OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term⋆

Rapid-response Characterization of Near Earth Objects with UKIRT/WFCAM

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Abstract of Scientific Justification

Near Earth Objects (NEOs) are bodies whose orbits bring them close to the Earth's orbit. They originate elsewhere in the Solar System and are dynamically delivered to near-Earth space. Hence, NEOs act as compositional tracers of the flow of material in the Solar System, and act as downstream probes of processes in the main asteroid belt and elsewhere in the Solar System that can be probed in no other way. Surprisingly, the properties of large (∼1 km) NEOs and meteorites (the end state of some NEOs, after impacting the Earth) have significant differences. We propose here a **rapid response program to characterize small NEOs** to determine the nature of this transition in properties, and to connect these two populations. NEOs are typically discovered around V∼21 but then can fade very rapidly, up to a magnitude per week or more. Immediate followup is the only way to characterize these objects, particularly for the many NEOs whose synodic periods can be years or decades. This experiment can only be carried out with a sensitive facility (WFCAM/UKIRT) with a rapid response (less than ∼24 hour turnaround) capability. Data from our WFCAM/UKIRT project in 2014A+B demonstrate that we can characterize faint NEOs that no other facility can reach. We have also initiated a complementary program using RATIR and the San Pedro Mártir 1.5m telescope. We are on pace to characterize **hundreds of NEOs per year**. The majority of our targets will be smaller than 100 meters, and we will increase the number of bodies in that size range with taxonomic identifications by nearly a **factor of ten**. This multi-institutional UKIRT partnership (NAU, UA, ASU, UH) puts us at the forefront of this exciting field. We have submitted a NASA funding proposal that would continue our support of this work.

Summary of observing runs requested for this project

								Scheduling		Sharing	
Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Optimal	Acceptable	Poss.	Adv.
1	UKIRT		WFCAM			7	bright	Jan–Jul	Jan–Jul	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: Observations to be carried out in the queue. We propose for 70 hours (roughly, 10 hours or one night per month of January–July). The observations will be triggered and executed throughout the semester.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	2014 ST223	$\sim$23:45	$\sim$+21	V $\sim$ 21.2, $\sim$8 m
2	2014 SX141	$\sim$00:15	$\sim$+02	V $\sim$ 20.0, $\sim$70 m
3	2014 SR223	$\sim$00:40	$\sim$+04	V $\sim$ 21.2, $\sim$12 m
4	2014 SS223	$\sim$01:30	$\sim$-11	V $\sim$ 21.4, $\sim$15 m
5	2014 SU141	$\sim$02:10	$\sim$-17	V $\sim$ 20.5, $\sim$150 m
6	2014 SY141	$\sim$02:55	$\sim$-03	V $\sim$ 21.1, $\sim$50 m
7	2014 SS143	$\sim$05:40	$\sim$-18	V $\sim$ 20.3, $\sim$10 m
8				
9	This representative target list is generated			
10	as if we were observing *tonight*, to			
11	demonstrate our target selection pipeline.			
12	All these targets were discovered in the last			
13	two weeks. Usually only one or two objects			
14	will be queued per night.			
15				
16	Note that 4/7 objects are smaller than $\sim$20 meters			
17	and still have V$<$21.5, which shows that our			
18	rapid-response technique allows us to measure			
19	the compositions of very small asteroids.			
20				
21	*No other program is capable of routinely measuring*			
22	*asteroid compositions in this size range.*			

Approval for Instrument Use from PI: ______________________

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

Graduate students *(provide the following information for **each** student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on **all** submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

Near Earth Objects (NEOs) are asteroids whose orbits bring them near the Earth's orbit. NEOs bridge the gap between meteorites here on Earth and more distant small body populations throughout the Solar System. Since they come close to the Earth we can study NEOs with ground-based telescopes, in analogy to sending spacecraft throughout the Solar System for *in situ* exploration, but at a small fraction of the cost. Measuring the physical and chemical diversity of NEOs can therefore help us to understand processes of planetary formation and evolution throughout the Solar System. Currently, the majority of asteroid types remain unlinked to specific meteorite groups, and there are fundamental discrepancies between these populations (e.g., Vernazza et al. 2008). These discrepancies may be a consequence of observational bias towards the largest asteroids. A statistically significant sample does not yet exist to determine whether small NEOs are more closely related to meteorites. The distribution of spectral types in the NEO population is unknown at sub-km sizes. This is important for interpreting the relative efficiency in which different source regions in the Main Belt produce NEOs and meteorites. This project will help will determine whether there are spectral trends associated with the overall NEO size distribution and will provide spectroscopic insight on the apparent prevalence of high albedo NEOs at low inclinations (Mainzer et al. 2012).

The most effective way to measure NEO compositions is through spectroscopy, but this is very expensive (requires a lot of telescope time), and is only possible for relatively bright objects. The vast majority of NEOs observed each month are too faint for spectroscopy except with large amounts of time on the largest telescopes. However, near-infrared photometry can be used to assign NEO taxonomies (Figure 1), and such taxonomies correspond well to NEO compositions (e.g., Thomas et al. 2014). Hence, NIR photometry is a quick and easy way to measure the compositions of a large number of NEOs in a relatively small amount of medium-aperture telescope time.

We propose here 70 hours of UKIRT/WFCAM time to characterize ∼75 Near Earth Objects with near-infrared photometry. With these observations we will measure the overall composition of small Near Earth Objects, which will have a wide range of implications. These observations are most efficiently carried out over many nights in the queue. This is a multi-partner proposal, with all of NAU, UA, ASU, and UH proposing this work. This project is complemented by our ongoing program at San Pedro Mártir. We are on pace to characterize hundreds of NEOs per year. The majority of our targets will be smaller than 100 meters, and we will increase the number of bodies in that size range with taxonomic identifications by nearly a factor of ten.

The data from this proposal will be used to test the soon-to-be-released "Granvik NEO" model (CoI Jedicke is a co-author) that makes specific predictions about the main belt sources of the NEOs as a function of size. Testing this model requires a large, well-controlled sample of taxonomically identified NEOs as we propose here. We can not perform this study with existing taxonomic information on NEOs because that data is derived from many sources (instruments), with different and uncontrollable sensitivities and selection effects. In this program, we will obtain data for a large number of NEOs down to small sizes. (Larger NEOs that are not otherwise observed and characterized will also be observed in this program.) This regular and rapid-response program will allow us to observe targets throughout the semester. We will take special care to measure the observational selection effects to allow us to debias our measured taxonomic distributions.

In 70 hours (as proposed here — nominally one night per month), we can observe ∼75 NEOs. Between this UKIRT project and our ongoing complementary project at San Pedro Mártir, we expect to characterize ∼250 NEOs per year. For context, there are about 11,000 known NEOs, of which several hundred have known spectra. At present, there are around 300 NEOs smaller than 500 meters with existing spectoscopic data. There are around 150 NEOs smaller than 250 meters with existing spectroscopic data. Essentially all of our newly measured NEOs will be smaller than 500 meters, more than doubling the number of small NEOs with taxonomic identifications. Around 75% of our targets will be smaller than 100 meters, increasing the number of bodies in that size range with taxonomic identifications by nearly a factor of ten (Figure 2). This is a very efficient, world-leading technique to characterize a large number of very small NEOs.

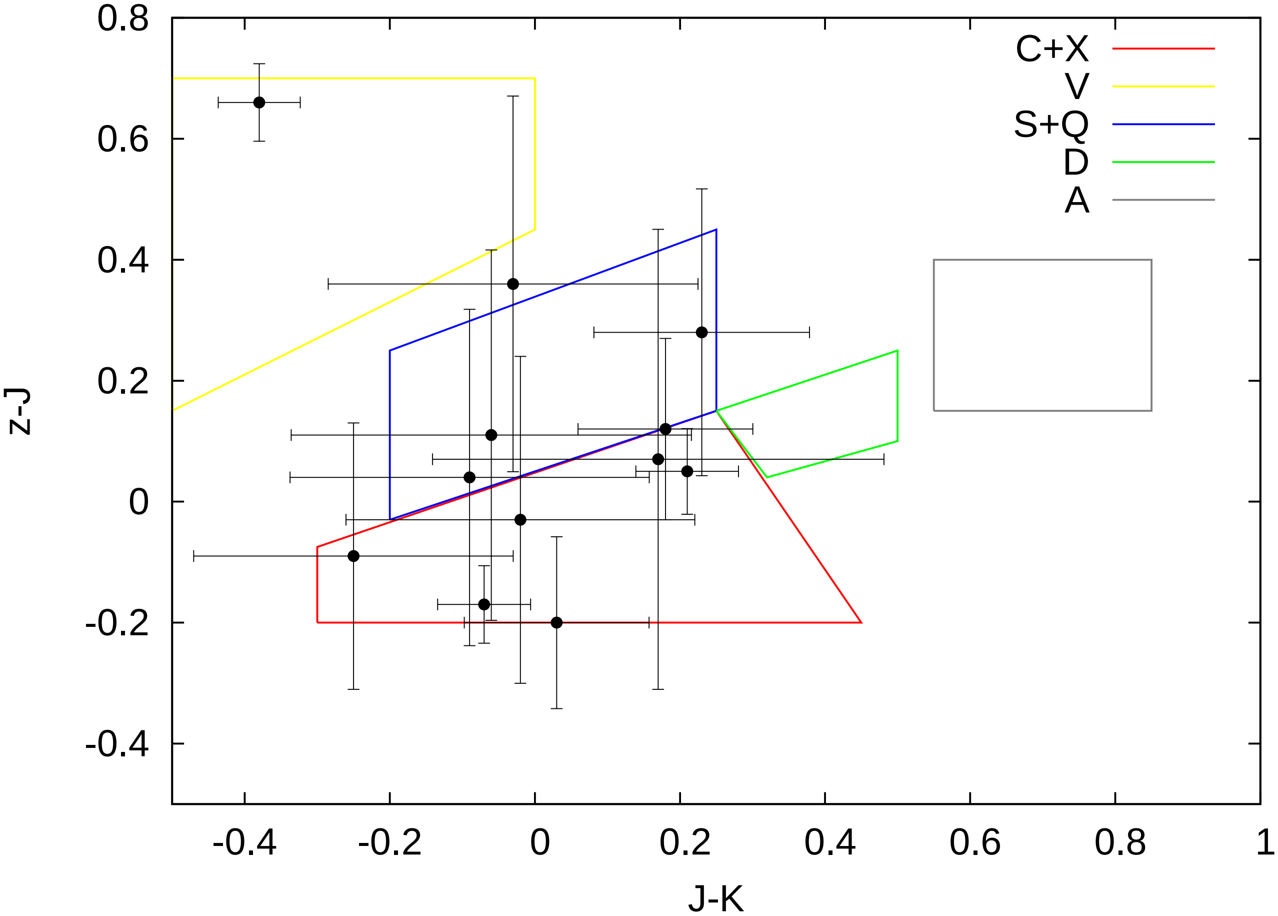

Figure 1: Color-color figure for NEOs, showing that zJK color photometry allows us to classify NEO taxonomies (C, S, V, etc.), which correspond to NEO compositions. The colored regions are derived empirically from known NEO spectra. The data points are from our 2014A UKIRT data. The points with large error bars are from early in the semester when we were still refining our exposure times. The points with small error bars (example: upper left) show our more recent results, based on our experience in the first part of the semester.

References:

Mainzer et al. 2012, ApJ, 752, 110

Thomas et al. 2014, Icarus, 228, 217

Vernazza et al. 2008, Nature, 454, 858

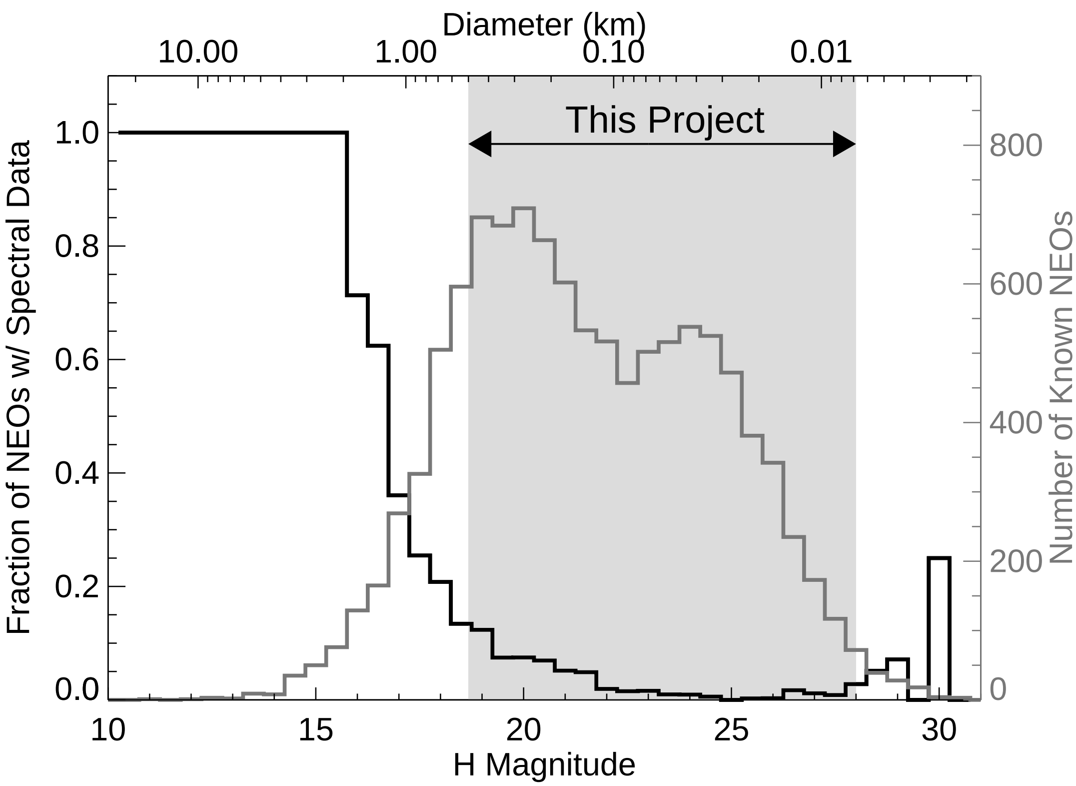

Figure 2: Left axis: Fraction of known NEOs with any form of spectral data as a function of size. No spectral information is available for the vast majority of NEOs smaller than 500 meters. (Note that the spike at H=30 is real and represents concerted community efforts to observe these very small objects soon after discovery; there are only a handful of objects known at that size.) Right axis: The number of known NEOs as a function of size. Most known NEOs — and most new NEO discoveries — are objects smaller than 500 meters. Both axes: The shaded region indicates objects that we will study in this program. These are objects smaller than 500 meters; many of our targets will be smaller than 100 meters. The bottom axis is the Solar System absolute magnitude, H, and the top axis shows diameter.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

We were awarded 42 hours in 2014A and 60 hours in 2014B for this project. 100% of our 2014A time has been used to observe 45 NEOs. (Our 2014B time will begin in early October when WFCAM returns to the telescope.) The faintest target we have observed had V$\approx$21.5. There is a substantial delay in getting processed data from CASU (Cambridge Astronomical Survey Unit), but all the data that we have received (about 20 targets) has been completely reduced (Figure 1). All of the software tools necessary for target selection, MSB preparation, and data analysis exist and work well.

Most NEO observations are made by the Catalina Sky Survey (CSS) and Pan-STARRS. Both surveys reach roughly V$\sim$21.5 across their survey areas (thousands of square degrees per night). Each survey detects 5–10 NEOs per night; most of these are close to the detection limit. Both surveys report their NEO observations to the IAU's Minor Planet Center (MPC) each night. NEOs are typically discovered at closest approach to Earth (when they appear brightest) and can fade very rapidly as they recede from the Earth, up to a magnitude per week or more. Immediate followup is the only way to characterize these objects, particularly for the many NEOs whose synodic periods can be years or decades. On a daily basis we select those targets that have been recently discovered and can be observed. *There is no other NEO characterization program that can rapidly respond and reach targets with V=21.5, where most NEOs are found.*

We have created a sophisticated tool that allows us to carry out automated target selection for NEO characterization observations. Each day we query the MPC database for all NEOs and NEO candidates. We predict position, apparent magnitude, etc., of each target on the next night. We select targets based on visibility constraints, apparent brightness, airmass, and recent discovery date, and require that the positional uncertainty be significantly less than one WFCAM FOV. From the list of observable NEOs, we select the brightest targets and automatically create one MSB (minimum schedulable block) per target. The observation plan (total integration time per band, dither patterns, etc.) is assigned based on the target's apparent brightness. The ephemeris for each target is taken from the latest JPL `Horizons` orbit solution on the same day as the observation. MSBs are uploaded into the queue on a daily basis. Each MSB is active only for one day, in order to provide the latest ephemeris for each target. Our targets are almost always observed on the night after appearing in the queue (i.e., within 18 hours of MSB submission). This automated pipeline requires a minimum of human interaction and provides a fast response in observing newly discovered NEOs.

Asteroids typically have V-J$\approx$2, z-J$\approx$0, and and J-K$\approx$0 (Figure 1). Hence, our typical asteroids will have z$\sim$J$\sim$K$\sim$19.5. Our experience shows that we can reach SNR=10 in 15 minutes total, including overhead, on a V=20 target. This is similar to the performance predicted by the exposure time calculator (seeing 0.9 arcsec, airmasss 1.2, average sky brightness). For V=21.5, SNR=10 observations require 30 seconds in z, 90 seconds in J, and 1200 seconds in K, for a total of about 30 minutes, with reasonable assumptions for overheads (30% of observation time, as used by UKIRT). Our experience shows that on average our targets require just under an hour of allocated time. Hence, we can observe 75 targets in the requested 70 hours. All observations will consist of dithered 10 sec frames in the moving frame of the target. Experience shows that this allows for proper photometric calibration using background sources even for the fastest NEOs. We will intersperse short J-band observations (JzJKJKJ) to characterize and minimize lightcurve effects. We will use on-chip 2MASS standards to enable accurate colors in *any transparency conditions except thick clouds. Seeing better than 1 arcsec is preferred, but conditions with seeing as poor as 1.5 arscec (or perhaps worse) are still usable,* by sacrificing the faintest objects on our target list, or by increasing the total integration times for each object and observing fewer objects. WFCAM's relatively large FOV will help us recover and observe objects with uncertainties of (many) arcminutes, which should include almost all NEOs on our target list. Based on our experience, as well as discussions with the instrument and data reduction scientists, we apply a dither pattern (3.2$''$) for all observations, with the target being placed on WFCAM camera 3, which provides the best sensitivity and detector homogeneity.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

In 2014A we were allocated 42 hours and observed 45 NEOs (project completion rate 100%). The faintest UKIRT target had a V brightness of 21.5. All of the software tools necessary for target selection, MSB preparation, and data analysis exist and work well. There is a substantial delay in getting processed data from CASU, but all the data that we have received (about 20 targets) has been completely reduced. In 2014B we were allocated 60 hours. The observations will begin in early October once WFCAM is available. We expect to observe around 60 NEOs in 2014B. The first paper for this project will be submitted by the end of 2014.

We expect to continue to propose for this project at the level of $\sim$10 hours/month for the next 2–3 years, at which time this program will be the largest NEO compositional study by far, and will have increased the number of small asteroids with known compositions by a factor of fifty or more.

In 2014B we were awarded 30 hours with RATIR on the San Pedro Mártir 1.5m telescope for this project. Observations have recently begun, and we are fine-tuning the target selection process, dither patterns, and other steps with these first targets. The RATIR automatic data reduction pipeline has been modified to produce photometry of our moving object targets, so processing and reduction of the data is complete by early on the next morning.

We have submitted a funding proposal to NASA that would continue the support of this project over the next few years.

This project is closely related to MANOS, the Mission Accessible Near-Earth Object Survey; the PI of MANOS is Nick Moskovitz, CoI on this proposal. MANOS is an NOAO Survey project that observes NEOs every month on a range of NOAO telescopes and which is funded by NASA's Near Earth Object Observations program. The compositional characterization of MANOS is dominated by Gemini/GMOS spectra, typically of objects with V<20. Thus, the objects observed in this program will be fainter than those generally accessible to MANOS. We will coordinate targets between this UKIRT (and RATIR) project and MANOS.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). **(up to one page)***

⋆ (1) This is third semester that we are proposing for this project. In 2014A we were allocated 42 hours and observed 45 NEOs (project completion rate 100%). The faintest UKIRT target had a V brightness of 21.5. All of the software tools necessary for target selection, MSB preparation, and data analysis exist and work well. There is a substantial delay in getting processed data from CASU, but all the data that we have received (about 20 targets) has been completely reduced. In 2014B we were allocated 60 hours. The observations will begin in early October once WFCAM is available. We expect to observe around 60 NEOs in 2014B. The first paper for this project will be submitted by the end of 2014.

(2) Trilling has been allocated six Magellan/FIRE nights over the past two years for a study of outer Solar System targets. The weather has been poor overall, but a paper presenting preliminary results is in progress.

(3) We were awarded 1.5 nights at Magellan/Baade with FIRE in 2014B for the Trilling/Thomas asteroid families projecct. Some of this time was lost due to weather. The reduction pipeline for this program is under development.

(4) Trilling leads the UAO part of a large consortium that is searching for additional flyby targets for the New Horizons spacecraft mission after its Pluto flyby in 2015. To date, six UAO Magellan/Megacam nights have been allocated to that project, as part of a large multi-institution, multi-telescope campaign. No more UAO observations for this project are planned. Some results from this program have been published in Parker et al. 2013 (AJ, 145, 96).

(5) Trilling and his postdoc Mommert have been allocated eight Bok/PISCES nights over two semesters for spectrophotometric measurements of KBOs in support of a Spitzer project. Although the 2014A conditions were not good, the data obtained is marginally useful, and has helped us plan our proposed 2014B observations, which are upcoming.

(6) Trilling has been allocated 14 nights on the VATT over the past two years to carry out spectroscopy of Uranian satellites. All data is reduced and the paper draft, led by UT graduate student Richard Cartwright, is circulating.