we need to acquire more observations of the distribution of volatile chemistry, and to aquire means to test the predictions of rapidly evolving solar system dynamical models.

We propose three projects related to understanding the distribution of volatiles in the early solar system.

A. Testing Solar System Formation Models

In Aug. 2013 the Pan-STARRS 1 survey discovered an asteroidal object, C/2013 P2, on a long-period (LP) comet orbit. This was highly unusual as typically LP comets are very active at 3.3 AU (*e.g.* Hale-Bopp, ISON, C/2011 L4 PANSTARRS, C/2013 A1 Siding Spring). Objects on these orbits have not likely experienced volatile depletion, not having spent much, if any time in the inner solar system. Immediate followup with Gemini N (DDT) showed a very weak dust coma (Fig. 1A), atypical of a LP comet so close to the sun. This triggered the nick name "Manx comet", after the tail-less cat. We obtained a spectrum (Fig. 2A) with Gemini that showed a surprising ultra-red object–more like the ultra-red material seen in TNOs. A second Manx, C/2014 S3, was soon discovered and it too was active (Fig. 1). Via our VLT (DDT) and CFHT observations, the colors were consistent with an S-type asteroid (Fig. 2A)!

Why is this interesting? Comets and trans-Neptunian objects (TNOs) are believed to have formed in the outer solar system, and their range of colors from neutral to red reflects a mix of organics, ice and surface weathering processes. S-type material, on the other hand is believed to have formed relatively dry in the inner solar system. From a histogram of 18 unperturbed orbits, Oort[6] hypothesized the existence of the Oort cloud at $\sim 10^5$ AU (Fig. 1B). On the basis of the narrow peak he suggested that objects on their subsequent passages through the inner solar system were not being detected because they had lost a layer of "volatile frosting". He proposed that this highly volatile layer was the result of cosmic ray chemical processing, and that it sublimated on the first passage, leaving a volatile-poor remnant. The volatile frosting aspect has not been proven, and it is expected that volatiles in ice-rich bodies should be able to survive up to ∼1000 perihelion passages[7]. Manxes represent something new.

A Dynamical Explanation. Our planet formation paradigm is changing (Fig. 3). The Nice model[8] explored the dynamics of small icy planetesimals post-giant planet formation and was instrumental in understanding how icy bodies that formed in the outer solar system could subsequently be injected into the inner solar system from 13-30 AU. The Grand Tack model[9] started simulations earlier in the formation process and followed giant planets' growth and migration in a gas disk. During their inward migration, the giant planets initiated significant movement of icy planetesimals to the inner solar system (from 3.5-13 AU); likewise inner solar system material moved outward. Widespread movement has been confirmed by more recent models[10]. Other models[11] suggest that no large-scale planetesimal movement is necessary to explain the masses and chemistry of the terrestrial planets. The Grand Tack model predicts that 0.14 Earth masses of inner solar system material was ejected into the outer solar system. This material was further redistributed during the late dynamical instability which resulted in the Late Heavy Bombardment.

The Grand Tack model predicts 0.1-0.2% of the bodies in the Oort cloud should be from inner solar system material. Other models[7,12] *make predictions that up to 4% of the Oort cloud is asteroidal.*

Could C/2014 S3 represent confirmation of giant planet migration models that ejected inner solar system material outward? If so, then what we think of as S-type material may not have always resided in bodies devoid of volatiles. What are the implications of seeing volatile-driven activity in S-type objects? The best meteorite match to S-type surfaces comes from the ordinary chondrites (OC)[13], previously thought to have formed dry. New work on a pristine OC has now shown evidence for aqueous alteration with very low water-rock mass ratios (∼0.1-0.2)[14] suggesting formation near the water ice-line.

All of the solar system simulations suggest that the inner solar system material in the Oort cloud should be dynamically indistinguishable from LP comets. At the time we reported the first Manx to the *Minor Planet Center*, T. Spahr (private comm.) commented that there had been a large number of astrometric reports of asteroids on "interesting orbits" that had never been followed up. Now all-sky NEO surveys, led by Pan-STARRS 1, are additionally discovering nearly inactive LP comets (up to 1000× less active than short-period comets (Fig. 2C)), likely also Manxes. There are now 123 Manx objects, however, most are either too faint (never to return in our lifetimes), or have orbital errors too large for recovery.

The implications of activity on S-type objects moving inward from the Oort cloud is that we may be seeing "fresh" early inner solar system (possibly Earth) planetary building blocks that were dynamically scattered outward. Determining the fraction of Manxes that represent inner solar system material will constrain dynamical models. We propose to characterize the surface composition of the Manxes still observable.

Experimental Design – The observing goal is to obtain colors to determine Manx compositional classes, and search for activity. Asteroids transition from S-class in the inner belt, to C-class, and finally D-class in the outer belt. Trojan asteroids at 5 AU are also very red, like the organic-rich D-class objects. Comet surfaces tend to be relatively red, similar to Trojans and D-types. Centaurs, and TNOs, on the other hand, have a wide range of colors from neutral (like C-class) to some of the reddest objects in the solar system. TNOs have featureless spectra at optical wavelengths, but some have ice-band absorptions in the near-IR (from water, methane, ethanol, etc.). In general, the Manx targets will be too faint for near IR spectroscopy, so we will use $grizY/JHK$-band photometry to characterize their surfaces. In the visible-λ this can discriminate between S, C, D classes and redder objects (Figs. 2A,B). The r' and i' filters can give the spectral slope, but the g' filter is needed to search for the presence of the UV downturn, and the z' filter is required to detect the presence of the 0.9μm pyroxene band in S-types. Optical colors (VRI) were obtained for a few of these type of objects ∼10 years ago[16] with the thought that they were extinct comet nuclei, but these filters lack coverage at 0.9μm so cannot distinguish S-type objects.

Our definition of a Manx is an object that formed in the inner solar system, was scattered to the Oort cloud, and then scattered inward, and may represent Earth-building material. Observationally, these include objects with perihelia, $q < 4$ AU, and aphelia, $Q > 1000$ AU, *i.e.* LP comet orbits that are likely dynamically new. Comet orbits for which $35 < Q < 1000$ AU ("intermediate period", IP) may also contain Manxes, but this population can include other dynamically scattered objects, and could have some of Oort's objects minus the "volatile frosting". Our Manx list of 123 objects is ∼evenly divided between LP and IP orbits. Because there are so few still observable (∼18), we propose to examine both classes.

The 0.9μm band depth ranges from ∼5-20%. To ensure classification of spectral type (since the shape of the different classes is also distinct in the near-IR), in addition to visible-λ colors we are also requesting time on UKIRT with WFCAM for 2 brighter northern objects and have a companion proposal requesting time on the VLT during P97 using HAWKI for near-IR photometry ($YJHK$). Because the visible and near-IR will not be obtained simultaneously, the Y filter will be measured using both instruments to tie the observations together (rotational color changes are not expected). Through NOAO, we are also requesting Gemini S with GMOS to obtain $grizY$ photometry on 2 targets in the far south–for a total of 9 targets.

We used a H_2O-ice sublimation model to reproduce the heliocentric light curve of C/2013 P2, and can estimate the low-level dust contribution; it contributed < 0.4 mag to the total flux (the gas is impossible to detect as the flux is far below 10-m detection limits). At this low level the dust will not affect the determination of the surface spectral reflectivities. We monitored the development of the coma in comet 9P/Tempel 1 for the Deep Impact mission[17]. With a nucleus color of 0.50±0.01[18], the color of the coma didn't deviate at all from the nucleus color until there was substantial dust (*i.e.* when the coma was 2-3 magnitudes brighter than the nucleus, Af$\rho \sim 130$ cm (a measure of the dust production)), and even then the effect was a 6% difference in the color. The amount of dust around C/2013 P2 at perihelion was >20× less (Af$\rho \sim 7$ cm) than comet 9P/Tempel 1 when it exhibited small color changes due to the dust coma.

There are currently several models that make predictions of the fraction of S-type material in the Oort cloud, and some models which predict no major movement of planetesimals. According to CoI A. Morbidelli "*There is a new model that Izidoro and Raymond are developing, the main difference with respect to the Grand Tack model is the presence/absence of S-type objects in the comet population! So, now I am even more interested in this project*". Thus, characterizing the composition of the Manx objects will be a key constraint for dynamical models. Assuming 3 competing models with S-type Oort cloud fractions of A) 0.15% B) 2.3% and C) 4%, we will ultimately want to look at ∼100 objects to distinguish between models. We use cumulative binomial statistics to examine which models are ruled out given a particular observation of S-types. Observing more than one S-type, the lowest S-type fraction model (A) is ruled out at probability p=0.01. Above six S-types, model B is ruled out with p=0.01. Between one and six S-types, both B and C are permitted with 2-σ confidence, but we will still be able to assign relative likelihoods to the models.

Many of the 123 Manxes are no longer observable because (1) they were discovered years ago and are now too faint, or (2) were not followed and the orbits are now bad. We also request 5.8 hr with Megacam on CFHT to get astrometry for new discoveries to ensure that the orbits are good throughout their observable period, and to get deep images to accurately assess the dust production to quickly determine if they are low activity. If sufficient astrometry exists for good orbits from other observers we will use some of the time allocated for astrometry to get deep images at more than one epoch for some targets.

Long-Term Plans – The Pan-STARRS1 survey cadence is now ideal for discovering more Manx objects. Within a year of PS1 moving fully to the NEO program, it has discovered 4 Manx objects in 2014 (2-LP, 2-IP), and 7 so far in 2015 (3-LP, 4-IP). PS1 will provide us with a steady flow of new objects in the future. For the objects proposed here, we have gone back into the PS1 database and have found ∼120 pointings per object between 2009-2015, which means that we potentially will have a few data points for heliocentric light curves for each target that we can use to search for any non-geometric brightening which would be indicative of activity. This is an exciting new area of science potentially providing an opportunity to look at unaltered material from the inner solar system that was ejected outwards during the era of giant planet formation. These objects are a newly recognized group, and we submitted a proposal to the NASA Solar Systems Observations program for funding to work in this new area (June 2015). We want to see the outcome of F2015B and S2016A observations, and see that the discovery rate of Manxes has held steady, and then we will consider putting in a Large Program.

[B] Mapping CO_2 Abundances with NEOWISE

After hydrogen, the most abundant volatiles in our Solar System's protoplanetary disk were H_2O, CO and CO_2. Comets are the primitive remnants of the transition from the disk to the growth of planets, and they may have played a key role in the delivery of volatiles to the terrestrial planets. Decades of chemical studies have investigated comet chemistry via optical spectroscopy, assessing outgassed daughter (molecular photodissociation product) minor species. Now, high-resolution near-IR and sub-mm spectroscopy can trace organic species parent molecules directly outgassed from the nucleus simultaneously with water and CO. The standard paradigm for comet activity is that comet outgassing is mostly controlled by water sublimation, with a few very active LP CO-rich comets. However, one of the key volatiles, CO_2, cannot readily be observed from the ground, because the atmosphere is opaque at the wavelengths where it radiates. Recent missions – *EPOXI*[19−20] and *Akari*[21] – have sharply changed our understanding of the role of CO_2 in comets, and we now believe CO_2 may be a key volatile controlling their activity. This will have wide implications for protoplanetary disk chemical models.

The *WISE* mission[22] mission surveyed the sky at four mid-IR wavelengths (3.35 μm (W1), 4.60 μm (W2), 11.56 μm (W3) and 22.08 μm (W4)) from 2009 to 2011. The data processing system was enhanced under *NEOWISE* with the *WISE* Moving Object Processing Software (WMOPS) to find solar system objects in the data[23]; and we are members of this new *NEOWISE* team. In 2013 NASA funded a re-start of the *NEOWISE* program for a warm all sky survey (bands W1 and W2) to look for NEOs, expecting to run through 2017. The new survey will also observe all active comets, and make new comet discoveries.

There are 298 known JF comets, and with ∼5-year orbital periods we have the potential to observe most of them active during the 4-year survey. We will also be observing newly discovered long-period and dynamically new comets. At the survey's sensitivity, we were expecting to observe ∼40 active comets per year to detect or place limits on CO_2 production – a 5-fold increase in the number of comets previously measured. So far this year NEOWISE has observed 28 objects, so we are on track for 40 total. With these observations, we will be in a position to interpret CO_2 chemistry as was done for optical species[24−25].

Proposed Observations – We propose to obtain *gri* images for all active comets observed and discovered in the new *NEOWISE* survey to model the dust contribution[26]. Since the mission restart in 2014, 111 comets have been observed, with 3 new discoveries, and CFHT has followed up 50% of these to date, with 40 now to put in the queue for 2015B. This project is not well-suited to classical observing. Having UH2.2m time for this program has not been efficient (time scheduled when the moon is too close to new objects observed by *NEOWISE*, or target discovery RA not suited to the nights we have after discovery). Further the override policy has been very disruptive. Thus we are collaborating with observers at Calar Alto for the brightest objects (they have 10 nts / mo on a 1-meter telescope), and we will do the fainter ones on CFHT. We request 9.6 hours of CFHT time for 2016A, but expect this to be lower the following semester.

NEOWISE is a powerful new space asset for studying solar system CO_2 volatile distribution. We propose to take advantage of this unique opportunity to obtain optical images in 3 bands for all of the WISE-observed active comets to estimate the CO_2 abundance or derive CO_2 upper limits.

Note: The NEOWISE work was submitted the last 2 semesters, and the text length is significantly reduced. We will continue to submit this while the mission flies.

[C] Main Belt Comet 238P/Read Activity

Water is common in space, but we don't know how it was delivered to our planet. Whether a special circumstance or planetary architecture was required to deliver water to our solar system's habitable zone has enormous implications for habitability of the numerous extrasolar planets residing in their host star's habitable zones. In the last few years a surprising and significant reservoir of water has been found in the outer region of the Main asteroid belt with the discovery of Main belt comets (MBCs)[28], direct detection of icy asteroid surfaces[29−31], and outgassing from Ceres[32]. This is an ideal region to trace the history of water because there are many dynamical models which make *specific* predictions about the source regions for their formation, unlike comets which formed anywhere from the solar system ice line to the outer solar system. The dynamical models can be coupled to disk chemistry models to understand the source region for inner solar system volatiles (Fig. 4A). The key to tracing where water comes from that arrives in the inner solar system is to use several isotopic markers (observed in-situ) which all have different radial dependencies driven by different physical processes and to use this to select among dynamical models.

To this end we have been observing MBC 238P/Read, our proposed mission target, to understand its level of activity around the orbit. The previous 2 apparitions have not been very good geometrically; it has not been possible to observe the beginning of the activity approaching perihelion and following it through post-perihelion until it turns off (Fig. 4B). Modeling the outgassing has been difficult without assuming a secular decrease. If real, a decrease can suggest that either there is a limited reservoir of volatiles, or that the ice depth has receded far enough that the overlying dust is insulating the interior from solar heating. We need to observe the full period of activity to model this. The 2016-2017 apparition is the first chance we have had to do this, and will be the only chance for the next 20 years. (Our mission was not selected; but we plan to propose again. Having more understanding of MBC activity will remove potential weaknesses.)

We also know very little about the surface mineralogy of Read, other than it's slightly blue spectral reflectivity which suggests it may be like the rare B-type of asteroids which have been shown to have surface compositions consistent with aqueous interaction[33]. We are requesting time on Gemini and UKIRT to get $grizY-JH$ photometry to characterize its surface, and deep images in r' to see if activity has begun.

Role of Team Members / Collaborators

All of the team members will be helping with interpretation, analysis, and writing the papers, to be led by the PI. More specific roles:

- **Karen Meech** – [ABC] Planning and coordinating all observations, analysis of data, including sublimation modeling, dust modeling.
- **Jan Kleyna** – [ABC] Pipeline processing, statistical analysis–assessing completeness for results interpretation, CFHT queue.
- **Jacqueline Keane** – [AC] Gemini queue management; [B] Near IR spectra, sub-mm observing to provide CO flux constraints for NEOWISE modeling.
- **Olivier Hainaut** – [AC] Leading VLT observations.
- **Bin Yang** – [A] VLT reductions, secure additional time on IRTF, Magellan as needed.
- **Marco Micheli** – [A] Rapid turn around on astrometry for all Manx objects, assistance in hunting for objects on orbits which have large errors.
- **Alessandro Morbidelli** – [AC] Dynamical interpretation, modeling.
- **Robert Jedicke** – [A] Simulations of completeness of population of Manxes discovered by Pan-STARRS.
- **James Bauer** – [B] Reporting to the team all NEOWISE discoveries for immediate followup, modeling the IR data using visible fluxes and sublimation modeling (from UH) to determine the 4.7μm excesses and assess the $CO+CO_2$ abundance.
- **Henry Hsieh** – Contribution to analysis of low level dust for Manxes and MBC Read. He will also try to secure a small amount of CFHT time for monitoring the dust and for astrometry.

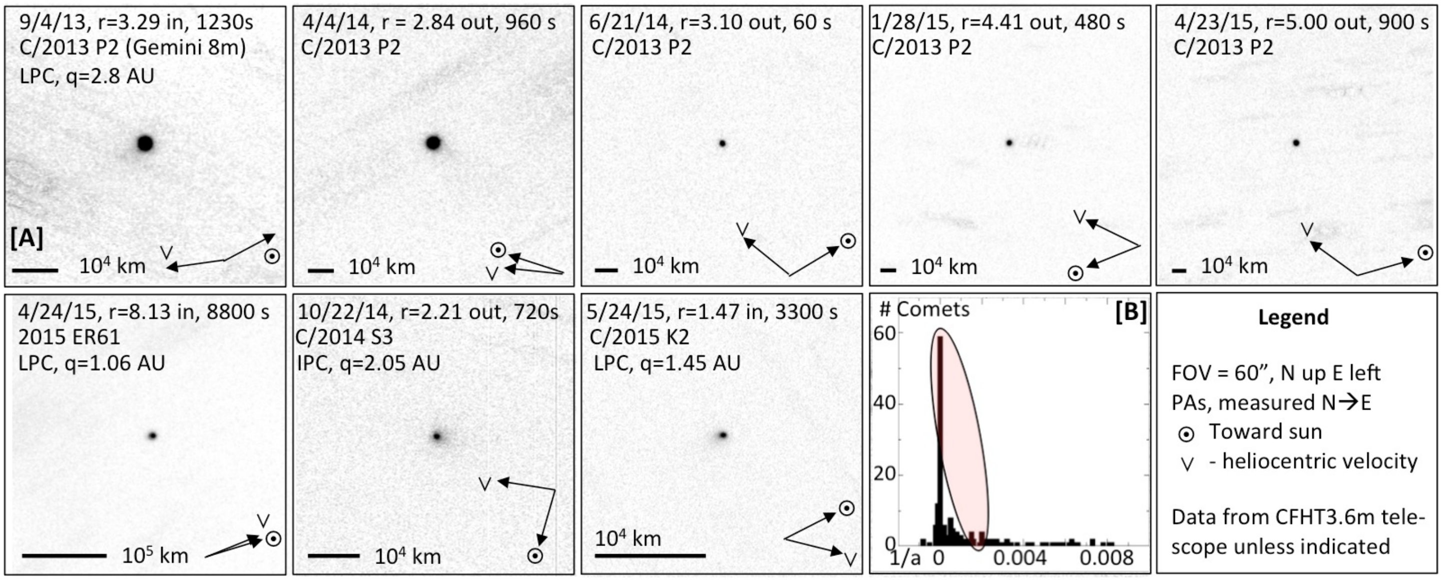

Figure 1: [A] Manx comets: objects on long-period (LP) comet orbits displaying little or no activity where a significant tail would be expected. [B] Histogram of LP comet orbits showing the narrow Oort cloud spike. Missing comets in the red shaded region were thought to have faded because of loss of a "volatile frosting" on the first inner solar system passage[6].

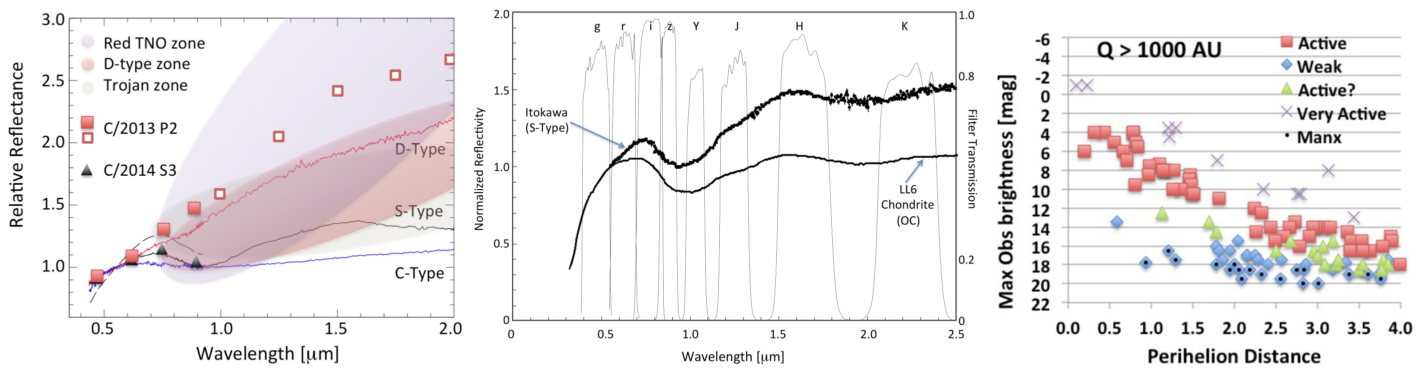

Figure 2: [A] Left – Reflectivity spectra of typical middle (C), inner (S) and outer (D) main belt asteroids (from the SMASS catalog[15]). The shaded regions show the spectral reflectivity ranges for Trojan asteroids, D-types, and trans-Neptunian objects. Comet colors fall primarily in the Trojan zone, but some are as red as D-types. The spectral reflectivities for 2 Manxes: C/2013 P2 (in optical and near-IR) and C/2014 S3 (optical) are shown as squares and triangles, respectively. The error bars are approximately the size of the symbols. [B] Center panel– Comparing $griz/YJHK$ filter bandpasses to the S-type spectrum of asteroid Itokawa showing that they are ideal for mapping the 0.9μm band. [C] Right – LP comet mags vs. perihelion distance. The symbol indicates the activity level. The active Manx candidates are marked with a dot.

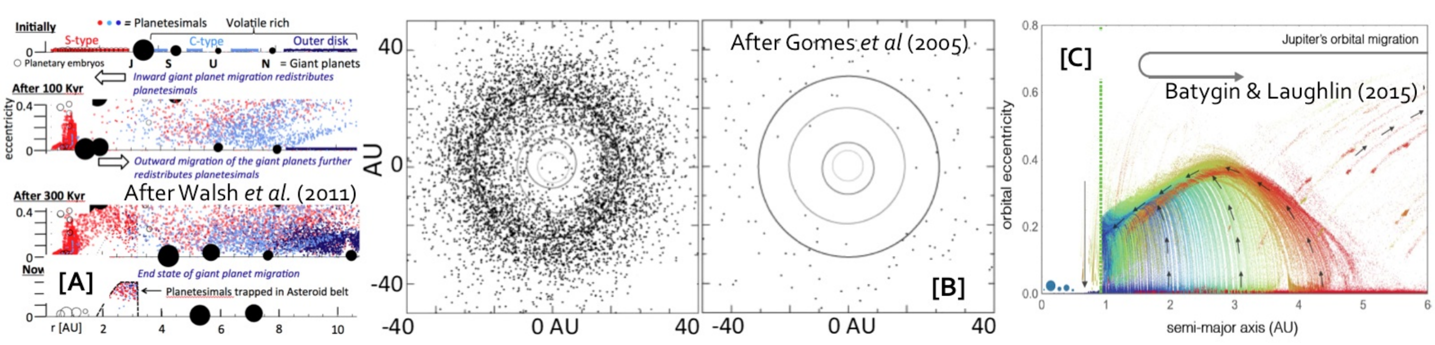

Figure 3: [A] Grand Tack model representation of inward and outward icy planetesimal (blue) migration as giant planets migrated in a gas disk, followed by inner solar system material (red) and icy material moving outwards as the giant planets migrated outward. [B] The late instability modeled in the Nice model, redistributed some of the material scattered outward into the Oort cloud. [C] Other models also show outward planetesimal migration during solar system formation.

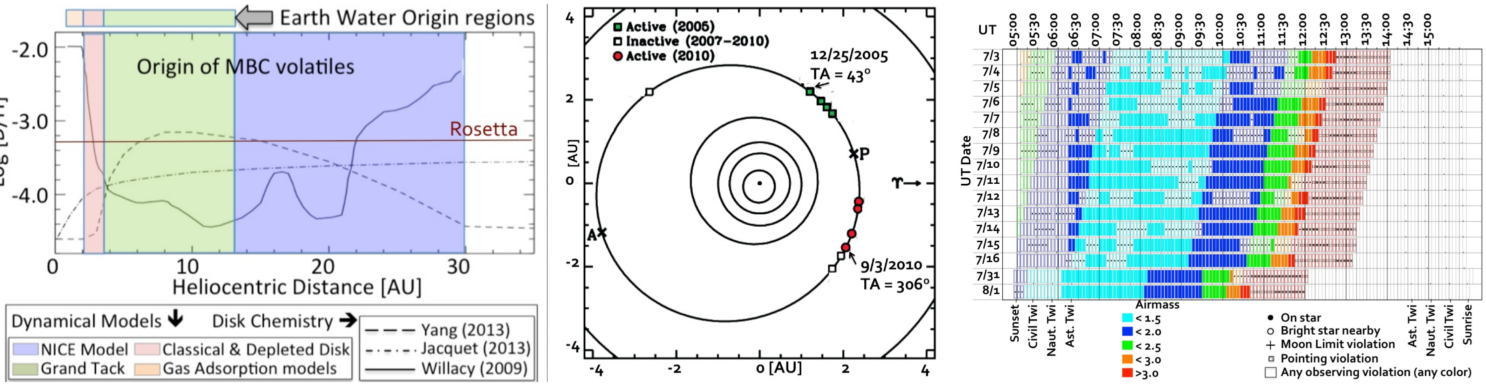

Figure 4: [A] Illustration of what a single isotope measurement on a small body can achieve. The black curves represent the D/H predictions as a function of heliocentric distance at the disk midplane from 3 state of the art disk chemistry models. The shaded regions represent predictions from 3 leading dynamical models for the source regions of inner solar system water. The red horizontal line represents the Rosetta D/H measurement which is consistent with 2 chemical and 3 dynamical models. [B] Position along orbit where 238P/Read has been seen active (filled symbols)[34]. For the 2016-2017 apparition Read will be visible from TA=326° through perihelion (P) until TA=37°. [C] Visibility for 238P/Read when the moon is down during 2016 July. Windows at χ<1.5 without star contamination are in light blue, showing there is reasonable observing opportunity.

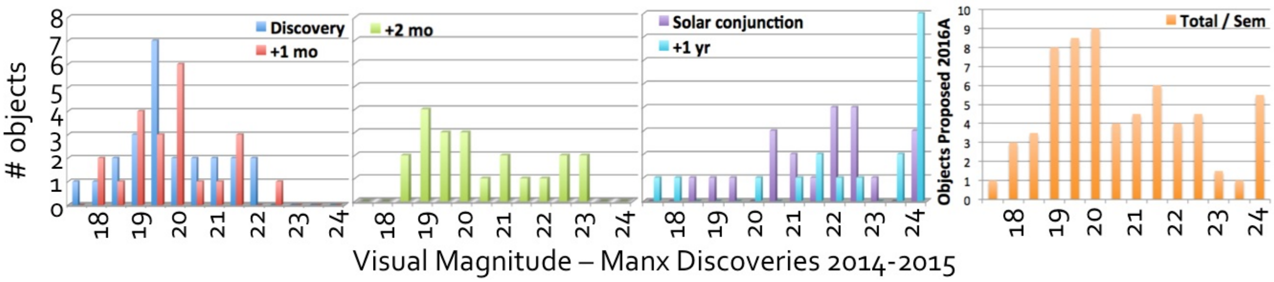

Figure 5: Distribution of Manx magnitudes for all discoveries in 2014-2015 at time of discovery, 1 and 2 months later, when they went into solar conjunction and one year later. The orange histogram shows the total magnitude distribution for one semester, assuming a discovery rate of 12 per year, and a repeat observing cadence suitable to get orbit errors to less than a few arcsec for the whole observable period.

Telescope			Table 1 - Exposure Time Calculations					Overheads				g'		r'		I'		z'		Y		g'		S/N	S/N	S/N
IR-S	IR-N	Vis	Designation	Other Name	Mag	#pics	Exp s	#fl chg	#offset	Tot s	Tot s	#	Exp	#	Exp	#	Exp	#	Exp	#	Exp	#	Exp	gri	z	Y
VLT		GN	2015 ER61		20.0	13	1250	5	7	790	2040	2	35	2	35	2	45	2	100	3	250	2	35	100	100	40
VLT		GN	C/2013 G3	PANSTARRS	21.4	19	3440	5	13	970	4410	2	50	2	50	2	70	3	200	8	300	2	50	50	50	20
VLT		GN	C/2014 XB8	PANSTARRS	24.5	18	5160	3	14	920	6080	4	270	4	300	6	300					4	270	20		
	UK	GN	2014 XS3		22.6	12	2940	4	7	750	3690	2	250	2	200	2	270	4	250			2	250	50	30	
VLT		GN	C/2015 M3	PANSTARRS	21.4	19	3440	5	13	970	4410	2	50	2	50	2	70	3	200	8	300	2	50	50	50	20
VLT		GN	C/2015 H1	Bressi	23.0	15	3520	4	10	840	4360	2	180	2	150	2	200	7	300			2	180	30	30	
	UK	GNFT	2015 AO44	(IQ70-grey)	20.0	13	1670	5	7	850	2520	2	35	6	125	2	35	2	55	2	300	2	35	>100	100	50
VLT		GS	C/2014 W6	Catalina	22.3	22	5360	5	16	1060	6420	2	150	2	120	2	160	2	300	12	300	2	150	50	30	15
VLT		GS	C/2015 O1	PANSTARRS	18.3	12	590	5	6	760	1350	2	35	2	35	2	35	2	35	2	120	2	35	<450	<250	100

This assumes that the mags are the same for griz which is conservative.
Ideal S/N=50, S/N=30 is min acceptable for gri, z~20, Y~15.
If overhead limited S/N>100 is used.

	Total	[hrs]
	GN	6.9
Bright	GNFT	0.8
IQ70,Gr	GNFT	0.7
Faint	GNFT	0.7
	GS	2.2

Manx Brightness		IQ	CC	WV	SB	χ	Overheads	sec
		Obs Cond Constraint						
Bright	V < 21.5	85	50	Any	80	1.5	Setup Img	360
Faint	21.5<V<23.2	70	50	Any	50	1.5	Filt change	20
Very Faint	23.2 < V	70	50	Any	20	1.5	2x2 read	20
GNFT (IQ70, Grey)		70	50	Any	80	1.5	Dither/offset	10

Figure 6: **Table 1** – Excel spreadsheet calculations for the total exposure times for the Manx Gemini campaign, showing all optical telescopes, including overheads. The observing condition constraints depend on brightness of the target. There are 3 cases for the Gemini FT proposal we are submitting for October. The FT is because of a disallowed *inaccessible* RA for one target for 2016A, and by 2016B it will be too far from the Sun.

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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:** Gemini **Alt. telescope:**	**Instrumentation:** GMOS **Alt. instrumentation:**

The most challenging spectral class to distinguish will be the S-type, because we need to detect the 0.9μm pyroxene absorption. The 0.9μm band depth can range in depth between ~5-20%. Ideally we desire S/N=50 for the individual filter measurements, but S/N=30 will get a detection. The z' and Y band fluxes are likely to be similar (Fig. 2B), but the Y-band is the tie in to the near-IR measurements. This λ is more difficult to obtain, and we will accept S/N~15 for our faint target for Y. We have 6 targets. For the bright targets we are overhead limited, so propose to get S/N~100. For these objects sky brightness is not critical, except for detecting dust, and image quality can be relaxed. To get good relative colors and to link the visible to the near-IR data we propose to get from the VLT, we require clear conditions. For the faint target, we require IQ=70, and SB=50 (with a brighter sky, SB=80 increases the total time by 25%).

The GMOS ITC observing constraints for the two objects we use for computing the exposure times are: (1) Faint IQ=70, CC=50, WV=Any, SB=50, χ=1.5, (2) Bright: IQ=85, CC=50, WV=Any, SB=80, χ=1.5. Based on the above observing constraints and S/N, Table 1 shows the sequence of observations for each target. We assume the following overheads: 360s for image acquisition/setup, 20s for filter change, 20s for readout (2×2 binning), 10s for dithering/offset. We break each exposure into at least 2 images, and dither between exposures in the same filter. Because these are moving objects and we don't know ahead of time what the star fields will be like, we keep exposures to no longer than 300s to avoid losses when the object passes over/close to field stars.

The sequence of observations is $g'\times n$, $r'\times n$, $i'\times n$, $z'\times n$, $Y'\times n$, $g'\times n$ to enable us to correct for changing flux caused by changing cross section with rotation. Here n is the number of exposures needed per target/filter to achieve the desired S/N (Table 1). Because the S-type spectrum will be the most challenging to detect in terms of integration time, we have made the conservative assumption of a flat spectrum when determining the integration time in the ETC. The magnitude was carefully determined by looking at all reported observations and modeling the behavior assuming decrease in the small amount of dust around the objects, and additionally by assuming a bare nucleus. The brightness will vary over 2016A, so for the purposes of the ETC we took the faintest magnitude. Our experience has shown that these objects tend to fade faster than we expect, so this conservative estimate is warranted. In the target list below, the optimum month and the month for the coordinates is listed with the target name.

The total request, including overheads is 6.9 hrs.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
A	2015 ER61-Apr	11:17	-02	20, V
A	C/2013 G3-Jul	00:59	+31	21.4, V
A	C/2014 XB8-Jul	21:37	+21	24.5, V
A	2014 XS3-May	18:07	+42	22.6, V
A	C/2015 M3-Jul	22:12	-11	21.4, V
A	C/2015 H1-Apr	13:59	+32	23.0, V
		See Table 1 for details		

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: 2	**Telescope:** CFHT **Alt. telescope:** UH2.2	**Instrumentation:** Megacam **Alt. instrumentation:**

Manx discoveries in 2014-5 give a brightness distribution for the expected new Manxes. Figure 5 shows all of the Manx objects discovered in 2014 and 2015 with the approximate magnitudes at discovery, 1 and 2 months later, as the object moved into solar conjunction and the estimated brightness 1 year later. The brightnesses are a combination of observed brightness and modeled brightness.

Per CoI Micheli, in order to get an orbit with few arcsec errors for the observable period, we require an observation shortly after discovery in the 1st and 2nd month following, before it moves into solar conjunction and 1 yr post-discovery. This guarantees $<1'$ uncertainties between observations. Each observation will have 2 images, and at discovery plus one month the Manx should be observed on two nights. From Figure 5 it is clear that the Manxes rapidly get fainter after perihelion. The right histogram is the projected number of targets at each mag during one semester using this observing cadence, assuming the current discovery rate of $\sim$12/yr. We require S/N$\sim$20 to model the heliocentric lightcurve. The table shows the Megacam ETC r' filter results for each magnitude bin. We assumed optimal aperture photometry, grey time, seeing $1.2''$ and χ=1.7 (we may be at high airmass near conjunction). The table shows the desired S/N per mag bin, the exposure time, and # of exposures. The total exposure time is at the right. With 40s per image for overhead. The astrometry requirement is for 4 hrs.

ETC Criteria	r'	SN=10	SN=15	SN=20	SN=30	100 sec	# Targets	SN	Exp	# images		Tot exp [s]	Total pics	Overhead	
Wave r'	> 20					> 100	25	100	50	2		2500	50	128	images
Apert optimal	20.0			7	13	SN=90	9	90	50	2		900	18	40	s / pic readout
Moon grey	20.5	5	9	14	30	SN=60	4	60	50	2		400	8	**1.42**	hrs overhead
Airmass 1.7	21.0	9	18	30	63	SN-38	5	38	50	2		500	10	**Total time**	**Request Astrometry/Phot**
Transp 0.9	21.5	19	39	67	147		6	30	75	2		900	12	**3.98**	hrs
Seeing 1.2	22.0	41	90	158	352		4	30	90	2		720	8	**Total time**	**Request Dust**
	22.5	98	217	384	860		5	20	150	2		1500	10	**1.8**	hrs
	23.0	238	533	945	2124		2	15	150	4		1200	8	**Total time**	**Request**
	23.5	589	1321				1	10	150	4		600	4	**5.8**	hrs
Dust coma extent		[5x180 sec gives S/N = 5 in r' for mag ~ 25.7] x 6 targets										**2.56**	**hrs exp**		

We will obtain a deep image for each target, shortly after discovery to estimate the amount of dust production. The Manxes have faint coma approximately at the level at which Chiron's coma was first discovered[35], visible a few arcseconds from the nucleus between $\sim$24-26 mag/arcsec^2. We can get to S/N=5 for r'=25.7 in 900 s. This will be obtained with 5$\times$180 sec dithered images for good background removal. With overheads this is 18 min per object $\times$ 6 objects for a total of 1.8 hrs. **The total request is 5.8 hrs.**

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
A	ToO-New Manxes	TBD	TBD	$r$$\sim$22-18

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: 3	**Telescope:** UKIRT **Alt. telescope:**	**Instrumentation:** WFCAM **Alt. instrumentation:**

We request 10.2 hours using WFCAM to obtain Z, Y, J, H, and K broad band imaging for 2 targets.

Because the S-type spectrum will be the most challenging to detect in terms of integration time, we have made the conservative assumption that all objects have S-type colors when estimating the brightness in each filter and determining the integration time using the UKIRT WFCAM ETC.

Our targets are small compared to the size of the detector and we will use the target images themselves to estimate the sky. We will offset the targets to ensure that they are in Camera 3, the best chip on WFCAM.

We used the WFCAM ETC assuming seeing=0.8″; airmass=1.2; sky brightness=average. We require a S/N=30 for the individual filter measurements in the case of 2015 AO44, and a S/N=15 for 2014 XS3. Chip overheads of 1.7 seconds per sequence [adopted from WFCAM overhead table] for observations with the following pattern of exposure × coadds: 10 sec × 2 coadds. A maximum of 1 hour is allowed for an individual UKIRT WFCAM minimum science block (MSB). The total on-source time of 9.3 hours means we require 10 MSBs for this program. An additional overhead of 6 mins per MSB is required for target acquisition, flush the array, and filter change.

The time breakdown between targets:
2014 XS3: on source + readout = 6.45 hrs, 6 min per MSB = 7×6 min = 0.7 hr
2015 AO44: on source + readout = 2.75 hrs, 6 min per MSB = 3×6 min = 0.3 hr

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
A	2015 AO44	01:49	+54	V∼20.4
A	2014XS3	18:07	+42	V∼22.6

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: 4	**Telescope:** CFHT **Alt. telescope:** UH2.2	**Instrumentation:** MegaCam **Alt. instrumentation:** Tek+LFW

We request 9.6 hours to follow up *NEOWISE* detections of active comets to provide optical photometry in 3 bands (g, r, i), and to estimate the amount of dust. This estimate is required to accurately model the nucleus+dust contribution to estimate the excess flux from $CO+CO_2$ in the W2 band[36]. If detected in *NEOWISE*, the comets will be relatively bright (V=19-22), depending on the dust color. We wish to get a high S/N photometric measurement of the nucleus, in addition to a deep image of the dust. With this, we can model the surface brightness and remove its contribution from the nucleus signal. For bright objects ($V<21$) we are overhead limited for colors, so request S/N>100; this is reduced to S/N=30 (our minimum) for faint objects. Our experience with follow up for MBCs to image their dust tails shows that 4×180 sec (dithered) gives good S/N (detection limit of ∼25.5 mag/arcsec^2 in r' in grey time) on the dust and allows us to remove field stars.

NEOWISE is observing ∼20 comets per semester, however, due to extensive bad weather recently and with some backlog of targets from 2015A, we will have ∼30 targets for 2016A. The table below shows the likely number of targets per magnitude bin based on past *NEOWISE* observations, and the S/N per magnitude. The required exposure time in sec is listed for each filter. In all cases the deep 4×180 sec dust coma exposure will be more than sufficient to meet our color goals, and this is the exposure time used for r-band. Keeping exposures to <200s to minimize trailing, and assuming an overhead (OH) of 40s readout, the breakdown of the time required is shown in the table.

# Obj	Mag	S/N*	g	r	i	#pics	OH	Sci	Tot
12	19	100	15	25	80	6	240	815	9780
4	20	100	60	110	430	7	280	1210	4840
6	21	50	70	140	600	8	320	1390	8340
8	22	30	140	290	600	11	440	1460	11680
		*for V=22 in i use S/N=20						**Tot hr**	**9.6**

This program is ideally suited to queue scheduling, giving us flexibility to secure observations as soon after observation with *NEOWISE* as possible. Last semester we found that the UH2.2m allocation was problematic for this program. In particular, we were badly impacted by the PS1 override time. We had some nights where there were no *NEOWISE* targets that weren't either in the override time or too close to the moon to observe.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
B	TBD			$gri \sim$ 19-22

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: 5	**Telescope:** Gemini **Alt. telescope:**	**Instrumentation:** GMOS **Alt. instrumentation:**

We request 1.2 hours using GMOS to obtain $grizY$ imaging for main belt comet 239P/Read. It will be coming out of solar conjunction in July, at V$\sim$22 mag. The color of Read is slightly bluer than the sun, but we have few measurements at different wavelengths, so do not know what the surface mineralogy is like. Therefore, we are assuming the same magnitude at all wavelengths a conservative estimate for determining the integration using the GMOS ITC.

Ideally we desire S/N=50 for the individual filter measurements, but S/N=30 will get a detection. The z' and Y band fluxes are likely to be similar (Fig. 2B), but the Y-band is the tie in to the near-IR measurements. This λ is more difficult to obtain, and we will accept S/N$\sim$15 for for Y. To get good relative colors and to link the visible to the near-IR requires clear conditions. The GMOS ITC observing constraints we use for computing the exposure times are: IQ=70, CC=50, WV=Any, SB=50, χ=1.5. Based on the above observing constraints and S/N, the table below shows the sequence of observations for Read. We assume the following overheads: 360s for image acquisition/setup, 20s for filter change, 20s for readout (2$\times$2 binning), 10s for dithering/offset. We break each exposure into at least 2 images, and dither between exposures in the same filter.

The sequence of observations is $g'\times n$, $r'\times n$, $i'\times n$, $z'\times n$, $Y'\times n$, $g'\times n$ to enable us to correct for changing flux caused by changing cross section with rotation. Here n is the number of exposures needed per target/filter to achieve the desired S/N.

Telescope			Exposure Time Calculations					Overheads				g'		r'		I'		z'		Y		g'		S/N	S/N	S/N
IR-S	IR-N	Vis	Designation	Other Name	Mag	#pics	Exp s	#fl chg	#offset	Tot s	Tot s	#	Exp	#	Exp	#	Exp	#	Exp	#	Exp	#	Exp	gri	z	Y
	UK	GN	238P	Read	22.0		3300	5	11	910	4210	2	100	2	80	2	120	2	200	7	300	2	80	50	30	15

The total request, including overheads is 1.2 hrs.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
C	238P/Read-Jul	00:43	+03	V$\sim$22

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: 6	**Telescope:** UKIRT **Alt. telescope:**	**Instrumentation:** WFCAM **Alt. instrumentation:**

We request 3.9 hours using WFCAM to obtain ZYJH broadband imaging for main belt comet 238P/Read. It will be coming out of solar conjunction in July, at V$\sim$22 mag. The color of Read is slightly bluer than the sun, but we have few measurements at different wavelengths, so do not know what the surface mineralogy is like. Therefore, we are assuming the same magnitude at all wavelengths a conservative estimate for determining the integration using the UKIRT WFCAM ETC.

238P/Read is small compared to the size of the detector and we will use the target images themselves to estimate the sky. We will offset Read to ensure it is in Camera 3, the best chip on WFCAM.

We used the WFCAM ETC assuming seeing=0.9$''$; airmass=1.2; sky brightness=average. We require a S/N=20 for the individual filter measurements. WFCAM manual states chip overheads of 1.7 seconds per sequence [adopted from WFCAM overhead table] for observations with the following pattern of exposure $\times$ coadds: 10 sec $\times$ 2 coadds. A maximum of 1 hour is allowed for an individual UKIRT WFCAM minimum science block (MSB). The total on-source time of 3.5 hours means we require 4 MSBs for this program. An additional overhead of 6 mins per MSB is required for target acquisition, flush the array, and filter change. All overheads are included in the total time request.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
C	238P/Read-Jul	00:43	+03	V$\sim$22