THE SEARCH FOR MOONS AND RINGS OF 2014 MU69. J. R. Spencer[1], M. R. Showalter[2], T. R. Lauer[3], M. W. Buie[1], S. B. Porter[1], H. B. Throop[4], W. M. Grundy[5], H. A. Weaver[6], S. A. Stern[1], D. P. Hamilton[7], D. E. Kaufmann[1], A. J. Verbiscer[8], A. M. Zangari[1], C. B. Olkin[1], J. W. Parker[1], the New Horizons Geology, Geophysics, and Imaging Team, the New Horizons LORRI Team, and the New Horizons Ralph Team. [1]Southwest Research Institute, Boulder, CO 80302, spencer@boulder.swri.edu, [2]SETI Institute, Mountain View, CA 94043, [3]NOAO, Tucson, AZ 85726, [4]Planetary Science Institute, Washington, DC, 20016, [5]Lowell Observatory, Flagstaff, AZ 86001, [6]JHU Applied Physics Lab, Laurel, MD 20723, [7]U. Maryland, College Park, MD 20742, [8]U. Virginia, Charlottesville, VA 22904.

Introduction: A prime ("Group 1") goal of the New Horizons flyby of Kuiper Belt object (486958) 2014 MU_{69} (nicknamed "Ultima Thule") [1] was to search for satellites and rings, both of which have been detected around larger KBOs, and around Centaurs derived from the Kuiper Belt [2,3,4]. The presence (or absence) of satellites provides important constraints on the origin and evolution of KBOs [5]. The detection of rings would also be of great interest, particularly because the origin of rings around small bodies is still very mysterious.

The search during early approach (through encounter minus 19 days) was motivated by concerns over potential hazards to the spacecraft during the flyby. Later in approach, prompt detection of any large satellites was important for characterization of any resulting offset of the primary body from the barycenter, which would need to be accounted for in close approach targeting. The team also had the option of retargeting a high-resolution observation to observe a satellite if one was found, as late as 2 days before encounter.

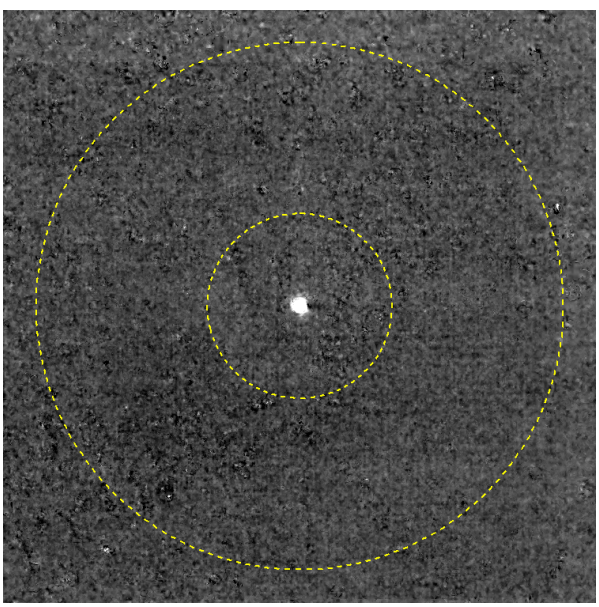

Figure 1. Example processed satellite search image, combining data taken between 6.9 and 3.2 days before encounter, showing the lack of detected satellites around 2014 MU_{69} (center). Dashed yellow circles denote radii of 3,500 km (the flyby distance) and 10,000 km.

Observations: Sets of up to 120 30-second exposure images, designed to search for both moons and rings, were taken starting 40 days before encounter with the Long-Range Reconnaissance Imager (LORRI) camera using its 4x4 pixel binning mode [6]. Between 3.3 and 0.25 days before closest approach, LORRI mosaics were made to increase the search area. Images taken for optical navigation also provided important constraints.

In addition, deep high phase angle imaging searches for forward-scattering rings were taken after closest approach with the Multi-spectral Visible Imaging Camera (MVIC) framing camera, part of the Ralph instrument [7], due to its superior rejection of scattered sunlight compared to LORRI [8]. Near close approach, high-resolution high-phase images with resolution as fine as 0.15 km/pixel were taken with both MVIC and LORRI to look for forward-scattering material.

Search Methods: Because UT was located in front of the galactic center during approach, moons and rings were difficult to recognize against the dense starfield. In preparation for the search, we developed five independent image analysis pipelines to address the challenge. Each involved subtracting out the starfield using images taken earlier during the approach, and searching for any residual point sources exhibiting motion between visits that was consistent with a location near 2014 MU_{69} (Figure 1). We also developed tools for astrometry, photometry, and orbit fitting. Detection limits were determined by searching for synthetic moons and rings implanted in the data. For the hazard search we also developed theoretical models for any plausible dust rings around UT, along with the software tools needed to detect and characterize them.

Moons: No moons have been detected as of early January 2019, although many images remain to be downlinked. Figure 2 illustrates the current limits, compared to expected final limits once all images have been downlinked and analyzed. Note that current limits are less constraining between 100 and 800 km radius. This is because the sensitivity of early searches is limited below about 800 km radius by the brightness of 2014 MU_{69} itself, and close approach images analyzed so far do not extend beyond ~100 km radius from 2014 MU_{69}. We will search this region much more

thoroughly when more images are available, beginning in late January 2019.

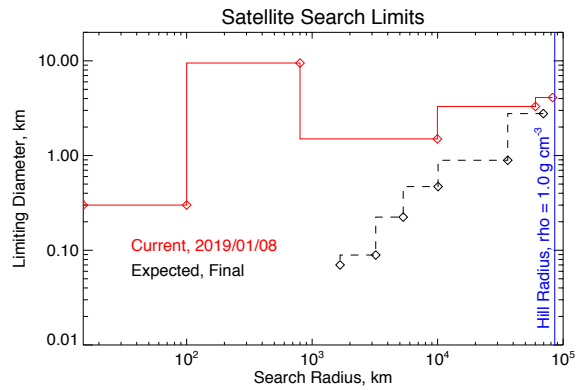

Figure 2. Satellite search limits as of early January 2019 (red), and expected after final analysis of all data (black). Limiting diameters assume that satellites have similar albedo and photometric properties to 2014 MU_{69}.

Rings: Dynamical analysis of potential rings around UT has revealed that they would have highly unusual structures because UT's very weak gravity is comparable to solar radiation pressure. The smallest dust grains, which are strongly perturbed by sunlight, are only stable in "sunflower" configurations, where the ring is always oriented with its rotation axis pointed toward or away from the Sun [9]. Larger grains are less affected by sunlight; these could form a more conventional ring centered on the local Laplace Plane. Beyond ~ 10,000 km, the Laplace Plane is equivalent to the ecliptic plane; inward, it is closer to UT's rotational equator.

No rings have been detected in the approach images analyzed so far. Any ring outside ≳ 1000 km with $I/F \gtrsim 5 \times 10^{-7}$ and width > 20 km would have been visible in our data. This limit is comparable to or below the reflectivities of many faint outer rings of the giant planets. A search for closer and denser rings, or forward-scattering rings best detected after close approach, awaits downlink and analysis of the appropriate images.

References: [1] Stern, S.A. et al. (2019) *LPSC 50.* [2] Noll K. S. et al. (2008), in *The Solar System Beyond Neptune*, Barucci, M. A. et al., eds., U. Arizona Press, p 345. [3] Braga-Ribas, F. et al. (2014) *Nature*, **508**, 72. [4] Ortiz, J. L. et al. (2017) *Nature* **550**, 219. [5] Nesvorny, D. et al. (2011) *Astron. J.* **141**, 149. [6] Cheng, A. F. et al. (2008) *Space Sci. Rev.* **140**, 189. [7] Reuter, D. C. et al. (2008) *Space Sci. Rev.* **140**, 129. [8] Lauer, T. R. et al. (2018) *Icarus* **301**, 155. [9] Hamilton, D. P. (2018) AAS/DDA meeting, 401.02.