GEMINI OBSERVATORY

observing time request summary

Semester: 2015A **Observing Mode:** Fast Turnaround **Gemini Reference:**

Instruments: GMOS North

Time Awarded: NaN **Thesis:** No

Band 3 Acceptable: No

Title: **The Phase Angle Dependence of sub-km NEA Spectra with GMOS-N**

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Reviewer: Diane Wooden

Partner Submission Details *(multiple entries for joint proposals)*

		PI Request		NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	Total Time	*2.6 hr*	*2.6 hr*		*0.0 hr*	*0.0 hr*	

Abstract

We propose to obtain 0.48–0.9 micron spectra of two NEAs, 1999 CU3 and 2002 GM2, with GMOS-N. The GMOS data will extend to shorter wavelengths the spectral characterization of these two NEAs that are under study from UKIRT and IRTF during 2015-Mar-06 and 2015-Apr-16 UT. Our study focuses on multi-epoch near-IR spectra over a wide range of phase angles to characterize the change in spectral slope (reddening) and Band I versus Band Area Ratio (BAR). Recent studies indicate the phase angle could contribute a large uncertainty to the BAR and hence propagate as uncertainty placing the surface composition of NEAs in the context of meteorite analogs. NEAs are of interest for planetary protection and for understanding asteroid collisions and dynamical evolution of small bodies, even through radiative forces (YORP and Yarkovsky). GMOS availability on the FT dates of Mar 9-11 and Apr 14 is ideal and needed to extend the study to shorter wavelengths where spectral slopes historically have greater response to phase angles than in the near-IR.

TAC Category / Keywords

Solar System / Asteroids, Solar system

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Scheduling Constraints

Scheduling 1999 CU3 for 1 observation each in Mar9-11 FT window and in Apr 14 FT window. 2002 GM2 is only for Mar9-11 FT window.

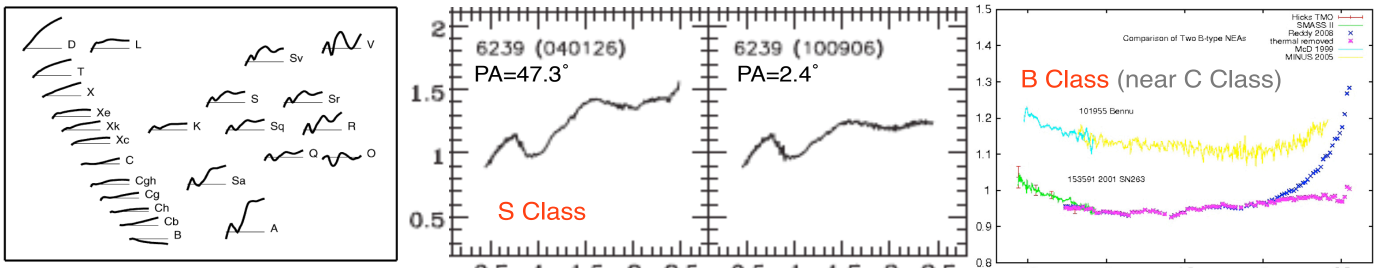
Observation Details (Band 1/2)

Observation	**RA**	**Dec**	**Brightness**	**Total Time** *(including overheads)*
1999 CU3	12:12:47.690	00:03:30.800		0.9 hr
Non-sidereal target (coordinates valid at: 2015-01-29) **Conditions:** CC 70%/Cirrus, IQ Any, SB Any/Bright, WV Any **Resources:** GMOS-N LongSlit N+S None R400 GG455 (> 460 nm) 2.0 arcsec slit				
1999 CU3	12:12:47.690	00:03:30.800		0.9 hr
Non-sidereal target (coordinates valid at: 2015-01-29) **Conditions:** CC 70%/Cirrus, IQ Any, SB 50%/Dark, WV Any **Resources:** GMOS-N LongSlit N+S None R400 GG455 (> 460 nm) 2.0 arcsec slit				
2002 GM2	21:39:22.820	-11:32:12.700		0.9 hr
Non-sidereal target (coordinates valid at: 2015-01-29) **Conditions:** CC 70%/Cirrus, IQ Any, SB Any/Bright, WV Any **Resources:** GMOS-N LongSlit N+S None R400 GG455 (> 460 nm) 2.0 arcsec slit				

Scientific Justification

The characterization Near Earth Asteroids (NEAs) is of interest to planetary protection and to understanding the origins of asteroids, to deciphering whether asteroid collisions result in solid bodies or rubble pile bodies and to understanding the dynamics of unstable resonance regions in the asteroid belt that are the source regions for the NEA population. Getting at the physical properties of these small bodies primarily relies on linking the surface composition to meteorite analogs and having measures of physical properties of meteroites. Determining the surface composition, also called the *asteroid class* (Fig. 1, *left panel*), relies on well-developed methods for measuring the reflectance spectra and assessing spectral slopes in the 0.5–2.4 µm region and, for ~60% of 0.6–0.2-km-sized NEAs (Hinkle et al. 2014, & priv. comm.), assessing the wavelength centers and band area ratios (BAR) of the 1 µm and 2 µm broad absorption features of Fe-bearing pyroxene and olivine silicate compositions (Fig. 1 *middle*). The remaining fraction of NEAs have nearly featureless spectra (D, X, C and B classes) and many are thought to have primitive carbonaceous materials on their surfaces, like the NEA targets of OSIRIS-REx (Bennu, Fig. 1 *right*) and HyabusaII (1999 JU3) missions. Both S and non-S class main belt asteroids have the appearance of redder spectra for increasing phase angles, i.e., the angle between the Sun-Target-Observer where zero degrees is opposition. As far back as Luu & Jewitt (1990), the trend for a sample of NEAs to have steeper spectral slopes or 'reddening' was suggested to be a consequence of NEAs typically being observed at higher phase angles due to their orbits being close to Earth. "Despite the fact that phase reddening has been known for a long time, its effect on the analysis of [Near Earth] asteroid spectra has not been fully assessed. (Sanchez et al. 2012)." In the most recent study, Thomas et al. 2014 demonstrate that <u>for two NEAs with high-signal-to-noise spectra, the greatest uncertainty in the Band-Area-Ratio determinations is in phase angle–dependence</u> (Fig. 2). With increasing phase angle, the BAR increases for two out of two NEAs whereas it behaves in the opposite sense for the third NEA. Sanchez et al. (2012) compare two spectra taken on each of 27 NEAs and show the range of compositions (by points connected by lines) derived in the Band I vs. BAR plot (Fig. 3a), which shows how the asteroid class can shift a subclass depending on the phase angle, and hence may shift in the meteorite analog and the meteorite's associated physical properties. The BAR phase angle–dependence also is suggested to be a contributor a long-standing apparent offset between the swath of NEA Band I vs BAR values and S(IV) 'boot' of meteorite reflectance BAR values (Fig. 3b "d"). The phase angle dependence of the BAR has yet to be quantified sufficiently to enable the derivation of a phase-angle correction for the BAR (Thomas et al. 2014). We propose GMOS spectra of three select NEAs to contribute to a data set we are obtaining on UKIRT and UKIRT+IRTF with the aim of bettering our understanding of and further quantifying the phase angle–dependence of spectral shape, asteroid class and (if silicate bands are identified) BAR analyses.

To contribute to this challenge of understanding the impact of phase angle on Band I – BAR analyses of sub-km NEAs, our team has ~60 hours of UKIRT time during 2015-Mar-05–2015-Apr-16 UT for multi-epoch near-IR spectroscopy (0.85–2.4 µm using UIST) of three NEA targets over a significant range of phase angles ($\sim 8^\circ \leq PA \leq 55^\circ$). Two of our chosen NEAs, 1999 CU3 and 2002 GM2 are faint enough (ApMag~16–17.5) to require Gemini FT. GMOS provides important short wavelength spectral information because the spectral slopes can be steep between 0.5–0.8 µm, thus affecting the Band I center, and (for asteroids) the spectral slopes appear to steepen at a faster rate as a function of phase angle at the shorter wavelengths. We request two GMOS spectra of 1999 CU3 at disparate phase angles and one spectrum of GM2.



DeMeo-Bus **Asteroid Classification**
0.45–2.45 μm Spectral Range

Fig. 1. (*left panel*) Reflectance spectra of S Class NEA 6239 at two phase angles, 47˚ compared to 2˚, showing the effects of steepening of slope ('reddening') and deepening of 1 and 2 μm bands that effect the Band Area Ratio (BAR). (middle panel) Triple NEA 2001 SN253 and Bennu (arbitrarily scaled). (right panel) Asteroid Classes. *All three panels show how the 0.4–0.8 μm spectral region contributes to spectral classification and to studying the effects of phase angle on NEA spectral analyses because the shorter wavelengths typically show stronger slopes than in the near-IR.* Effects of Phase Angle (PA) recently are reported for S Class NEAs and not yet for C Class NEAs.

Fig. 2

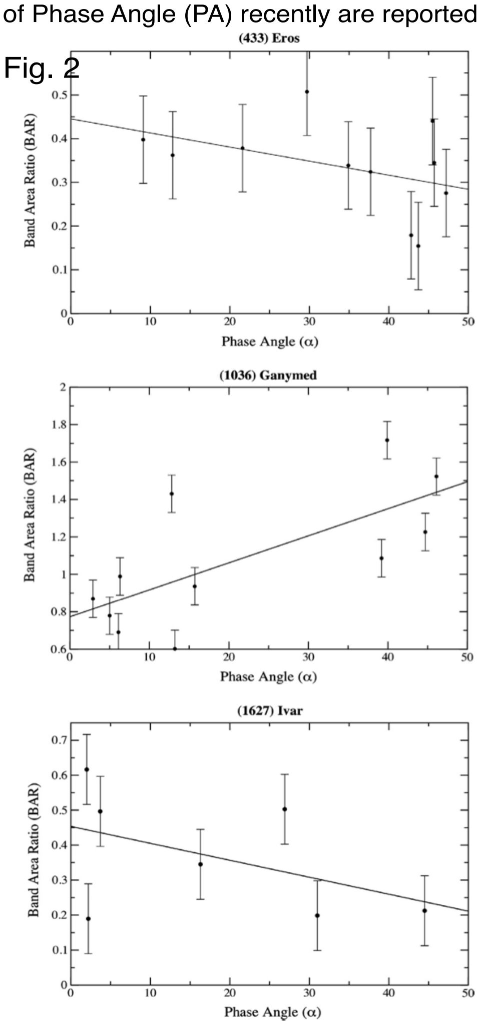


Fig. 3. Band Area Ratio (BAR) versus phase angle (α) for (433) Eros, (1036) Ganymed, and (1627) Ivar. For Eros and Ivar, BAR is anti-correlated with phase angle. Ganymed has an opposite correlation with a trend of increasing BAR with increasing phase angle.

Fig. 3a

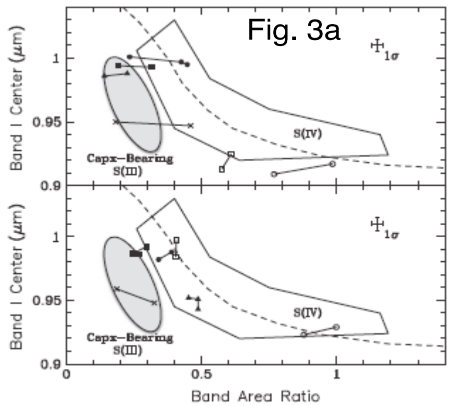


Fig. 3b

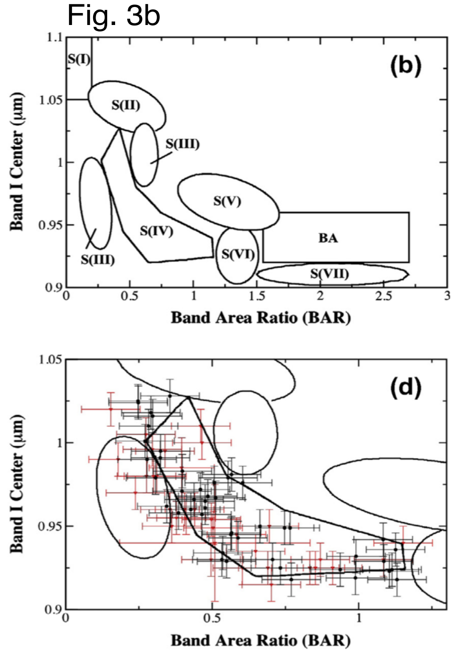


Fig. 2. Band Area Ratio (BAR) of the 2 μm to 1 μm bands versus phase angle (PA or alpha) for three NEAs, each observed ≥8 times. BAR decreases with increasing PA for Eros and Ivar but increases with PA for Ganymed. (Fig 3 of Thomas et al. 2014).

Fig. 3a. Band I Center versus BAR, used to link to Asteroid Class and meteorite type. Lines connect different phase angle analyses for the same NEAs, indicating that meteorite analog may change depending on the PA of the spectra. (Sanchez et al. 2012)

Fig. 3b. ("b" and "d") Band I versus BAR spectral subtype regions and data for a large sample of NEAs. The range of BAR for an individual NEA, such as shown Fig. 3 by the same authors, indicates a larger range in Band I vs. BAR plot than the formal uncertainties. For example, Ivar's BAR spans 0.45 to 0.2 for Phase Angles 0–50˚, which could place Ivar in S(III) or S(IV) or a different mineralogy -- calcium-bearing pyroxenes or ?. Also, the swath of NEAs lays slightly offset from the S(IV) 'boot', and they suggest a PA correction might account for this. (Thomas et al. 2015).

References

Becker, T. M., et al. 2015, "Physical modeling of triple near-Earth Asteroid (153591) 2001 SN_{263} from radar and optical light curve observations", Icarus 248, 499-515

Binzel, R. P., et al. 2004, "Observed spectral properties of near-Earth objects: results for population distribution, source regions, and space weathering processes", Icarus 170, 259-294

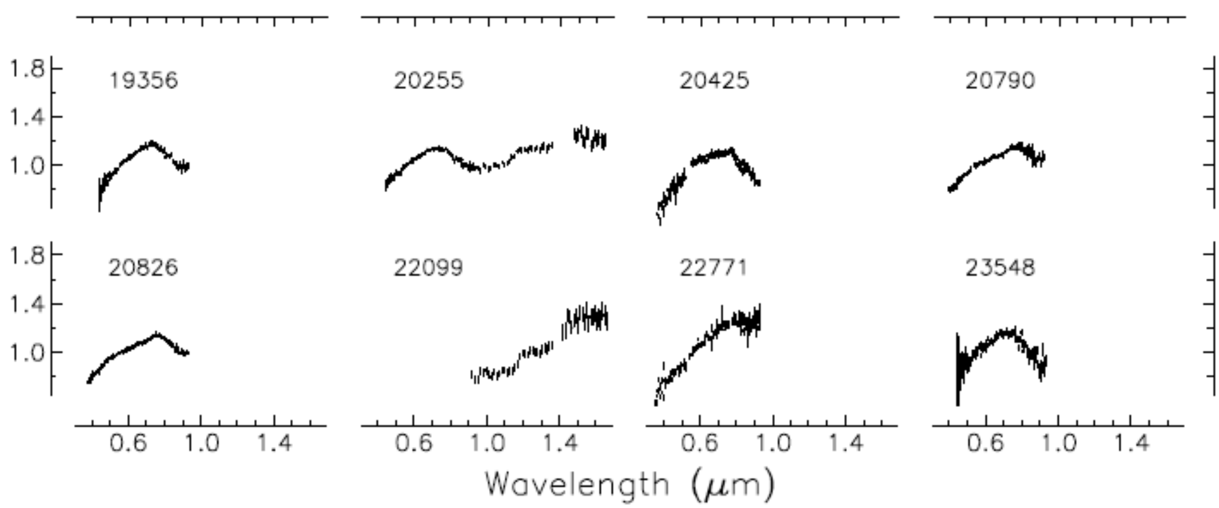
DeMeo, F. E., Binzel R. P., Slivan, S. M., Bus, S. J. 2009, "An extension of the Bus asteroid taxonomy into the near-infrared", Icarus 202, 160-180

Hinkle, M. L., Moskovitz, N., Trilling, D. 2014, "The Taxonomic Distribution of Mission-Accessible Small Near-Earth Asteroids", DPS 46, #213.07

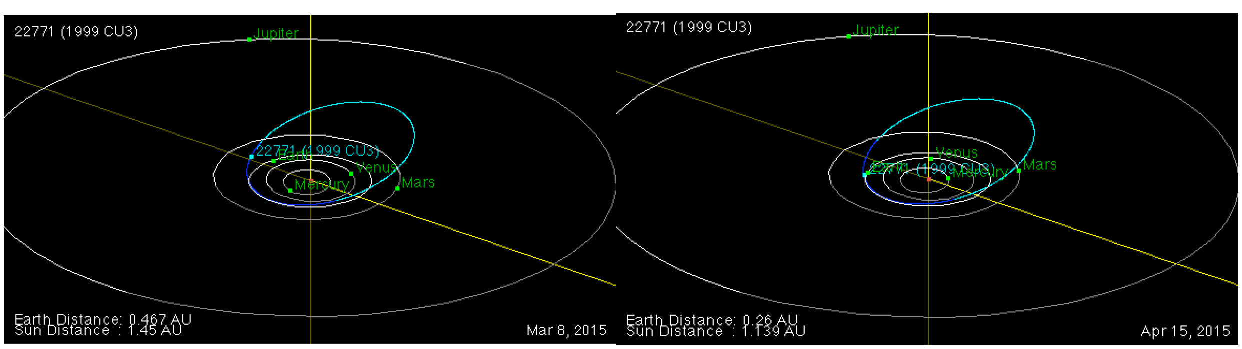
Luu, J.X., Jewitt, D.C., 1990, "Charge-coupled device spectra of asteroids: I – Near-Earth and 3:1 resonance asteroids", Astron. Journal 99, 1985–2011

Sanchez, J. A. et al., 2012, "Phase reddening on near-Earth asteroids: Implications for mineralogical analysis, space weathering and taxonomic classification", Icarus 220, 36–50

Thomas, C. A., et al. 2014, "Physical characterization of Warm Spitzer-observed near-Earth objects", Icarus 228, 217-246



Exp. Design 22771 (1999 CU3) has a steep red slope and is of the SI class (Binzel et al. 2004).



Experimental Design

Characterizations of non-binary NEAs focus on determining their size, composition, and inferred macrodensity through association of their composition with a meteorite analog. An NEA's composition is analagous to its *asteroid spectral classification*, which is determined from its reflected light spectrum from ~0.5–2.5 µm, and this is a well-developed field for several decades based on observations of their larger main belt asteroids. Main belt asteroids can be measured at relatively low phase angles (Sun-Target-Observer angles) as the asteroid in its orbit is passing by the Earth. However, for many NEAs, and in particular the Potentially Hazardous Asteroids (PHAs), low phase angle observations are rarely feasible because for their brighter apparitations (closer approaches to Earth), the asteorids are passing Earth quickly and are in less favorable geometries. Moreover, the fainter sub-km NEAs are often brightest at the epoch of discovery; even though they may return in a decade, rarely do they return so close as when first discovered.

Recently, NEA classifications have been shown to be dependent on phase angle but the dependency has yet to be characterized well enough for a phase-angle-correction to be developed (Thomas et al. 2014). The phase-angle dependence in the Band-Area-Ratio (BAR) is the largest uncertainty, being 2 to 3 times greater than the propagated instrumental uncertainties and systematic uncertainties in determining the BAR. Specifically, for three bright (i.e., larger) NEAs for which more than a half-dozen measurements are on record (Thomas et al. 2014), the BAR increases or decreases with increasing phase angle. More data are needed and specifically, data on sub-km-sized NEAs. Phase angle effects may be linked to grain size or regolith properties and it has been suggested that smaller NEAs may not be able to hold on to a fine-grained regolith; Eros has a ~10 m-deep fine-grained regolith whereas Itokawa appears as a rubble pile with pebbles, gravel and boulders. Our team has a "startup program" on UKIRT, between 2015-Mar-05–2015-Apr-15 UT, to obtain multiple epochs of near-IR spectra of three NEAs selected for their brightness, sky visibility, and wide range of phase angles. Our UKIRT program includes near-IR spectroscopy with UIST (2 settings required for 0.85–2.4 µm), as well as mid-IR photometry with Michelle to constrain the NEATM thermal model parameters of {Diameter, albedo, and IR beaming parameter that is a proxy for surface roughness}, and Michelle mid-IR+IRTF near-IR simultaneous measurements on 3 dates: March 5, 14 and April 14. We propose to the Gemini FT program to obtain GMOS spectra to complement the near-IR spectra for two of the three NEAs based on their faintness (~17 mag). GMOS spectra will provide a sensitive indicator of changes in slope (Fig. 1) since the shorter wavelengths have steeper slopes and an expected greater slope response to changes in PA than the near-IR spectra (based on spectra of MB asteroids). The GMOS short wavelength spectra offer an important handle on the PA-correction, especially for those primitive NEAs without silicates absorption bands. 2002 GM2 (PHA) lacks any spectral data and 1999 CU3 is SI class with Mg-rich pyroxenes. Thus, GMOS spectra are very important for improving the assessment of the phase angle-dependence on the spectra for the entire 0.5–2.4 µm region. Our UKIRT program was designed, submitted and accepted after the G-N 2015A CfP deadline, so we love the FT CfP!

Three GMOS spectra are requested: 2 for NEA 1999 CU3 at PA≈8˚ and 51˚ in the Mar 9-11 and Apr 14 FT windows, respectively, and one spectrum of 2002 GM2 in Mar 9-11 FT at PA=45˚–36˚. We propose to compliment our approved UKIRT program and our UKIRT+IRTF simultaneous observations with this GMOS shorter wavelength spectroscopy.

• For robust data analyses of NEAs, the good habit is to obtain a solar anlog calibrator.

Technical Description

The GMOS-N instrument configuration is as follows:

Filter=GG455
Disperser=R400 (Note that R150 is a much better grating for asteroids than the R400, however it is rarely installed and so we default to the R400 for ITC)
Central wavelength = 3 exposures at 700nm, 3 exposures at 710nm
Binning = 2x2
Slit=Longslit 2.0”
The three exposures at each central wavelength setting are done at three different slit positions: +15, 0, and -15 arcsec relative to the center of the slit.
The time per target in the OT is about 52 min for 6x120s exposures of the NEA target plus observations of a solar analog (6x10s exposures) and calibrations. Much of this time is overhead, so we have taken the nominal exposure time of 6x300s for a much smaller NEA (Moskovitz’s program MANOS on ≤0.15 km NEAs) and simply subtracted the time saved in exposure time for these 2 targets to estimate how long this will take. We have requested IQAny CC70 WVAny SB50 AirMass≤1.5. 1999 CU3 on Mar 9-11 is ApMag 16.4, which yields a total SNR of 75. On Apr 14, 1999 CU3 is ApMag 16.1, which yields a similar SNR with the same setup. On Mar 9-11, 2002 GM2 is ApMag 16.8, which yields a total SNR of 55. Since the NEA spectra of 1999 CU3 is expected to drop faster than the solar spectrum towards shorter wavelengths, we still anticipate a SNR of >20.

Below are the SMASS solar analogs that we use, in this RA range:

SA 102-1081	10 57 04.4	-00 13 12	2000.0	9.9
SA 105-56	13 38 42.1	-01 14 14	2000.0	10.0
SA 107-684	15 37 18.1	-00 09 50	2000.0	8.4
SA 107-998	15 38 16.4	+00 15 23	2000.0	10.4

The G-N FT dates and GMOS’ availability in March (March 9-11) ideally overlap with the March 9 UKIRT+SpeX simultaneous observations of 22771 (1999 CU3) [PA=8.3˚–7.6˚ for Mar 9–11 or 2015-Mar-10 08UT-14UT] and the FT Apr 14 date also samples a considerably different phase angle for 1999 CU3 [PA=51˚ for Apr 14 or 2015-Apr-15 05UT-08UT]. NEA 2002 GM2, which is a Potentially Hazardous Asteroid (PHA), is available also on the March 9-11 during which time GM2 has a Phase Angle of 45˚, 40˚, and 36˚, respectively. By Apr 14, GM2 has PA=17˚ but GM2 is too faint (ApMag=19.5, ssd.jpl.nasa.gov) for complimentary UKIRT near-IR spectroscopy on this date.

The April FT date of April 14 is only two days different than our planned simultaneous IRTF near-IR SpeX spectra and UKIRT Michelle photometry to derive albedos and thermal properties. That is, the dates of the FT opportunity are ideal for obtaining the shorter wavelength spectra to splice onto the near-IR. Specificially, we request three GMOS spectra, two GMOS spectra for 1999 CU3, one on Mar 9-11 and one on Apr 14, and one GMOS spectra of 2002 GM2 on Mar 9-11. Each GMOS spectrum will take 0.5 hr plus solar analog standard stars and can be achieved in IQ Any seeing conditions with a wide slit.

Band 3 Plan

April 14 is between Last Quarter and Full Moon and we want that date for 1999 CU3. We could relax to SB80/Grey.

We note that typically, a Band 3 allocation probably would mean that the data are not acquired and these data for FT are in a sense time-critical, because these NEAs will not return for a decade and then may not provide the large range of phase angles.

Classical Backup Program

This is not a classical request.

Justify Target Duplications

The GSA search revealed no duplicate observations.

Two observations of 1999 CU3 are requested by this program but a significantly different phase angles (see text).

Publications

Hinkle, M. L., Moskovitz, N., Trilling, D. 2014, DPS 46 #213.07, " The Taxonomic Distribution of Mission-Accessible Small Near-Earth Asteroids".

Lindsay, S. S., Wooden, D. H., et al. 2013, " Absorption Efficiencies of Forsterite. I. Discrete Dipole Approximation Explorations in Grain Shape and Size", ApJ 766, 54, 25pp

Moskovitz, N., et al. 2014, DPS 46, #503.09, "The Mission Accessible Near-Earth Object Survey (MANOS): Project Overview"

Moskovitz, N., et al. 2013, "Rotational characterization of Hayabusa II target Asteroid (162173) 1999 JU3", Icarus 224, 24-31

Lim, L. F., Emery, Moskovitz, N. A., Granvik, M. 2012, "The Near-Earth Encounter of 2005~YU55: Thermal Infrared Observations from Gemini North", LPI 43 #2202

Use of Other Facilities or Resources

There is a significant approval of time (~60 hours) on UKIRT with a combination of UIST and Michelle. The Science Justification and Experimental Design sections discuss how GMOS spectra is requested to compliment the near-IR spectra and the phase angle sampling of only a few NEAs. These GMOS observations are important for five reasons:

1) GMOS can add important phase angle-dependent spectral slope information, and especially for the S class NEA 1999 CU3, the shorter wavelenghts are important for defining the shortwavelength onset of the 1 μm pyroxene band (Band I);
2) these targets are only favorable now and not for another decade;

3) the phase angle sampling on UKIRT also is possible on Gemini-N because of the serendipitous choice of FT dates that overlap with planned UKIRT (CASS availability dates) AND with planned UKIRT+IRTF simultaneous observations to sample the near-IR through mid-IR (DDT on March 9, 14, and April 14);
4) GMOS is required because of the faintness of these two NEAs;
5) The UKIRT research program was designed after October 1 so our team missed the 2015A CfP deadline; on October 1, the PI was offered NASA directed funding for this effort to characterize NEAs (NASA Ames' new directive in studying NEAs for planetary protection).

Here is our plan for the UKIRT + IRTF time:

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Eng. Mar 9, 03:00 - 06:30 HST  (Mar 9 13:00-16:30 UT)
    (22771) 1999 CU3 V~ 16.6    PA~8.8deg    AM=1.31-2.4 for 13:00-15:00 UT or 3:00-5:00 HST
    (1036) Ganymed    V ~ 14.4    PA~19deg   AM=1.45-1.33 for 13:00-16:00 UT or 3:00-6:00 HST
(brighter source, good into dawn, lower priority than 1999 CU3 or 2002 GM2, previously studied)
    2002 GM2              V ~ 16.8    PA~49deg    AM=1.39-1.61 for 13:00-16:00 UT or 3:00-6:00 HST
    (3691) Bede            V~ 14.9    PA~19deg     AM=1.7-2.7 for 13:00-14:00 UT or 3:00-4:00 HST
[lower PA and at higher AM, conflicts with fainter sources in same time frame]

Eng. Mar 14, 18:30 - 20:45 HST (Mar 15 4:30-6:45 UT)
    (3691) Bede            V ~ 15.0    PA~23deg     AM=1.6-1.1AM for ~04:30-07:00 UT or 18:30-21:00
HST   (brighter source, good from dusk)
    (22771) 1999 CU3  V ~ 16.1   PA~7.5deg   AM=3.1-1.9AM for 06:00-07:00 UT or 20:00-21:00 HST)
 [this target would be easier if the Engineering window extended to ~21:30 HST]
   2002 GM2              [ not available in this UT time frame on this date]

Eng. April 12, 18:20 - 21:20 HST  (Apr 13 4:30-7:20 UT)
    (3691) Bede           V ~ 15.7   PA~42.0deg   AM=1.1-1.05 for 04:30-07:00 UT or 18:00-21:00 HST)
  (brighter source, good from dusk)
    (22771) 1999 CU3  V ~ 16.1   PA~47.5deg  AM=1.31-1.22-1.32 (transiting) for 05:00-07:20 UT or
19:00-21:20 HST)
    (1036) Ganymed    V ~13.5    PA~12.0deg  AM=1.6-1.2-2.0 for 10:00-16:00 UT or 0:00-6:00 HST
   [need to get this from UKIRT at about this date with Michelle AND UIST to maximize use of SpeX
Mar 9 data]
   2002 GM2       V~19.3    PA~16deg     AM=2-1.2 for 05:00-07:00 UT or 19:00-21:00 HST (too faint)
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Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data
GN-2013A-Q-86	5hr Band3	100	Comet PanStarrs had a strong near-IR thermal continuum and showed no solid state or macro-molecular emission features. GNIRS data is complimenting thermal dust modeling data at longer wavelengths.

ITC Examples

Instrument: GMOS-N

Source spatial profile, brightness, and spectral distribution:
The z = 0.0 point source is a 16.4 mag G2V star in the R band.

Instrument configuration:
Optical Components:
Filter: gg455

Fixed Optics
Grating Optics: R400_G5305
Detector - EEV DD array
Focal Plane Mask: slit2.0

Central Wavelength: 700.0 nm Spatial Binning: 2 Spectral Binning: 2 Pixel Size in Spatial Direction: 0.1454arcsec Pixel Size in Spectral Direction: 0.1346nm Telescope configuration:
silver mirror coating.
side looking port.
wavefront sensor: oiwfs

Observing Conditions:
Image Quality: 100.00%
Sky Transparency (cloud cover): 70.00%
Sky transparency (water vapour): 100.00%
Sky background: 50.00%
Airmass: 1.50
Frequency of occurrence of these conditions: 35.00%

Calculation and analysis methods:
mode: spectroscopy
Calculation of S/N ratio with 6 exposures of 120.00 secs, and 100.00 % of them were on source.
Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 5.00 times the target aperture.