

OVERVIEW OF INITIAL RESULTS FROM THE RECONNAISSANCE FLYBY OF A KUIPER BELT PLANETESIMAL: 2014 MU₆₉ S.A. Stern¹, J.R. Spencer¹, H.A. Weaver², C.B. Olkin¹, J.M. Moore³, W.M. Grundy⁴, G.R. Gladstone⁵, W.B. McKinnon⁶, D.P. Cruikshank³, L.A. Young¹, H.A. Elliott⁵, A.J. Verbiscer⁷, J.W. Parker¹, and the New Horizons Team. ¹Southwest Research Institute, 1050 Walnut St. Suite 300, Boulder, CO 80302 (astern@boulder.swri.edu), ²Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, ³NASA Ames Research Center, Moffett Field, CA 94035. ⁴Lowell Observatory, 1400 West Mars Hill Road, Flagstaff, AZ 86001, ⁵Southwest Research Institute, 6220 Culebra Road, San Antonio, TX, 78238, ⁶Dept. Earth and Planetary Sciences, Washington University, St. Louis, MO 63130. ⁷Department of Astronomy, University of Virginia, Charlottesville, VA 22904.

Introduction: The centerpiece objective of NASA's New Horizons first Kuiper Extended Mission (KEM-1) was the close flyby of the Kuiper Belt Object (KBO) 2014 MU₆₉, nicknamed Ultima Thule [1]. On 1 Jan 2019 this flyby culminated, making the first close observations of a small KBO. Final pre-flyby trajectory predictions indicated the spacecraft would approach to within $3,500 \pm 30$ km of MU₆₉ at 05:33±0:01 UT.

Here we summarize the earliest results obtained from that successful flyby. At the time of this abstract's submission, only 4 days of data downlink from the flyby were available; well over an order of magnitude more data will be downlinked by the time of this LPSC meeting in 2019 March. Therefore many additional results not available at the time of this abstract submission will be presented in this review talk.

Objectives: 2014 MU₆₉ was discovered by members of the New Horizons team using the Hubble Space Telescope in 2014 [2]. MU₆₉'s orbit identifies it as a cold classical KBO. This means it has probably been resident at its current heliocentric distance (43 AU) and cold conditions for the past ~4.5 Gyrs. This, combined with its small size which prevents it from maintaining a strong internal geologic engine to the present, combine to make MU₆₉ the most primitive body ever studied by any planetary spacecraft.

Other than its orbital parameters and brightness, the only information known about Ultima Thule prior to observations by New Horizons were its red color [3], an approximate size (25-30 km diameter) and shape profile at the time of a 17 July 2017 stellar occultation [2], and a visible albedo estimate (~0.1) also from this occultation-measured size [2].

Key objectives of the flyby of MU₆₉ [1] were: to obtain panchromatic imaging, visible/near-IR wavelength four-color imaging, and stereo imaging of MU₆₉'s surface; to map Ultima Thule's surface composition across the 1.25-2.5 μ m IR; and to make sensitive searches for both rings and satellites orbiting Ultima Thule and any gas or particulate coma. Secondary objectives included day and night side disk-integrated average brightness temperature measurements at a wavelength of 4 cm, an attempt to measure Ultima Thule's bistatic radar reflectivity at 4 cm, a search for

dust impacts onto the spacecraft near Ultima Thule, and a search for detectable plasma interactions with the solar wind. Most of these objectives require data not yet on Earth before they can be written about. However, some data, comprising well under 1% of the total stored aboard New Horizons, is presently on the ground. We report on those data here.

Initial Results. New Horizons has revealed MU₆₉ to be a bi-lobate contact binary that appears to have merged at low speed. In addition to being the most primitive solar system object ever to be explored in situ by any spacecraft, MU₆₉ thus also becomes the first primordial contact binary. The appearance and contact binary nature of this object is consistent with it being a relic planetesimal possibly created by pebble accretion. How MU₆₉'s two lobes merged, how gently, and how much angular momentum was lost prior to contact are puzzles to be solved as more data are returned and detailed modeling can be undertaken.

MU₆₉'s panchromatic and color appearances are shown in Figures 1 and 2, respectively.

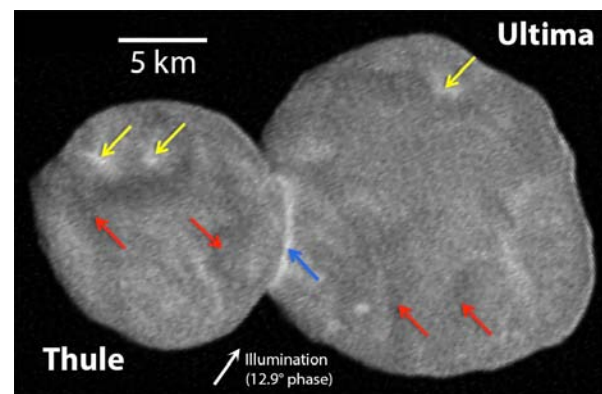


Figure 1: Ultima Thule as seen by the LORRI imager in the close approach CA04 observation (140 m/pixel), including relatively bright circular patches a few km wide (yellow arrows), darker regions up to several km wide (red arrows), a bright, cylindrically symmetric neck (blue arrow), and quasi-linear and arcuate bright features; note also the mottled appearance.

The two lobes of MU₆₉ have very similar, quasi-spherical shape profiles in the available imaging. This

* Some feature names mentioned in this paper are now formalized while others are informal

near sphericity is likely an important clue to their accretional mechanism. Ultima Thule's overall major axis length is 31.7 ± 0.5 km.

For the purposes of discussion, MU₆₉'s larger and smaller lobes have been informally designated "Ultima" and "Thule," respectively, by the New Horizons team. Ultima and Thule have best-fit measured diameters of ~ 19.5 and ~ 14.2 km, respectively, with errors of only a few percent at this time. This, combined with its low amplitude lightcurve determined by New Horizons, suggests that the two lobes have $\sim 2.6:1$ volume, and perhaps, mass ratios.

Ultima Thule's rotation period has been measured by New Horizons at 15 ± 1 hours. How it slowed to this relatively long period after merging is another puzzle to be solved.

Although a mottled appearance and limb topography (amplitudes >1 km for Ultima and ~ 0.5 km for Thule) was resolved on each lobe, geological features are not clearly identifiable in the currently available images, which have only a limited range of low (11 – 13°) solar phase angles. However, the significant limb topography variations detected suggest a mechanically strong "crustal zone" and/or bulk interior, perhaps composed of some combination of H₂O-ice, CO₂-ice, other ices, and refractory organics/rock.

Although the two lobes of Ultima Thule have closely similar reflectivities, significant albedo variations of 0.06 – 0.14 are seen on both lobes. The average I/F for the object as seen in Figure 1 is 0.09 . Initial analysis reveals that this average albedo is similar to other cold classical KBOs. The most prominent albedo feature is a narrow (<300 m tall) bright, cylindrically symmetric neck where the lobes Ultima and Thule are joined. The origin of this remarkable feature is unclear; either endogenic (fine particle accumulation) and/or exogenic (lobe merger) possibilities may be the cause.

Ultima Thule's overall color displays a red slope of $+24.3\%$ per 1000 \AA at 5500 \AA . Additionally, New Horizons found 1.25 – 2.5 \mu m near-infrared I/F varies between 0.17 and 0.19 .

Little significant color variegation across either lobe has been detected as of this writing, however, the brighter neck region at the interface of the two lobes is slightly less red than the bulk color. Initial analysis reveals that Ultima Thule's color is similar to other cold classical KBOs (see also [3] with lower SNR HST color measurement than New Horizons). In comparing our Ultima Thule observations to Nix, we do not yet

see strong evidence for the 2.0 \mu m H₂O-ice band, and therefore the abundance of H₂O-ice on the surface is likely to be much less than observed by New Horizons on Pluto's satellites [4].

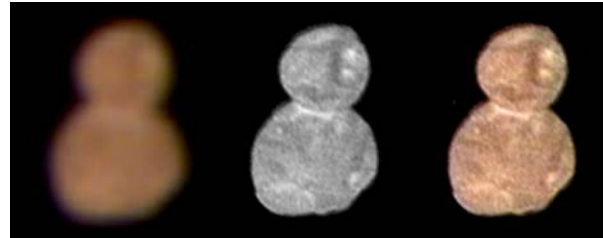


Figure 2: Left to right: Enhanced color image at 1.5 km/pixel resolution, panchromatic image at 140 m/pixel resolution, and enhanced color overlaid on the panchromatic image.

As expected, we found no evidence for a gas coma in initial inspections of UV airglow and solar apulse coma absorption datasets collected by the UV spectrograph on New Horizons, though the majority of those data are still to be downlinked. As also expected, no solar wind interaction or emitted pickup ions were detected in initial data analyses of the New Horizons plasma and charged particle spectrometer instruments, though the majority of those data are also still to be downlinked.

Regarding dust near Ultima Thule, New Horizons saw no evidence down to $I/F \sim 5 \times 10^{-7}$ in imaging available by 4 Jan 2019. In addition, zero impacts onto the New Horizons dust counter were detected inside MU₆₉'s Hill sphere. And no satellites were detected down to 1.5 km diameter (under the assumption of an Ultima Thule-like reflectivity) outside of 1000 km from Ultima Thule. A search for closer rings or satellites has not yet been performed.

References. [1] Stern, S. A., Weaver, H.A., Spencer, J.R., and Elliot, H.A. (2018), *Space Science Reviews* 214, 76-99. [2] Buie, M.W. et al. (2018), DPS Meeting #50, id.509.06. [3] Benecchi, S., et al. (2019), *Icarus*, in press. [4] Cook, J., et al. (2018), *Icarus*, 315, 30-45.

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