COLORS OF (486958) 2014 MU69 AS OBSERVED BY NEW HORIZONS' MULTI-SPECTRAL VISIBLE IMAGING CAMERA (MVIC) C. J. A. Howett[1], A. H Parker[1], C. B. Olkin[1], S. Protopapa[1], W. Grundy[2], B. Schmitt[3], J. Kavelaars[4], D. Britt[5], J. W. Parker[1], D. Reuter[6], S. A. Stern[1], J. R. Spencer[1], A. J .Verbiscer[7], H. A. Weaver[8] and the New Horizons Composition Team. [1]Southwest Research Institute, Boulder, CO, howett@boulder.swri.edu, [2]Lowell Observatory, Flagstaff, AZ, [3]Université Grenoble Alpes, IPAG, Grenoble, France, [4]National Research Council of Canada, Victoria, BC, [5]University of Central Florida, Orlando, FL, [6]NASA Goddard Space Flight Center, Greenbelt, MD, [7]University of Virginia, Charlottesville, VA, [8]Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

Introduction: On the 1st January 2019 NASA's New Horizons spacecraft had a close encounter with the Kuiper Belt Object (486958) 2014 MU69 (nicknamed Ultima Thule). An overview of the results from the flyby will be presented in [1]. During the encounter the Ralph instrument's Multi-spectral Visible Imaging Camera (MVIC) took 32 sets of color images. This work shows the analysis of the highest spatial resolution observation returned to date, but the analysis of all color images downlinked by March 2019 will be presented.

Introduction to the MVIC instrument: MVIC is has a single substrate, which holds seven independent CCD arrays. Four of these CCDs have a color filter (Red, Blue, NIR, CH4, see Table 1); it is the results from these CCDs that are the subject of analysis here. Details of the post-launch calibration of MVIC are given in [2], using both stellar observations and observations of Pluto's moon Charon.

Array name	Wavelength range (nm)	Pivot wavelength (nm)
Blue	448-547	492
Red	542-697	624
NIR	781-971	861
CH4	860-909	883

Table 1 - The details of MVIC color arrays.

Introduction to the MVIC observations taken of MU69: As stated above 32 color observations were made of MU69 by MVIC, of these 2 were in the outer core (>24 km/pixel), 26 in the inner core on approach (between 22.0 and 1.5 km/pixel), 3 during the inner core prime (between 0.5 and 0.9 km/pixel) and 1 was taken on departure (2.7 km/pixel). Details of the three observations returned at the time of writing are given in Table 2. Of these three MU69 is only resolved in one of them (APROTH_MC_2019001J), which is the focus of the work presented here.

Between now and March 2019 another 11 observations will be returned (with hope that another 2 will also be returned, see Table 3), which will provide additional phase coverage and at least one higher spatial resolution observation (CA10).

Observation Name	Start time (UTC)	Pixel Scale (km/pix)
MU69_ROTCOVER_MC_2018365	30 Dec 2018 16:49:31	37.8
MU69_APROTL_MC_2018365C	31 Dec 2018 09:33:26	20.6
APROTH_MC_2019001J	31 Dec 23:32:49	1.5

Table 2 – List of MVIC color observations downlinked at the time of writing.

Observation Name	Start time (UTC)	Pixel Scale (km/pix)
MU69_APROTH_MC_2018365D	31 Dec 2018 19:46:26	10.5
MU69_APROTH_MC_2018365E	31 Dec 2018 20:23:26	9.4
MU69_APROTH_MC_2018365H	31 Dec 2018 22:06:56	7.6
MU69_APROTH_MC_2018365J	31 Dec 2018 23:32:49	6.2
MU69_APROTH_MC_2018365K	31 Dec 2018 23:54:20	5.8
APROTH_MC_2019001B	1 Jan 2019 00:37:22	5.1
APROTH_MC_2019001C	1 Jan 2019 00:58:53	4.7
APROTH_MC_2019001E	1 Jan 2019 01:41:55	4.0
APROTH_MC_2019001F	1 Jan 2019 02:03:26	3.6
APROTH_MC_2019001H	1 Jan 2019 02:25:05	3.2
CA02_MAP_2019001*	1 Jan 2019 04:42:50	0.81 to 0.91
CA05_HIRES_2019001*	1 Jan 2019 05:09:42	0.35 to 0.40
CA10_PHASE_MC_2019001	1 Jan 2019 06:01:31	0.6

Table 3 – List of MVIC color observations expected between time of writing and March 2019. * indicates observations expected to be returned in this time frame, but not yet sequenced.

Figure 1 – MVIC NIR/Red/Blue enhanced color image of MU69 taken on 1st January at 04:08:41UTC.

Figure 2 – The color from Figure 1 overlaid onto LORRI image taken on 1st Jan 2019 at 05:01:47 UTC.

Results: The resolved color image of MU69 is shown in Figure 1. It shows MU69 at 11.68° phase to be a red, confirming the findings of [3]. MU69 is shown to be a double lobed object, with possible small-scale coloration variations. To compare the coloration with surface features the color image is overlaid onto the released LORRI image taken closest in time: KELR_MU69_CA04-MAP_L1_2019001. This LORRI image has a spatial resolution of 0.14 km/pix, and was taken on the 1st Jan 2019 at 05:01:47 UTC. This means there is ~1 hour between the MVIC and LORRI images, and so MU69 will have rotated minimally (assuming a 15.3 hour rotation period [4]).

Figure 3 shows that the coloration of the two lobes (the big one is nicknamed Ultima, and the small one Thule) are the same within uncertainty in all filters. However, the figure also shows that the neck region connecting the lobes (while still red) may have a distinctively different color in the Red and Blue: Red I/F of 0.090±0.003 compared to that of Thule (0.084±0.004) and Ultima (0.079±0.005); Blue I/F of 0.066±0.004 compared to Thule (0.058±0.005) and Ultima (0.053±0.005).

Conclusion: The similarity in colors between the lobes suggests a common origin [5], while the appearance of the neck at these low phase angles to be less-red could be evidence of particle size variations or other surface differences including composition. Higher resolution images and spectral information (yet to be returned) will enable testing of these hypotheses.

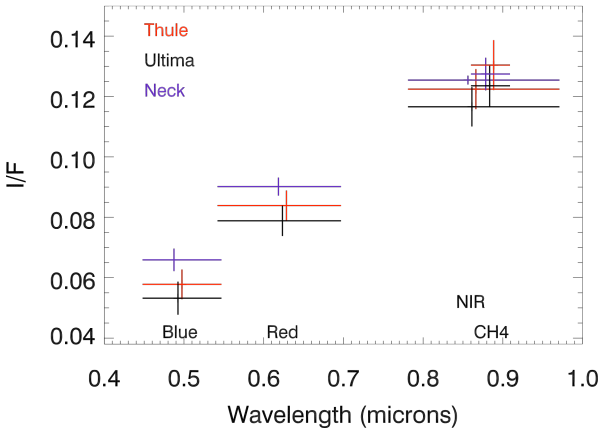

Figure 3 – I/F Blue, Red, NIR and CH4 colors of the Thule (small lobe), Ultima (large lobe) and the neck region. The wavelength range of the filters covers those that have a throughput above 0.05 (with different regions slightly offset from that of Ultima for clarity). The I/F error bar is the standard deviation of pixels within each region. The names of each filter used are indicated on the bottom of the plot.

Acknowledgments: New Horizons team members gratefully acknowledge funding from NASA's New Horizons project.

References: [1] Stern, S.A. et al. (2019) 50th LPSC, [2] Howett, C.J.A. et al (2017) Icarus 287, 140-151. [3] Benecchi, S.D. et al. (2018) Icarus Submitted. [4] Porter, S.B. et al. (2019) 50th LPSC. [5] Umurhan et al. (2019) 50th LPSC.