University of Hawaii • Institute for Astronomy

Research Proposal—Observing Time Request

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Institution/Dept (if not IfA): IfA

Proposal Number:

Semester: A **Year:** 2012

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

A. Rapid followup of important solar system discoveries from Pan-STARRS

B. Properties of new PS1 discoveries including Comet C/2011 L4

C. A search for large undiscovered NEOs at low solar elongation

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

A. The Pan-STARRS 1 (PS1) survey is proceeding well, and numerous interesting solar system discoveries are made each month. These include approximately 30 Near Earth Objects per month, new comets, and Centaurs. We seek a modest amount of observing time with Megaprime on CFHT to make rapid followup observations of important new solar system discoveries. The discoveries we expect to target will come from both the 3π survey and from observations specifically designed to find NEOs. Key discoveries will include:

- Rapidly moving asteroids: Near Earth Asteroids are discovered through their rapid motion, and need to be immediately reobserved within one or two nights to establish a preliminary orbit. Many of the PS1 NEO discoveries will be followed up by other telescopes on the US mainland, but we have already found that bad weather periods on the mainland, along with very fast moving NEOs require us to do substantial amounts of followup ourselves to ensure NEOs are not lost. Establishing a continuing track record of successful NEO discovery is essential for continued funding for Pan-STARRS from the NASA NEOO program.

- New comets: A major comet (C/2011 L4) was discovered during the 2011A semester, and four other comets have been discovered. Another major comet may be discovered. Observations on a single night yield a comet candidate, likely characterized by fuzzy PSF, and anomalous motion, but this is not sufficient to claim discovery or calculate an orbit. Additional observations are immediately needed for confirmation, to establish an orbit, and claim discovery.

PS1 will not do any targeted followup observations itself. Because Megaprime is scheduled during each dark moon period, and it is queue scheduled, it is the best choice for rapid followup of PS1 discoveries.

B. We request a modest amount of observing time on Gemini for followup spectroscopy of important new PS1 discoveries. Our targets will include Comet C/2011 L4 (PANSTARRS) which is expected to be visible to the naked eye in 2013 when it reaches perihelion. We also propose to obtain observations of new dwarf planets discovered by PS1 in the outer solar system. These observations will consist of infrared spectroscopy to determine surface composition.

C. The "sweet spots"—located between 60 and 90 degrees solar elongation and within 20 degrees of the ecliptic—are locations where many NEOs spend substantial parts of their orbits. Because of extensive surveying in the opposition direction, most of the large NEOs that have orbits with aphelia well beyond Earth have been discovered. The sweet spots remain a rich location for discovery of large NEOs. We propose to exploit the large aperture of CFHT and Subaru and their excellent image quality to make a search for NEOs in the sweet spot that is substantially more sensitive than PS1. These observations will continue an effort that will be started in 2011B. We will specifically target the area near 60 degrees solar elongation and should detect Earth Trojans if they are present near Earth's L4 and L5 Lagrange points.

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)	Observer's initials	Future est. # of: nights/sem.	semesters
1	A	CFHT	Megaprime	10 h	±8	queue	10 h	4
2	B	Gemini	GNIRS,GMOS	11.5 h	±7	queue	1	1–2
3	C	CFHT	Megaprime	6 h	±8	queue	0	0
4	C	Subaru	SuprimeCam	2 h	none	RW	0.5	1–2
5								
6								
7								
8								
9								

Run	Optimum Dates	Acceptable Dates	Unacceptable Dates *(Give reasons)*
1	any	any	
2	February–July	Gemini queue preferred	
3	March, July	April, June	all other
4	June–July, last hour	2 consecutive nights	
5			
6			
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.

Unused/returned or cancelled:
0.5 nights Keck II NIRC2/LGS in 2010B: "Physical properties of large bodies in the outer solar system" returned for reallocation.

10 hours Gemini NIRI (queue) in 2010B: "Physical properties of large bodies in the outer solar system" — no observations requested.

0.5 nights Keck II NIRC2/LGS in 2011A: "Physical properties of large bodies in the outer solar system" returned for reallocation.

10 hours Gemini NIRI (queue) in 2011A: "Physical properties of large bodies in the outer solar system" — no observations requested.

0.5 nights Keck II NIRC2/LGS in 2011B: "Physical properties of large bodies in the outer solar system" returned for reallocation.

2 hours Subaru/SuprimeCam: "Rapid followup of important solar system discoveries from Pan-STARRS" — cancelled due to coolant leak.

Executed programs:
5 hours CFHT Megaprime in 2010B: "Rapid followup of important solar system discoveries from Pan-STARRS" — this observing time proved to be critically important to the PS1 NEO effort on January 30 UT, 2011, on which 19 NEOs were discovered, including 2 Potentially Hazardous Asteroids. CFHT was used to confirm 13 of the 19 discoveries. Weather on the US mainland was very poor, making followup in Hawaii critically important.

3.5 hours CFHT Megaprime in 2010B: "Search for fragments of 2008 TC3" — no fragments were found, but a new NEO that is possibly a member of an NEO family was discovered. This is still being investigated by collaborator Shinsuke Abe. No NEO families are presently known, so this would be an important discovery, and would show that part of the NEO population consists of fragments of larger parent bodies that have been broken up either by collisions or spin-up.

5 hours CFHT Megaprime in 2011A: "Rapid followup of important solar system discoveries from Pan-STARRS" — this observing time has been critical for followup of many NEO candidates, and was used to confirm 5 comet candidates, and 6 Centaurs. One of the PS1 comet discoveries, C/2011 L4, will likely become a major comet, and should be visible to the naked eye in 2013.

Future:
10 hours CFHT Megaprime in 2011B: "Rapid followup of important solar system discoveries from Pan-STARRS"

6 hours CFHT Megaprime in 2011B: A search for large undiscovered NEOS at low solar elongation. This cannot be executed optimally because CFHT did not schedule Megaprime at all during October, which was the ideal month. It will be carried out at somewhat reduced effectiveness in another month.

10 hours Gemini GNIRS (band 3 queue) in 2011B: "Physical properties of large bodies in the outer solar system" — no observations requested so far.

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.

Detection of Earth-impacting asteroids with the next generation all-sky surveys, P. Vereš, R. Jedicke, R. Wainscoat, M. Granvik, S. Chesley, S. Abe, L. Denneau, T. Grav, Icarus, 203, 472 (2009)

Lighting and Astronomy, C.B. Luginbuhl, C.E. Walker, and R.J. Wainscoat, Physics Today, December 2009, p. 32.

The impact of different light sources, including LEDs, on astronomy, Richard J. Wainscoat and Elizabeth Alvarez del Castillo, 2009, in CIE Selected Papers, CIE Light and Lighting Conference, Budapest (refereed paper)

Supernova 2009kf: An Ultraviolet Bright Type IIP Supernova Discovered with Pan-STARRS 1 and GALEX, Botticella et al., The Astrophysical Journal Letters, Volume 717, Issue 1, pp. L52-L56 (2010). [PS1]

GALEX and Pan-STARRS1 Discovery of SN IIP 2010aq: The First Few Days After Shock Breakout in a Red Supergiant Star, Gezari et al., The Astrophysical Journal Letters, Volume 720, Issue 1, pp. L77-L81 (2010). [PS1]

Hawaii Quasar and T Dwarf Survey. I. Method and Discovery of Faint Field Ultracool Dwarfs, Kakazu et al., The Astrophysical Journal, Volume 723, Issue 1, pp. 184-196 (2010). [Subaru]

Ultra-bright Optical Transients are Linked with Type Ic Supernovae, Pastorello et al., The Astrophysical Journal Letters, Volume 724, Issue 1, pp. L16-L21 (2010). [PS1]

The magnificent night sky—why it must be protected from light pollution, Richard J. Wainscoat, in "The Role of astronomy in society and culture," Proceedings IAU Symposium 260 (2011), eds. D. Valls-Gabaud and A. Boksenberg.

⋆ **Objective Bonus (first-author paper):** The impact of different light sources, including LEDs, on astronomy, Richard J. Wainscoat and Elizabeth Alvarez del Castillo, 2009, in CIE Selected Papers, CIE Light and Lighting Conference, Budapest (refereed paper)

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.*

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:** CFHT **Alt. telescope:** none	**Instrumentation:** Megaprime **Alt. instrumentation:** none

The typical observations required to followup PS1 discoveries will be short exposures of 60 seconds, because CFHT is a larger telescope than PS1, and because seeing on Mauna Kea is normally better than on Haleakala. The overhead for camera read is 40 seconds, and this is charged to the observer. We will normally use r band, but may use i band if the moon is bright. In all cases we will need to obtain at multiple exposures in order to identify the correct moving object. Most observations for this program will consist of four consecutive exposures, dithered slightly to cover chip gaps. This technique has been proven to be very effective. Longer exposures may sometimes be needed for objects that are moving away from Earth.

This means that a one-night observation of an object typically requires 400 seconds of charged observing time. Observations to confirm cometary activity sometimes need to be deeper to detect low surface brightness.

The total requested time will allow us to make 90 observations of this type during the semester. We expect that the number of suitable candidate observations will be well in excess of 90, and will choose the most interesting and urgent of the potential targets, as well as increasing usage when mainland recovery/confirmation telescopes have poor weather.

Scheduling these observations on the 2.2-meter telescope is not possible. Almost half of the observing time on the 2.2-meter telescope is now externally used. It is no longer possible to rely on begging short observations from colleagues, and some instruments are not suitable for NEO recovery. The wide field-of-view of Megaprime is absolutely essential for recovery of many of these objects, because we will be recovering them before any orbit has been calculated. This is particularly the case for fast moving asteroids.

Observations on CFHT will be triggered by one of the team members after verification that an automatic detection of an interesting object is real and that followup is needed. Rapid download of data from CFHT will be used to obtain morphological, photometric, and astrometric information. Marco Micheli is now employed 10% FTE by the PS1 NEO program and one of his main roles in this capacity will be to evaluate the PS1 discoveries and prepare queue observations. Dave Tholen will continue to take the lead on critical astrometric measurements; other software such as Astrometrica will be able to be used in other cases.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)

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:** Gemini **Alt. telescope:** Subaru	**Instrumentation:** GNIRS, GMOS **Alt. instrumentation:** MORICS

We request 7.5 hours for Comet C/2011 L4 (PANSTARRS) and 4 hours for additional PS1 solar system discoveries that may include a dwarf planet.

GNIRS on Gemini will be used to obtain infrared spectroscopy of the nucleus of Comet C/2011 L4. The GNIRS integration Time Calculator suggests that a signal-to-noise ratio of approximately 40 can be achieved across the JHK windows in 1 hour of integration if the nuclear magnitude is V=17. The main goal is to obtain spectra to look for signatures of crystalline ice, and volatile ices in the near-infrared for C/2011 L4, other comets (including main belt comets), and distant objects in the outer solar system. The Gemini queue is preferred because of the flexibility it affords for target(s) that are not yet discovered. We will observe C/2011 L4 at six separate epochs in 2012A, starting in February, as it approaches the Sun.

We will also obtain optical spectroscopy of the nucleus and coma of C/2011 L4. The Gemini Integration Time Calculator shows that a 15 minute exposure will yield S/N ratio of 30–60 on a V=18 nucleus across the 500–900 nm region of the spectrum. We will bin pixels away from the nucleus to obtain a spectrum of the coma.

Trujillo et al. (2007, ApJ, 655, 1172) obtained a 4 hr K-band, 1.3 hr H-band and 1.7 hr J band spectrum of 2003 EL_{61} (Eris) which has V=18.7. Their spectra have more than adequate signal-to-noise ratio to show the presence of crystalline ice. GNIRS allows J, H, and K-band spectra to be obtained simultaneously, making the observations we require much more efficient. We will target any newly discovered KBOs with similar brightness but will not target fainter objects because of the difficulty of the observation. If we discover bright Main Belt Comets (see Kleyna proposal), we will use the same system to obtain IR spectroscopy of the MBCs. No IR spectra have ever been obtained for MBCs.

The queue on Gemini makes GNIRS our preferred instrument. MOIRCS on Subaru is a good alternative if Gemini is heavily oversubscribed, but it only records the J and H windows simultaneously, and is not queue scheduled. We ask that our proposal be considered for observations on Subaru in case the 11.5 hours requested cannot be scheduled in bands 1 or 2 on Gemini.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)
B	C/2011 L4	17h00m	-24	March
B	C/2011 L4	15h15m	–25	July

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:** CFHT **Alt. telescope:** none	**Instrumentation:** Megaprime **Alt. instrumentation:** none

We will use 60 second exposures with the r filter to search for large NEOs at low solar elongation. An overhead of 40 seconds is charged for each exposure, and we need 3 images to search for moving objects. This means that one square degree can be imaged in 300 seconds. Trailing losses mean that longer exposures do not go deeper.

Although CFHT has a smaller field of view than PS1, it has the following advantages or this work:

- Image quality is better. Mauna Kea is higher than Haleakala, and seeing is consistently better. This is particularly important for these observations that will be obtained at relatively high airmass. CFHT also has better intrinsic image quality, because its optical system is less complex. We will request that our observations are acquired as 45 minutes per night in better than average seeing. For the night of Oct 1, these observations would span 04:30–05:15 HST, with altitude ranging from 34 to 45 degrees for 60 degrees solar elongation on the ecliptic. We do not plan to go closer to the Sun than 60 degrees.
- CFHT has more than four times the collecting area of PS1. Although CFHT's diameter is exactly twice that of PS1, vignetting in PS1 is substantial. Although PS1 has a *w* filter that gives is a substantial gain in sensitivity, the *w* filter is not well suited to high airmass, because atmospheric dispersion worsens image quality, and because the shorter wavelengths of 400–550nm in the *w* filter have substantially worse seeing than the r band.
- It has a much higher fill factor, close to unity, compared to approximately 0.7 for PS1.

We estimate that these factors will combine to deliver a 2-magnitude gain in sensitivity over PS1.

In one night we will therefore image a total of 9 square degrees in 45 minutes. In 5 hours, we can therefore cover 60 square degrees, or about one fifth of the sweet spot area within 10 degrees of the ecliptic. We request one additional hour for followup of the near-earth asteroids that we discover — these objects will be faint and therefore difficult for some of the mainland NEO recovery telescopes.

A large Near Earth Asteroid with an H magnitude of 18 (1 km size) at a distance of 1AU will have an approximate V magnitude of 22 at 60 degrees solar elongation. This is within reach of CFHT, but not within reach of PS1.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)

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:** Subaru **Alt. telescope:** none	**Instrumentation:** Suprime Cam **Alt. instrumentation:** none

The technical justification for Subaru (Run 4) is similar to that for CFHT (Run 3). We are specifically requesting 1 hour on two consecutive nights at the beginning or end of night at a time that there is minimal interference with the main scheduled program - e.g., if the principal target has set at 4 a.m.

As with CFHT, exposure times will be 60 seconds. Read time is slightly longer at Subaru. Suprime Cam/Subaru offers an aperture that is 5 times as large, but with an imaging area approximately one quarter that of CFHT. Etendue is similar, but Subaru has better image quality. CFHT was chosen as the principal telescope for this investigation because its queue scheduling is more appropriate for the type of observations we are proposing.

We will use the r filter. We expect that Subaru will go approximately one magnitude deeper in the same exposure time as CFHT, but the area covered will be slightly less than one quarter the area that CFHT can cover in the same integration time.

The Moon must be down for these observations. Crescent and quarter moons are generally very close to the sweet spot, making the observations impossible. Three observations will be obtained of each field. We will image an area of approximately 2.5 deg^2 in 1 hour on the first night. We will use the 1 hour on the second night to obtain followup observations of the NEO candidates that we discover on the first night.

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

Program	**Object**	**RA** (h,m)	**Dec** (deg)	**Mag** (specify band)

STATUS OF THESIS WORK

This section is mandatory for all students.

Which of the programs listed on Page 1 are part of an approved thesis *(ABC, none)*? ☐

Title:

Advisor:

List of all approved observing runs: telescope/instrument, time allocated, dates, percentage of useful time, status of data reduction, relation to thesis work. Include approved runs for the upcoming semester.

Run no.	Telescope	Instrument	Allocation	Dates (mo/yr)	% useful	Reduced?	Thesis work?
1							
2							
3							
4							
5							
6							
7							
8							
9							

For additional runs append a separate sheet.

Provide a brief progress report. Please comment about the quality of the data obtained.

Provide a timeline for this project. Estimate the total amount of future telescope time that will be requested.

Program A—Rapid Followup of PS1 discoveries

This proposal requests observing time for rapid followup of some of the most interesting new solar system objects discovered by Pan-STARRS 1. A broad spectrum of science will be covered. The unifying property of the observations requested in this proposal is urgency, and the need for rapid followup observations. The observations proposed here will lead to some of the most highly visible discoveries by Pan-STARRS, and are critically important for continued funding of the Pan-STARRS project from the NASA Near Earth Object program.

PS1 has discovered 140 Near Earth Asteroids including 10 Potentially Hazardous Asteroids so far in 2011 (despite very poor weather), and detects a higher fraction of large (i.e., more hazardous) Near Earth Asteroids than the other surveys, due to its depth. A discovery rate of 30 NEOs per month was achieved in September 2011, and is expected to be sustained (weather permitting) and improved upon.

The observing time we have had on CFHT has been critically important for followup of NEO candidates discovered by PS1. We used it to confirm 5 comet discoveries, including Comet C/2011 L4 (PANSTARRS) which may become a major comet and should be visible to the naked eye in March 2013. CFHT was also used to confirm 6 Centaur discoveries, more than half of the Centaurs discovered by all telescopes so far in 2011.

We presently receive approximately $1 million per year from NASA's NEO program, and approximately half of this is used to pay for PS1 operating costs. It is very important that a high NEO discovery rate from PS1 is sustained in order to maintain this funding. Access to CFHT for followup observations is critical.

Automated processing of images by IPP and MOPS: The PS1 Image Processing Pipeline (IPP) processes data soon after it is acquired. The IPP produces a list of transient sources for the Moving Object Processing System (MOPS), along with additional useful parameters such as aperture and PSF magnitude (from which fuzziness of a moving object can be determined), and shape information. MOPS produces tracklets (sequences of observations) from the transients it ingests from IPP. PS1 observes the same field four times, and three or four detections with common motions are linked into a tracklet. Many NEOs can be identified from their motion in a tracklet from one night, but subsequent observations are needed with other telescopes on later nights to determine the orbit. Typical signatures of NEOs include fast motion, or prograde motion at opposition.

This proposal seeks observing time for rapid followup of moving objects that are seen to be unusual and important. Web pages have been created for inspection of NEO and comet candidates. Screening of these objects is now being done carefully using postage stamp images of the moving objects. False detections have decreased, but careful screening by astronomers remains essential to extract the real objects.

Newly discovered comets: Pan-STARRS has become an important comet discovery telescope. A total of 5 comets have been discovered to date. There is a 15% chance each year of PS1 discovering a major comet (e.g., Comet Hale-Bopp). We must immediately report these important discoveries in order to claim "discovery," but we must not "cry wolf."

Many comets are recognizable from one night's observations alone. Clear indicators of cometary activity include evidence of a coma and/or tail, and anomalous orbital motion. We must use other telescopes for followup. Megaprime is the ideal choice, because of the queue operation, good image quality, and large field-of-view. Obtaining higher resolution images is key to confirming the non-point source nature of the suspected comet.

Rapidly moving asteroids: Any asteroid moving fast enough to leave a trail in a PS1 3π survey image is very likely a Near Earth Asteroid. We have a good chance of discovering another 2008 TC_3 type impactor (Jenniskens et al. 2009). The discovery will be much more meaningful if it can be confirmed, an orbit established and other followup observations obtained before impact. We are also likely to find many objects that have near misses. Many of these will be larger than 2008 TC_3, and so can be discovered many days before closest approach.

Objects that pass very close to Earth have a higher likelihood of impacting Earth in the future, making these of particular interest. A fast moving object discovered in one night may be completely missed in the future PS1 observations. In fact 2008 TC_3 was discovered only 20 hours before it hit Earth. PS1 should be able to discover an object the size of 2008 TC_3 at greater distances—at least 2 days out. The motion of impactors as they get closer to the Earth becomes dominated by topocentric motion (due to Earth's rotation). Recovery of a fast moving asteroid requires a large field of view to overcome uncertainties in position.

MOPS can now detect asteroids with motions of up to 4 degrees per day. Asteroids with such fast rates of motion have high positional uncertainty one day later, and only CFHT is capable of recovering them one day later. Asteroids with prograde (eastward) motion are close enough that their apparent motion overwhelms topocentric motion from Earth rotation and motion from the Earth around the Sun, and positional errors for these objects also requires the large field of view to recover them one day later.

Main-belt comets: MBCs have main-belt type motion, but exhibit a tail or coma. Detailed followup of main-belt comets is the subject of a separate proposal by Kleyna.

Asteroid collisions—Measuring the size-frequency distribution of 10–100 meter main belt asteroids: We will obtain observations of candidate collisions between Main Belt asteroids (only two have been identified) to 1) verify their collisional/transient nature (by monitoring their brightness: we should see them expand and fade away with time) and to 2) obtain surface photometry to measure the expansion properties of the residual dust cloud. Jewitt et al. (2010) reported the first detection of an asteroid disruption by collision; (596) Scheila is the second.

We have not yet detected good candidate events. Access to the modest amount of observing time requested in this proposal will allow us to pursue the best candidates and report in the future whether false positives are an issue. We stress that detection of collisions in the asteroid belt has tremendous scientific value. The size frequency distribution of the smaller asteroids is closely related to the number of impactors that are hitting the Earth, ranging from 4-meter 2008 TC_3 up to 100-meter or larger objects that would have much more serious consequences.

Summary: The PS1 survey will discover many new important solar system objects. A modest amount of observing time is requested for followup observations of some of the most important of these objects. These observations will yield astrometry, orbits, and confirm the nature of these important objects. The objects that will be discovered will be among the most important early PS1 discoveries. The NEO work that is described here is of critical importance for NASA NEO funding of Pan-STARRS 1 operations, and for PS2 construction.

The NEO discoveries by PS1 made to date hint at two possibly important results:

1. Mainzer et al. (2011) claim that the Spaceguard congressional mandate for NASA to find 90% of NEOs with size > 1 km has been achieved (911 of 981 discovered). PS1 has increased the discovery rate of > 1 km objects to $\sim$35/year, which if sustained is in direct conflict with this claim.

2. Claims of a deficiency of $H \simeq 23$ asteroids relative to a power law by Harris (2008) based on number/size distribution of NEOs appear to be in conflict with the number/size distribution of PS1 NEOs discoveries.

Searches for NEOs have tremendous biases. These preliminary results have tremendous consequences for the danger from NEOs, and if confirmed, significantly increase the danger to Earth from NEOs. After about 1 more year of surveying, we will be able to make these claims with a more statistically robust basis.

Program B—Properties of new PS1 discoveries including Comet C/2011 L4

Comet C/2011 L4 (PANSTARRS) may become the brightest comet since Comet Hale-Bopp in 1996. It is presently just under 7AU from the Sun, is showing considerable activity, and is growing brighter faster than predicted. It is now moving close to the Sun in the sky, but it will become observable again in February 2012.

The targets of all spacecraft encounters with comet nuclei have been short period comets. This will be true in the future as well, since these are the only comets whose orbits we know well enough to plan to visit them with spacecraft. The surface and near-surface materials of these comets have been "baked" by multiple perihelion passages. This means that we have never seen or obtained spectra of a pristine nucleus.

To do so we need ground-based studies of a large, potentially bright Oort cloud comet when it is far enough from the Sun that its nucleus is not totally hidden by a coma. Comet C/2011 L4 affords us just such an opportunity.

We propose to obtain near-IR spectra of this comet as it approaches the Sun, beginning when the comet is at 5.7 AU. Since we don't know the albedo of the nucleus we cannot make an accurate calculation of its surface temperature. Baked out nuclei are the darkest objects in the solar system, with albedos of typically $A = 0.04$, similar to the albedo of the dark side of Iapetus. Our expectation is that a pristine nucleus will have a higher albedo from frozen volatiles on its surface, principally ices of water and CO_2. The extreme case of an ice + dirt object would be Jupiter's satellite Callisto, with $A = 0.2$. Within this range of albedos, the surface temperature of a comet nucleus at 5 AU should be approximately 100 K, well below the sublimation temperature of water ice. This is important as we want to obtain a spectrum of water ice on the nucleus. Activity — especially significant activity — beyond about 5–6 AU is not driven by water ice sublimation, but instead by more volatile molecules such as CO or CO_2, or by processes such as amorphous to crystalline ice transition (Meech 2009).

C/2011 L4 will move from 5.7 AU from the Sun in February to 3.7 AU from the Sun in July. Fig. 3 of the complementary proposal by Yang shows how activity is believed to change as a comet approaches the Sun. It is important to understand what drives comet activity as a function of distance in order to understand what is an evolutionary effect, and what is primordial. Solar system formation models are changing rapidly. New solar system architectures may alter our beliefs of where comets formed; understanding primordial chemistry and how comets evolve may place constraints on these models. The search for surface ice will tell us first of all if there really should be a paradigm shift from thinking of comets as dirty snowballs, i.e., objects dominated by ice, to regarding them as icy dirtballs, a description based on observations of short period, baked out comet nuclei. The answer affects attempts to infer what comet impacts actually brought to the inner planets.

C/2011 L4 is likely a dynamically new comet making its first pass close to the Sun. It is a large comet. Because of its size and predicted brightness, we have an unprecedented chance to look at the chemistry now. Is CN coming off now? Is it CO rich? Both of these questions can be addressed using optical spectroscopy. Is there a large swarm of ice chunks that can be detected through near-infrared absorption at 1.5 and 2 microns? Fig. 4 of Yang's proposal shows a near-IR ice spectrum from Eris (from Trujillo et al. (2007)).

No one has ever convincingly detected amorphous ice in a comet. It would be seen as a subtle 1.65 micron feature in the H band. With a high enough signal-to-noise ratio, it should be visible, and detection of it would be a spectacular result — many believe it ought to be there in the nebula. At 137 K ice undergoes an irreversible transition from amorphous to crystalline ice (squeezing out trapped other gases) and this can cause activity long before water sublimates at 180 K. However, cosmic rays can re-amorphize ice. There are no detections of ice from the ground in comets. Davies et al. (1997) claim to have detected amorphous ice in Comet Hale-Bopp using CGS4 on UKIRT, but that result is not widely believed. GNIRS on Gemini is much better suited to this observation.

We intend to watch the evolution of gas species seen through optical spectroscopy as heliocentric distance decreases. We will also search for water ice absorption from large chunks using near infrared spectroscopy. We will also search for other possible condensed volatiles, especially CO_2. Solid CO_2 has been found on satellites of Uranus and most prominently on Neptune's Triton, where solid CO, CH_4 and N_2 have also been detected. Commonly accepted ancient lore suggests that the Oort cloud comets formed between Uranus and Neptune. Thus we could expect the pristine nuclei to contain these same ices.

Our present intent is to devote 7.5 hours of observing time to spectroscopy of C/2011 L4, which will comprise of 1 hour for infrared spectroscopy and 0.25 hours for optical spectroscopy at 6 separate epochs — once per month in the semester starting in late February. After July, the comet heads to the south and will be difficult to observe from Mauna Kea before perihelion.

We intend to primarily use the cross-dispersed mode of GNIRS that delivers spectra in the JHK windows simultaneously. A complementary proposal is being submitted by Yang for H- and K-band long-slit spectroscopy of the nucleus and coma with MOIRCS on Subaru in the later part of 2012A when the comet is more active.

We intend to use the remaining 4 hours of observing time that we are requesting for spectroscopy of other PS1 discoveries. However, if the results for C/2011 L4 are spectacular, we would like to be able to devote the entire 11.5 hours requested to C/2011 L4.

An example of another likely PS1 discovery for which we would obtain spectroscopy is the discovery of a new dwarf planet in the outer solar system (*e.g.* Brown et al. 2005). The spectroscopically determined composition of these bodies will provide insight into the solar system's formation. We will use near-infrared spectra to understand the distribution of crystalline water ice and volatile ices in the outer solar system.

Program C—A search for large undiscovered NEOs at low solar elongation

Congress has mandated that NASA discover most ($> 90\%$) of the large (1 km or larger) Near Earth Objects. We believe that in excess of 100 1 km NEOs remain undiscovered despite the claim of Mainzer et al. (2011), and that the congressional mandate has not yet been met (see Figure 1). Opposition surveys have made substantial progress towards the goal, but have failed to see objects like 2011 BQ_{50}, which has q=0.857 AU and Q=1.044 AU. 2011 BQ_{50} spends most of its time interior to the Earth, and seldom passes through the opposition region.

The "sweet spots" are the regions between 60 and 90 degrees solar elongation and within 10–20 degrees of the ecliptic where asteroids like 2011 BQ_{50} spend a substantial portion of their orbit. We are much more likely to find this type of asteroid in the sweet spot than at opposition. Because the sweet spots are close to the Sun, they must be observed immediately after evening twilight, or immediately before morning twilight, and must be observed at relatively high airmass. The high airmass causes higher background, increased extinction, and poorer seeing. The phase angle at which the asteroid is viewed causes substantial dimming relative to opposition.

PS1 comes tantalizingly close to the sensitivity needed to detect large NEOs in the sweet spots: on exceptional nights we discover NEOs in the sweet spots, but in lesser conditions, we discover none. PS1 has not yet discovered NEOs at the lower solar elongations near 60 degrees that should be rich with NEOs because that line of sight has a very high cross section with NEO orbits.

We propose to image about 1.5 times the area of a PS1 "chunk" approximately 2 magnitudes deeper than PS1 as a continuing experiment to probe fainter in the low solar elongation sweet spot. We expect to make a significant number of NEO discoveries, including a few large objects. Because of the low fill factor of PS1, the effective area that we will cover with CFHT will be actually be approximately 2 PS1 "chunks."

Asteroids with $H = 18$ (1 km diameter) 1 AU from us at solar elongation of 60 degrees have $R \sim 22$. This is within the reach of CFHT, but beyond PS1's current capability. Malhotra et al. (2011) suggest that Earth's L4 and L5 Lagrange points may harbor a substantial inventory of asteroids, and that leakage of these asteroids can explain asymmetry in cratering on the Moon. Our search will be very sensitive to Earth Trojans (one was recently discovered), and will place limits on how many Trojans can exist.

In the future, we hope to continue this experiment with HyperSuprimeCam (HSC) on Subaru. HSC has a field of view of approximately 1.75 square degrees and Subaru has is over 5 times as large. Subaru can go considerably deeper, and therefore see 1 km size asteroids further away. We request two consecutive one-hour periods adjacent to twilight with Subaru to further this experiment to even greater depth. We will use simple software developed by Kleyna for detection of moving objects, and also have software developed by Gladman and Kavelaars for CFHT data. Processing nine fields per day is easily manageable with existing NEO computer hardware.

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Figure 1: Plot of number of NEOs versus diameter.