Scientific Justification

With the discovery of C/2019 Q4 (Borisov) is the second confirmed interstellar visitor and first with a visible coma, the Solar System is getting an up close view of a relic from planet formation around a star beyond our Solar System. There have been observations of planet forming disks and debris disks studying the bulk properties of these extrasolar planetesimals. But the passage of an active planetesimal through our Solar System provides a rare window to study in these small bodies up close in the same ways in which we reach out and study the small body populations residing within our Solar System.

The Kuiper belt is the material leftover from the construction of our planets. By studying these distant icy planetesimals, we can probe the early dynamical history and compositional structure of the primordial disk. The majority of Kuiper belt object (KBO) surfaces can be divided into two broad categories: spectrally featureless surfaces and the volatile rich dwarf planets. Most KBOs are either too small or hot to retain their primordial abundance of volatile ices (Schaller & Brown 2007). Generally, the surfaces of these volatile-less bodies are poorly understood. Other than a linear spectral slope, the optical spectra of the majority of non- dwarf planet KBOs < 22 mag are featureless. For the typically smaller > 22 mag KBOs, ground-based spectra are impossible; we must rely on what broadband photometric colors reveal about their surfaces. Colours of the Outer Solar System Origins Survey (Col-OSSOS) measured simultaneous g,r, and J photometry with Gemini North for a sample of KBOs found in a well-characterized survey.

Our unbiased statistics affords the first opportunity to explore the true frequency of KBO surface types. **grJ photometry probes the spectral behavior of small body surfaces in the longer-wavelength region, where the wide absorption features of likely surface materials like silicates and tholins become more prominent and identifiable and separate the Kuiper belt surfaces into different taxonomic classes.** Utilizing Col-OSSOS taxonomic classifications, we clearly identify 2 compositional classes of dynamically excited KBO population at a boundary of (g-r) = ~0.75: the neutral (less red [0.5 < (g-r)< 0.75]) and red classes [0.8 < (g-r) < 1.2] (Schwamb et al. 2019; Pike et al. 2017). This has allowed us to develop a basic model of the compositional structure of the protoplanetesimal disk (see Schwamb et al. in 2019). In Figure 1 we plot the optical and NIR colors of 60+ KBOs from our sample. Previous color measurements for KBOs in the same size region as the Col-OSSOS sample have errors of +/- 0.1 mag. Using Gemini's large aperture and carefully accounting for light curve variations, we obtain color uncertainties of +/- 0.03 mag for the Col-OSSOS sample.

Our established Gemini North grJ colour sample of KBOs provides ideal context for studying interstellar objects. 2017, our team measured the near simultaneous grJ colors of the first interstellar object, 'Oumuamua (see Figure 1). 'Oumuamua had a surface near the neutral end of the range of Solar System solar-reflectance colors, similar to some dynamically excited KBOs and Jupiter Trojans (Bannister et al. 2017). With cometary activity, telescope imaging of are not directly probing the nucleus of Q4 directly but measuring the composition of the dust within the coma. This dust originated from the surface or internally from Q4. Recent, optical spectra of Q4's dust coma by Leon et al. (2019) reveal a featureless sloped spectra similar to reddened D-type asteroid (see Fig 2). This broadly groups it with the spectral slopes seen for KBOs, Jupiter-Family comets (JFCs) and long period comets. Given dust produced by Q4 is featureless and looks reddened like KBOs (Fig. 2), getting similar data to Col-OSSOS is crucial to putting this surface in context to the Kuiper belt. **Obtaining similar data to Col-OSSOS is crucial to putting Q4 in context with the Kuiper belt. We request 1.86 hours of GMOS-N and NIRI imaging to study the surface properties of Q4.**

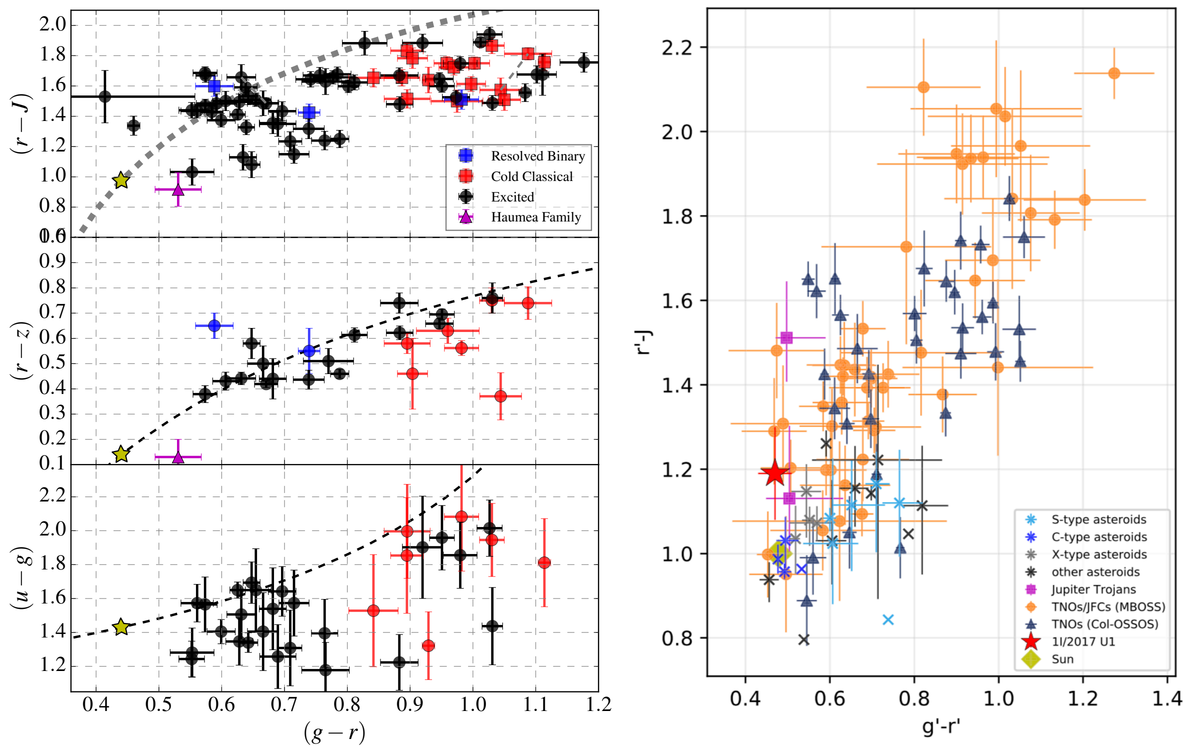

Figure 1: Left: UV-optical-NIR colors of Col-OSSOS KBOs obtained to date on the left. Neutral surfaces ("less red") represent 0.55 < (g-r) < 0.8), and red surfaces represent 0.8 < (g-r) < 1.2. Solar colors are marked by the yellow star. The dashed curve indicates the reddening line, a line of constant spectral slope through the grJ/grz/ugr spectral range, calculated using pysynphot (Lim et al. 2015). **Right:** Optical-NIR colors of the instersteallar object 'Oumuamua (red star), previously published values for KBOs + JFCs, and KBOS from Col-OSSOS sample reduced at that time. Neutral surfaces ("less red") represent 0.55 < (g-r) < 0.8), and red surfaces represent 0.8 < (g-r) < 1.2. Solar colors are marked by the yellow star. Oumuamua

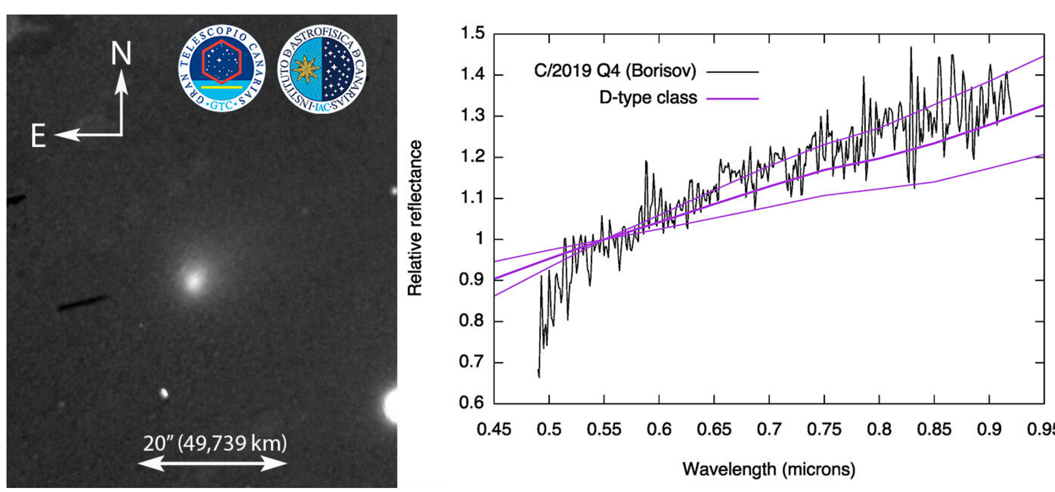

Figure 2: Optical Imaging and optical spectrum of Q4 obtained on September 13, 2019 by (Leon et al. 2019) . The moderately redder-than-solar color is in common with KBOs, long and short period comets, D-type asteroids

References:

Experimental Design

We request time on Gemini North to image Q4 with NIRI and GMOS-N. Q4 has been in deep freeze for a long time, and so it may not behave like long period or short period comets originating from our Solar System. Exposure times in each filter is tuned assuming Q4's future predicted brightness by JPL Horizons taking into account that the object may be several magnitudes fainter (2-5 mag) in case there is a sudden dimming due to a decrease in activity or a breakup event. We assumed an optical color of (g − r) = 0.63 and a nearly NIR neutral, (r − J) = 1.0-1.6 colored for KBOs, JFCs, and 'Oumuamua, and then looking at these brightnesses over a 2 magnitude range. This ensures that we have sufficient SNR in case of color evolution or significant changes in cometary activity over time.

We are in unchartered territory with the apparition of Q4. It is not clear that we should expect to see similar evolution to our resident active small bodies in our Solar System. Q4 is experiencing its first heating event since a journey of at least ten million years at temperatures of only tens of degrees, so outburst events as its activity increases toward perihelion will be both likely, and unpredictable. Thus, we are asking for two epochs of NIRI+GMOS imaging. The first observation is requested in early November to sample the dust color/composition of the coma and compare to 'our Col-OSSOS sample The second epoch is requested at the end of November/early December when the interstellar comet is at/near perihelion to examine the evolution and recompare the coma dust composition to our small body sample. Q4's closest approach to the Sun is on December 10 2019 UT.

Any significant amplitude changes due to rotational variability of the Q4 will impact our measured colors. Small KBOs typically have 15 hour rotation periods with peak-to-peak variations of ~0.3 magnitudes (Duffard et al. 2009). 'Oumuamua had a light curve with over 1.8 magnitude amplitude (see Bannister et al. 2017). Such a rotational light curve would significantly impact a (r-J) color estimate of Q4 if we only take NIRI observations and extrapolate with the previously taken GMOS-N data. Without a well measured rotational light curve for Q4, our observing scheme is designed to mitigate the impact of rotational variance. Specifically, we will take advantage of Gemini's fast instrument switching capabilities to acquire a r-g-J-g-r sequences with the NIRI and GMOS instruments. This filter pattern is necessary to ensure that we can take out light curve effects. W**ith g and r band images bracketing the J band observations, we can identify if the Q4 is variable on the timescales of our observations and apply a linear correction assuming all filters are impacted the same, which is reasonable because brightness variations in this size regime are due to object shape.** This technique has worked well for our past GMOS-NIRI-GMOS observations.

Gemini, with its built-in fast instrument switching capabilities, is the only large aperture telescope that can efficiently observe such a near-simultaneous optical-NIR imaging sequence. The PI does not have telescope access that can guarantee observations that will enable direct comparison to the Col-OSSOS KBO and 'Oumuamua observations . VLT X-Shooter can obtain simultaneous optical-NIR spectra, but if the Q4 suddenly dims NIR spectra may be impossible. Thus, we are requesting Gemini Director's Discretionary time with NIRI and GMOS-N. Other groups are getting optical data and near-infrared spectra, as stated on the Gemini queue status pages and likely at other large telescope facilities. If the object or the dust produced is spectrally variable depending on rotation, we may get different answers when attempting to combine past optical and NIR observations together. However, the optical data that we request here is needed in conjunction with the J band to remove light curve effects and variable surface compositions/dust production, and in case the cometary activity/Sun's thermal heating changing Q4's properties.

Technical Description

Our proposed observations are simple broad-band imaging in optical in near-infrared with GMOS-N and NIRI. The exposure times are aimed to gather a minimum of SNR=25 in optical and NIR. The requested SNR is more than sufficient to identify taxonomic membership compared to the Col-OSSOS sample and the measurements of 'Oumaumua. **Based on the ITC, we require a 30s exposure in g and r filters taken at airmasses < 2 in IQ 85 CC 50 BG Any We require ten 30s exposures in J taken at airmasses < 2 in IQ 85 CC 50 BG Any (13 min of observing time including overheads).**

Although a single GMOS-N observation in each filter would more than satisfy our SNR constraints, there is the risk of the object moving over a bright star or a cosmic ray hitting the detector at the target's position. Not having an observation at the start and end of the sequence in the same filter to use for the light curve correction makes the light curve difficult if not impossible if both g and r observations are unlucky. We have never had both consecutive observations with the Hamamatsu CCDs in the same filter both impacted by cosmic rays**. Based on our team's past experience with 'Oumuamua and observing KBOs with this technique, we request two observations at the beginning and of end of the NIRI sequence each optical filter to ensure we can perform our light curve correction technique.**

The rapid rate of motion of the target (~100 arcsec/hr in Dec and 65 arcsec/hour in RA) requires non-sidereal tracking using the ephemeris provided by JPL Horizons. We will bracket the observations in each filter of GMOS with a 200s sidereal-tracked exposure for additional calibration certainty and to diagnose any images in the NIRI sequence where the minor planet is likely to have tracked over background sources. This observing setup worked well for our 'Oumuamua observations; Gemini North was able to track non-sidereally when 'Oumuamua's on-sky apparent motion was ~200 arcec/hour in Dec. Photometric standards are provided by Gemini for every 2 hours of continuous NIRI imaging. To provide an airmass correction, we require NIRI photometric standards at the beginning and end of the sequences. We request a NIRI program standard (12 minutes including overheads) in addition to the baseline standards.

Per epoch we require 28.0 minutes for the optical observations including 2 r band and 2 g-band observations and photometric calibrations before and after the NIRI observations. All our requested observations can achieve the desired SNR in CC 50 IQ 85 SB Any WV Any conditions with airmass < 2. Including overheads, baseline standards, and the additional program calibration, we need 28 minutes of NIRI imaging per epoch. **Including overheads, we request 56 minutes per epoch in IQ 85 CC 50 WV Any SB Any. One epoch will be sufficient to compare dust colors to the Col-OSSOS small body sample. If granted two epochs to look for any changes in the combined NIR-optical properties of the Q4's dust coma we would need in total 1.86 hours of IQ 85 CC 50 WV Any SB Any conditions.**

Q4 is observable at less than 2 airmasses during the time frame when NIRI will be available. The predicted positional uncertainty of Q4 is currently much smaller than the GMOS and NIRI fields-of-view. Additional, astrometry is expected to be submitted to the Minor Planet Center by the amateur and professional observers in the coming days and weeks that will continue to refine the orbit. We ask for Gemini North time as our large comparison KBO sample and 'Oumuamua observations were uniformly collected on Gemini North. We have a software pipeline developed to reduce our previous Gemini North Col-OSSOS data, which can easily be applied to these observations. Additionally, using the same instruments as our previous measurements will also improve our systematics. The Gemini North queue coordinators and observers are familiar with our observing programs, how to update the ephemeris manually for observing (needed to obtain our photometric calibration fields).

Band 3 Plan

Our observations require CC 50 conditions. This is typically not achievable in Band 3, and thus we request Band 1 or Band 2 observations.

Classical Backup Program

Not Applicable

Justify Target Duplications

The GOA search reveals some optical g and r imaging acquired previously by Gemini for Q4. ‘Oumuamua had a light curve with over 1.8 magnitude amplitude. Such a rotational light curve would significantly impact a (r-J) color estimate of Q4 if we only take NIRI observations and extrapolate with the previously taken GMOS-N data. Our observing technique, bracketing the infrared observation with a optical imaging is designed to take out rotational light curve effects. Thus, the full rgJgr sequence needs to be taken in order to achieve our science goals.

Publications

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Use of Other Facilities or Resources

M. Bannister has applied for observations with VLT's MUSE, VLT's optical IFU, which will look at structure and optical composition within the coma for C_2, CN, and NH_2. The NIR-optical serves as a different probe that we can use to compare directly to our Col-OSSOS sample. Also the fast switching capability of Gemini enables the near-simultaneous optical-NIR color independent of rotation providing a unique measurement on this object.

Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data
GN-2017A-FT-13	2.3 hours	100	Data reduced. We are now beginning to work on writing up these results in a paper. Early results were presented at the Transneptunian Solar System conference in 2018.Paper is now in progress, but was delayed to address second referee report on the survey overview paper. M. Schwamb is currently writing up the results and presented new interpretation of the data at the EPSC-DPS meeting in this month.
GN-2017B-FT-12	2.3 hours	100	Data reduced. We are now beginning to work on writing up these results in a paper. Early results were presented at the Transneptunian Solar System conference in 2018. Paper is now in progress, but was delayed to address second referee report on the survey overview paper. M. Schwamb is currently writing up the

			results and presented new interpretation of the data at the EPSC-DPS meeting in this month.
GN-2018B-DD-104	5.5 hours	100	Observations to obtain final rgJ photometry of the remaining resonant KBO in the Col-OSSOS primary sample. Data was taken in June and observations were processed. Data analysis is on-going.
GN-2018B-FT-116	4 hours	100	The program was completed in June. The observations are being reduced and M. Schwamb's graduate student starting on October 2nd will be analyzing the data as part of her PhD thesis.

ITC Examples