COMPARISON OF NEAR INFRARED SPECTRA BETWEEN PLUTO-SYSTEM OBJECTS AND 486958 2014 MU_{69}: ANALYSIS OF *NEW HORIZONS* SPECTRAL IMAGES J. C. Cook[1], C. M. Dalle Ore[2,3], F. Scipioni[2,3], D. P. Cruikshank[2], W. M. Grundy[4], S. Protopapa[5], R. P. Binzel[6], D. T. Britt[7], A. M. Earle[6], L. Gabasova[8], C. Howett[5], D. J. Jennings[9], J. J. Kavelaars[10] A. W. Lunsford[9], C. B. Olkin[5], A. H. Parker[5], J. W. Parker[5], E. Quirico[8], D. Reuter[9], B. Schmitt[8], J. R. Spencer[5], S. A. Stern[5], A. J .Verbiscer[11], H. A. Weaver[12], the New Horizons Surface Composition Theme Team and the Ralph Instrument Team, [1]Pinhead Institute, Telluride, CO, [2]NASA Ames Research Center, Moffat Field, CA, [3]SETI Institute, Mountain View, CA, [4]Lowell Observatory, Flagstaff, AZ, [5]Southwest Research Institute, Boulder, CO, [6]Massachusetts Institute of Technology, Cambridge, MA, [7]University of Central Florida, [8]Université Grenoble Alpes, CNRS, Grenoble, France, [9]NASA Goddard Space Flight Center, Greenbelt, MD, [10]National Research Council of Canaa, Victoria BC & Department of Physics and Astronomy, University of Victoria, Victoria BC, [11]University of Virginia, Charlottesville, VA, [12]John Hopkins University, Applied Physics Laboratory, Laurel, MD. (jasoncampbellcook@gmail.com)

Introduction: Obtaining good quality spectra of Kuiper belt objects from Earthbound telescopes is difficult mainly due to the faintness of the majority of Kuiper belt object targets. This issue limits Earth-based observatories to large (few 100 km in radius) and bright ($V \lesssim 20$) targets. Furthermore, the spectra of many small KBOs lack the identifiable H_2O-ice bands at 1.5 and 2.0 μm and appear featureless compared to the noise level. Earlier this year, *New Horizons* became the first spacecraft to make *in situ* observations of (486958) 2014 MU_{69}. Comparing these observations with observations of comets[1] (few km), irregular satellites ($\sim$ 20-30 km) and local sites on Pluto help to expand our understanding of these objects. Also, see [2] for a broader comparison to irregular satellites, [3] for comparison to ground-based observations of Kuiper belt objects and Centaurs and [4] for an overview of the surface composition. Here we present a comparison of the near-infrared spectrum of 2014 MU_{69} with Nix and Cthulhu Regio on Pluto.

Observations: On January 1, 2019, NASA's *New Horizons* spacecraft approached within 3500 km of the surface of 2014 MU_{69}, informally referred to as Ultima Thule. This flyby represented the first encounter with a cold classical Kuiper belt object. Images of 2014 MU_{69} (see Fig. 1) showed it was comprised of two nearly spherical bodies with one being $\sim$9 km in radius, and the other being $\sim$7 km in radius. Using the Ralph [5] instrument, *New Horizons* successfully obtained images and spectra necessary to map the composition and distribution of ices and organics on 2014 MU_{69}'s surface. Ralph is a dual channel instrument with MVIC (Multispectral Visible Imaging Camera), the visible color imager, and LEISA (Linear Etalon Imaging Spectral Array), the near-infrared spectrograph. LEISA covers the spectral range of 1.25 to 2.50 μm at a resolving power ($\lambda/\Delta\lambda$) of 240 and 2.10 to 2.25 μm at a resolving power of 560. At the time of writing this abstract, select wavelengths have returned to Earth (see Fig 2) from the highest spatial resolution LEISA observation, during which the surface of 2014 MU_{69} was $\sim$31,000 km from *New Horizons* yielding a spatial scale of 1.8 km/pixel.

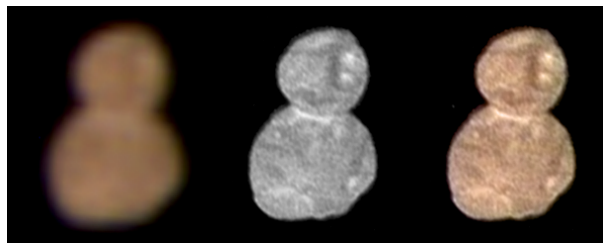

Figure 1: Color image of 2014 MU_{69} from a distance of 137,000 km. (From left to right) Enhanced MVIC color image, LORRI (Long-Range Reconnaissance Imager) image and color overlaid onto the LORRI image.

Data Reduction: At the time this abstract was prepared, only a subset of the full data has returned to Earth. We received 25 wavelengths, focused on 7 windows that were each 3 to 4 wavelength channels wide. Missing from the data (so far) is the housekeeping information, used to remove motion distortion from the data. During the acquisition of the data, thrusters fire to prevent the target from drifting out of the field of view. Without this information, our correction tools only partially correct for the motion distortion, which adversely increases the uncertainties from our reduction. We anticipate receiving the full spectrum and housekeeping data before the conference convenes.

Methodology: [6] reported on the spectra of Pluto's irregular satellites, Nix, Hydra, and Kerberos. The spectra of the former two revealed deep H_2O-ice absorption bands and detected absorption around 2.2 μm. We show the spectrum of Nix (blue spectrum in Fig. 2) in Fig. 2, scaled and offset to the approximate level of 2014 MU_{69}. [6] showed that a mixture of H_2O-ice, Pluto tholin (a featureless absorber that contributes a blue slope at these wavelengths) and an ammoniated-species ([6] presented NH_4Cl, NH_4NO_3 or $(NH_4)_2CO_3$ as candidates) likely comprise the observed surface of Nix. We also compare the 2014 MU_{69} spectrum to

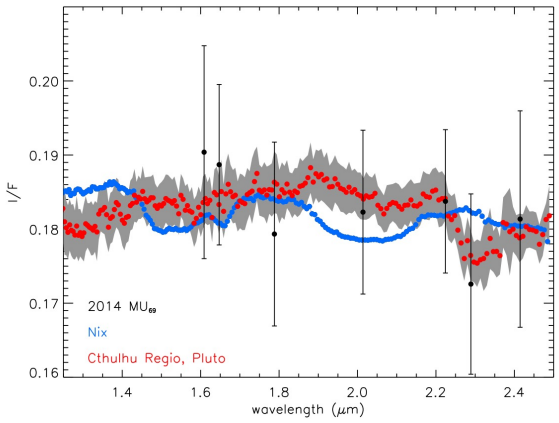

Figure 2: Spectra of 2014 MU_{69} compared to Nix (blue points) and Cthulhu Regio (red points). The spectra of Nix and Cthulhu Regio have been rescaled and shifted to match the level of 2014 MU_{69}(black points). A 1-σ error range is shown in grey for Nix (smaller than the size of the points) and Cthulhu Regio, and error bars for 2014 MU_{69}.

a spectrum from the H_2O-ice-poor region of Cthulhu Regio[7] (red spectrum in Fig. 2). The strongest absorption feature in the Cthulhu spectrum lies between 2.2 and 2.3 μm. [7] report that the band is possibly due to C_3H_8, but may be due to a wide variety of organics[8] that share an absorption feature at a similar wavelength and lack laboratory derived optical constants.

Results: We show the spectrum of 2014 MU_{69} from the seven wavelength windows in Fig. 2. We find the near-infrared I/F is between 0.17 and 0.19. The unscaled spectrum of Nix (see Fig 1 of [6]), however, ranges in I/F from $\sim$0.4 at the continuum levels to $\sim$0.1 in the 1.5 and 2.0 μm H_2O-ice bands. After scaling and shifting Nix's spectrum, we do not see strong evidence for the 2.0 μm H_2O-ice band, and therefore the abundance of H_2O-ice on the surface of 2014 MU_{69} is likely to be much less than seen on Nix. And therefore, the comparison between 2014 MU_{69} and H_2O-ice rich Nix does not appear to be a strong one. The spectrum 2014 MU_{69} does, however, suggest a $\sim$10% absorption around 2.3 μm and the spectrum compares well with the spectrum of Cthulhu Regio on Pluto. The (unscaled) spectrum from Cthulhu Regio (see Fig. 15 of [7]) has an I/F around 0.45 with the absorption at $\sim$2.3 μm being a $\sim$20% decrease or relatively 2$\times$ deeper than seen on 2014 MU_{69}. Given the overall red color of 2014 MU_{69} in the color image (see Fig. 1) and the red color of Cthulhu Regio, this agreement is not too surprising.

Discussion & Conclusion: We have compared the spectrum of 2014 MU_{69} with that of Nix and Cthulhu Regio. Our preliminary results indicate that 2014 MU_{69} is darker at all wavelengths than Nix and Cthulhu Regio by a factor of $\sim$2, but scaling these spectra to the level of 2014 MU_{69}'s spectrum shows 2014 MU_{69} more closely resembles the spectrum from Cthulhu Regio. The possible absorption band detected $\sim$2.3 μm in the spectrum of 2014 MU_{69} is about half the depth of the one seen in the spectrum of Cthulhu Regio. The agreement in the spectrum of 2014 MU_{69} and Cthulhu Regio supports the idea that Cthulhu Regio is one of the older terrains on Pluto's surface since little can be done to prevent 2014 MU_{69} from reddening over the age of the solar system. Furthermore, the apparent disagreement between the 2014 MU_{69} spectrum and Nix suggest the small satellites of Pluto were not captured and were likely remnants of the collision that produced Pluto and Charon. We anticipate either detecting or presenting upper limits for H_2O-ice once the remainder of these data and additional LEISA scans from a greater distance are returned to Earth from the spacecraft in the following weeks.

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