

ULTIMA THULE, TNOs AND THE IRREGULAR SATELLITES OF THE OUTER PLANETS: SPECTROSCOPIC AND COLORS COMPARISON. F. Scipioni¹, C. M. Dalle Ore¹, W. M. Grundy², D. P. Cruikshank³, J. C. Cook⁴, A. M. Earle⁵, S. Protopapa⁶, B. Schmitt⁷, E. Quirico⁷, C. B. Olkin⁶, C. J.A. Howett⁶, R. P. Binzel⁵, A. H. Parker⁶, J. W. Parker⁶, D. C. Reuter⁸, S. A. Stern⁶, J. R. Spencer⁶, A. J. Verbiscer⁹, H. A. Weaver¹⁰, J.J. Kavelaars¹¹, D. T. Britt¹², and the New Horizons Composition Team. ¹SETI Institute, Mountain View, CA, ²Lowell Observatory, Flagstaff, AZ, ³NASA Ames Research Center, Moffett Field, CA, ⁴Pinhead Institute, Telluride, CO, ⁵MIT, Cambridge, MA, ⁶South West Research Institute, Boulder, CO, ⁷Institut de Planetologie et Astrophysique de Grenoble, Grenoble, France, ⁸NASA Goddard Space Flight Center, Greenbelt, MD, ⁹University of Virginia, Charlottesville, VA, ¹⁰Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, MD, ¹¹National Research Council of Canada, Victoria BC & Department of Physics and Astronomy, University of Victoria, (Victoria, BC), ¹²University of Central Florida. (fscipioni@seti.org)

Introduction: Irregular satellites are broadly defined by their position within the host planet's Hill sphere, and by their orbital characteristics. They have semi-major axes greater than 0.05 times the Hill sphere radius, and eccentric, highly inclined, and sometimes retrograde orbits [1]. Their chaotic orbit is evidence that they did not form in their current orbital position, but they were most likely captured by their host planet from heliocentric orbits [2].

One possible reservoir for irregular satellites of the outer planets is the Kuiper Belt, also referred to as the Solar System's *Third Zone*. The origin and physical similarities of the irregular satellites with the Trans Neptunian Objects (TNOs) can be investigated by comparing their colors and their average spectra. TNOs spread over a wide range of colors, from grey all the way to red or ultra red for which their visible colors increase with increasing wavelengths [3]. TNOs are also grouped in four different dynamical classes, based on their orbital parameters: Classical, Resonant, Scattered, and Detached [4] [5] [6] [7] [8] [9] [10].

The New Horizons spacecraft gave us the opportunity to explore one object belonging to the *Third Zone* of the Solar System, (486958) 2014 MU₆₉, informally nicknamed "Ultima Thule", for the first time.

We will compare the colors and the spectrum of 2014 MU₆₉ with those of irregular satellites of Saturn, Uranus, and Neptune to investigate whether these objects originated in the Kuiper Belt and were subsequently captured by their planet. Our aim is to improve our knowledge of how the migration process occurred in early stages of the Solar System and compare 2014 MU₆₉ with the average colors of the four TNOs dynamical classes.

Data Selection: 2014 MU₆₉ was closely observed by the instruments on board the New Horizons spacecraft. In this analysis, we will use the data returned by the Linear Etalon Imaging Spectral Array (LEISA), and the Multi-spectral Visible Imaging Camera

(MVIC) [11]. LEISA spans the spectral range 1.25-2.5 μm , while MVIC's channels cover the visible (VIS) and near infrared (NIR) range: blue (400–550 nm), red (540–700 nm), and NIR (780–975 nm), and a narrow CH₄ band filter (860–910 nm) [11].

For the irregular satellites we will use published ground-based observations covering the same LEISA and MVIC spectral range, e.g. in [12][13][14] [15] for the satellites of Saturn, [12][13][16] for Uranus, and [12][13] for Neptune. Furthermore, the Cassini spacecraft observed Saturn's irregular satellites with both the Imaging Science Subsystem (ISS), and the Visual and Infrared Mapping Spectrometer (VIMS). We use Cassini data to expand the available dataset for Saturn's irregular satellites.

Average color values from ground and space-based telescopes spanning the spectral range covered by MVIC of the main four TNOs classes were published in [17][18][19], and will be used as a comparison with 2014 MU₆₉ results.

Methodology: We will compare 2014 MU₆₉ spectral slope from MVIC data with those of the irregular satellites, and of the TNOs dynamical classes. Because the satellites, and the TNOs were observed with different instruments (e.g., Cassini ISS, Gemini telescope, Keck telescope, IRTF telescope), we will first convolve their spectral range, and the MVIC broad bands with the Johnson photometric parameters. The slopes of 2014 MU₆₉ and of the satellites will then be calculated by following the method described in [3], and they will be represented as a color-color plot, and as a function of distance from the Sun.

The same data analysis method will be applied to LEISA data, and to the satellites spectra acquired in the H, J, and K bands. At the time this abstract was submitted, 25 LEISA wavelengths were available, making the spectrum on 2014 MU₆₉ from incomplete. The wavelengths were chosen in order to cover some key regions of the spectrum, such as the location of the

water ice absorption bands at 1.5 and 2.0 μm . The complete LEISA spectrum is expected to download before the beginning of the conference.

Preliminary results: Figure 1 from [13] compares the colors of the Solar System's small body population, including the main TNOs dynamical classes, and the irregular satellites of the outer planets. The irregular satellites show, on average, a lower reddening effect than the TNOs (see also [1][13][19]). If the satellites originated in, and then migrated from, the Third Zone, surface alteration processes must have acted to modify their spectral characteristics.

The first images acquired by New Horizons camera, LORRI, 2014 MU₆₉, is a binary contact, composed of two almost spherical objects connected by a thin neck[20][21][22].

Preliminary MVIC data analysis showed that the two spherical 2014 MU₆₉ has an average red coloration [23, 24]. The expected composition of this object are H₂O, CH₄, NH₃ ices, and possibly tholin [25].

[26][27] and [28] compared the spectrum of 2014 MU₆₉ with those of Pluto's terrains and of Pluto's satellites, the comet 67P/Churyumov-Gerasimenko, and of known TNOs and Centaurs, respectively. From preliminary results, 2014 MU₆₉ spectrum shows the closest resemblance with Cthulhu Regio's signature, rather than the comet 67P/CG.

We will calculate the average color, and the average spectrum, of 2014 MU₆₉ to understand which small body group better resembles it's surface characteristic.

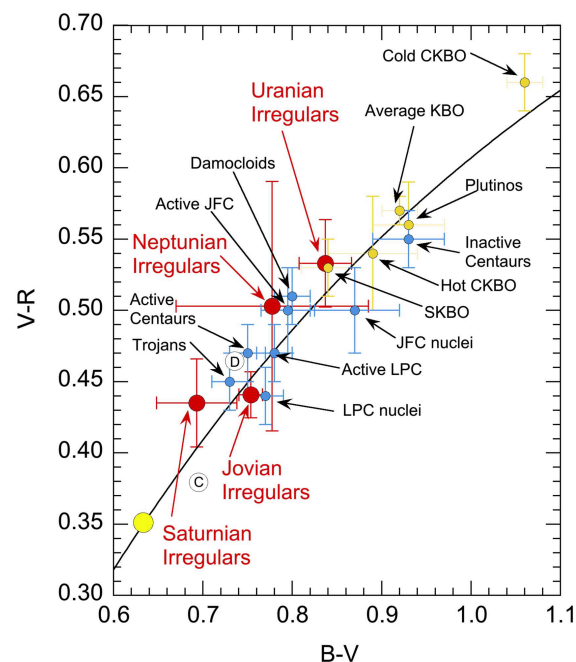


Figure 1: Colors comparison of the main small body classes of the Solar System from [13].

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