Photometry of Kuiper Belt Object Ultima Thule and Comparisons with Cognate Solar System Objects. J. D. Hofgartner*[1], B. J. Buratti[1], H. A. Weaver[2], A. F. Cheng[2], C. M. Lisse[2], A. J. Verbiscer[3], R. A. Beyer[4], S. A. Stern[3], C. B. Olkin[3], J. R. Spencer[3], J. W. Parker[3], J. J. Kavelaars[5], R. P. Binzel[6], New Horizons Geology and Geophysics Team, and New Horizons LORRI Team, *Jason.D.Hofgartner@jpl.nasa.gov, [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [2]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, [3]Southwest Research Institute, Boulder, CO, [4]Sagan Center at SETI Institute, Mountain View, CA, [5]National Research Council of Canada, Victoria, BC, Canada, [6]Massachusetts Institute of Technology, Cambridge, MA.

Introduction: On January 1st, 2019 the New Horizons spacecraft flew by the cold classical Kuiper belt object 2014 MU69 (informally named "Ultima Thule") [1]. Ultima Thule is the first cold classical Kuiper belt object to be explored by a spacecraft and the flyby results have important implications for planetary formation and evolution. Ultima Thule was discovered to be a bilobate object, the larger and smaller lobes are informally named "Ultima" and "Thule" respectively.

Photometry of Ultima Thule: The highest-resolution image sequence returned from the spacecraft to date is CA04-MAP, acquired by the LORRI instrument [2] ≈ 45 minutes prior to closest approach from a distance of ≈ 30,000 km. The pixel scale is ≈ 140 m, the solar phase angle is ≈ 13^{O}, and the pivot wavelength is ≈ 610 nm. A map of the calibrated I/F is shown in Figure 1 and a histogram is shown in Figure 2. The I/F was calculated assuming a visible spectrum similar to Pluto and is not corrected to 0^{O} solar phase angle as the phase curve of Ultima Thule is not yet known.

The mean I/F of Ultima Thule in Figure 1 is ≈ 0.09 and the two lobes have identical means to within error. The maximum I/F is ≈ 0.14, at both the top left of the smaller Thule lobe and the neck that connects the two lobes. The minimum I/F is ≈ 0.06, at the top left of the Thule lobe. The distribution of the Ultima lobe has a sharper peak at the mean I/F. This is partially from the bland region near the center-left of the lobe in Figure 1, suggesting that region may be less processed than other areas of Ultima Thule.

Comparison with Cognate Solar System Objects: The reflectance of Ultima Thule can be compared to other bodies in or hypothesized to originate from the Kuiper belt. Figures 3 and 5 show normal reflectance maps (I/F at 0^{O} solar phase angle) of Pluto and Charon and Figures 4 and 6 show the histograms (from [3]).

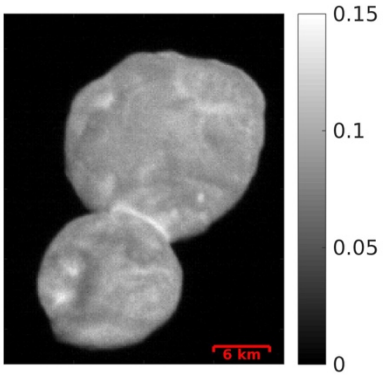

Figure 1: Reflectance (I/F) of Ultima Thule at 13^{O} solar phase angle.

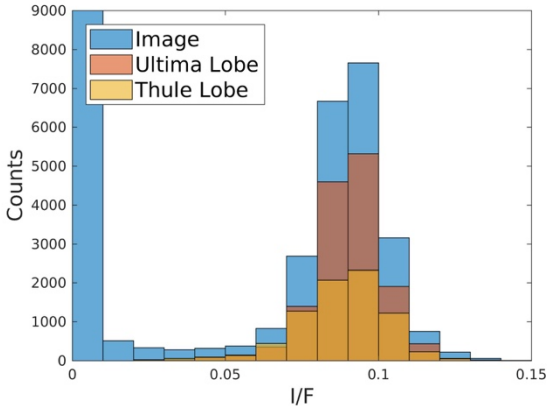

Figure 2: Histogram of I/F values in Figure 1.

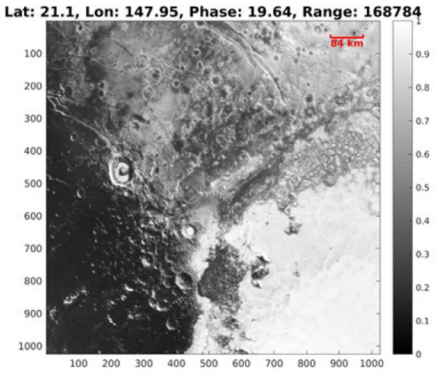

Figure 3: Normal reflectance of a region of Pluto that includes Sputnik Planitia and Cthulhu Regio, the brightest and darkest observed terrains on Pluto.

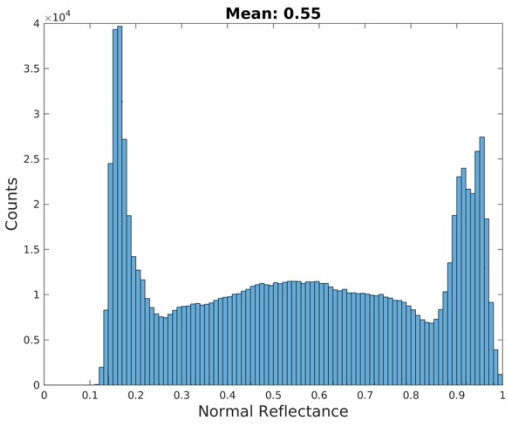

Figure 4: Histogram of normal reflectance values in Figure 3.

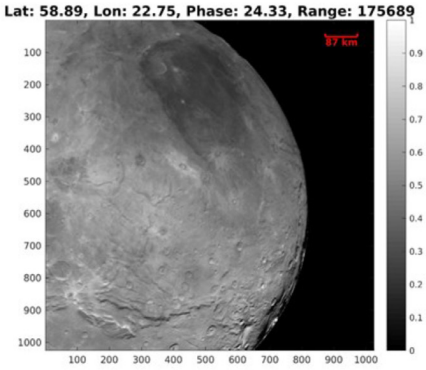

Figure 5: Normal reflectance of a region of Charon that includes Mordor Macula, the darkest observed terrain on Charon.

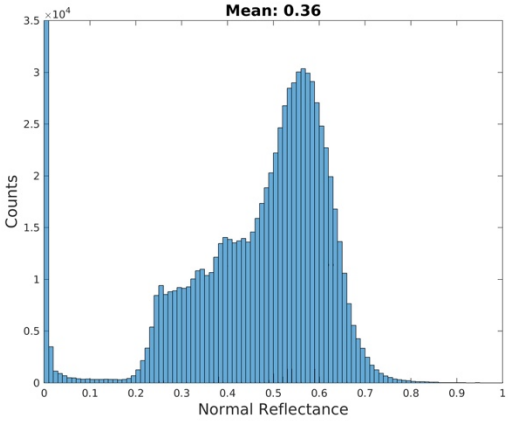

Figure 6: Histogram of normal reflectance values in Figure 5.

Cthulhu Regio on Pluto has a normal reflectance of ≈ 0.11 – 0.25. This is a good analog for the reflectance of Ultima Thule which has an of I/F of ≈ 0.09 at ≈ 13^{O} solar phase angle and will have a greater I/F at 0^{O} solar phase angle. Cthulhu Regio is also red, as is Ultima Thule [4]. Cthulhu Regio's surface may be dominated by radiolytically and photolytically processed hydrocarbons (tholins) [5] and Ultima Thule likewise probably has a similar surface composition. Mordor Macula, the darkest terrain observed on Charon, however, has a normal reflectance of ≈ 0.3. Since we do not expect the I/F of Ultima Thule to increase by a factor of 3 when corrected to 0^{O} solar phase, Mordor Macula is not similar in reflectance to Ultima Thule.

Saturn's irregular satellite Phoebe is hypothesized to be a captured Kuiper belt object [6]. It has a mean normal reflectance of 0.08 at both 480 nm [7] and 1 μm [8] and thus is darker than Ultima Thule. Phoebe also has a bimodal normal-reflectance distribution and the distribution is broader than that of Ultima Thule [7,8]. The geometric albedo of the nucleus of comet 67P/Churyumov-Gerasimenko is 0.06 at 550 nm [9] and thus is also darker than Ultima Thule.

The neck of Ultima Thule is only 1-2 pixels wide in the CA04-MAP image and thus may not be resolved, in which case it may actually be narrower and have a greater I/F than shown in Figure 1. Thus its brightness cannot be reliably compared to other objects at this time.

The New Horizons spacecraft will continue transmitting its bounty of close-approach observations of Ultima Thule for greater than a year, including images at higher-resolution and with substantially better solar phase angle coverage. We will include additional images that are expected to be received in the near future but not yet available in the analysis for our presentation.

References: [1] Moore J. M. et al. (2018) *Geophysical Research Letters, 45,* 2018GL078996. [2] Cheng A. F. et al. (2008) *Space Sci. Rev. 140,* 189-215. [3] Buratti B. J. et al. (2017) *Icarus 287*, 207-217. [4] Grundy W. M. et al. (2019) *LPS this issue.* [5] Grundy W. M. et al., (2016) *Science 351*, aad9189. [6] Johnson T. V. and Lunine J. I. (2005) *Nature 435*, 69-71. [7] Simonelli et al. (1999) Icarus 138, 249-258. [8] Buratti B. J. et al. (2008) *Icarus* 193, 309-322. [9] Ciarniello M. et al. (2015) *Astronomy and Astrophysics 583*, A31.