**INVESTIGATIONS OF THE ORIGINS OF PLUTO'S SURFACE DARK MATERIALS: SPECTRAL MODELING.**
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**Introduction:** When *New Horizons* encountered Pluto, the Ralph instrument [1] revealed a world diverse in color and composition [2, 3, 4, 5, 6]. Prominent regions of Pluto's surface ranged in brightness from Sputnik Planitia ($I/F \sim$ 0.4-0.6) to Cthulhu Macula ($I/F \sim$ 0.1-0.2). The darkening agent, which dominates in Cthulhu Macula and is seen at varying levels across Pluto, is likely due to organic refractory materials resulting from a combination of surface (ice irradiation) and atmospheric (photochemistry, radiolysis) processes. We are interested in understanding the importance of Pluto's atmospheric haze particles ($i$) as an origin of the dark materials and ($ii$) to better understand the processes resulting in the diversity of colors and spectra observed by *New Horizons*[7]. Here we report on spectral modeling, with a focus on the tholin contribution.

**Observations:** On July 14, 2015, NASA's *New Horizons* spacecraft flew past Pluto at about 12,000 km from the surface [2]. Using the Ralph [1] instrument, *New Horizons* successfully obtained images and spectra necessary to map the composition and distribution of ices and organics on Pluto's surface (*e.g.* [2]). Ralph is a dual channel instrument with MVIC (Multi-spectral Visible Imaging Camera), the visible color imager, and LEISA (Linear Etalon Imaging Spectral Array), the near-infrared spectrograph. MVIC images the surface in blue (0.40-0.55 $\mu$m), red (0.54-0.70 $\mu$m), near-infrared (0.78-0.98 $\mu$m), a narrow $CH_4$-band (0.86-0.91 $\mu$m), and panchromatic (0.40-0.98 $\mu$m) wavelength regions[1]. LEISA covers the spectral range from 1.25 to 2.50 $\mu$m at a resolving power ($\lambda/\Delta\lambda$) of 240 and 2.10 to 2.25 $\mu$m at a resolving power of 560. We list the observations used in this project in Table 1.

Table 1: Table of New Horizons/Ralph observations.

| Request ID | Distance (km) | Resolution (km/pix) |
|---|---|---|
| PELE_01_P_ LEISA_Alice_2a | 114,000 | 6-7 |
| PELE_01_P_ LEISA_Alice_2b | 103,000 | 6-7 |
| PELE_01_P_ LEISA_Hires | 47,000 | 3 |
| PEMV_01_P_ COLOR_2 | 34,000 | 0.66 |

**Methodology:** We have selected three regions of interest on Pluto to study the presence and distribution of tholins: Sputnik Planitia, Cthulhu Macula, and Lowell Regio. Each region is broken into several smaller groupings based on the clustering of the LEISA-only data [8]. To study Pluto's tholins, we use *New Horizons* MVIC and LEISA data listed in Table 1 and fit Hapke spectral reflectance models to the data. Such models rely on understanding the optical constants of each refractory substance. In the case of ices present on Pluto, the optical constants are well understood. In the case of tholins, we use the optical constants from [9] since they were developed using Pluto's atmospheric composition at three altitudes. We also use new optical constants developed as part of this project [7, 10].

**Results:** Figure 1 shows a map of the extracted spectra from each cluster in and around Sputnik Planitia [8]. The average LEISA spectrum from each cluster is shown in the lower part of Fig. 1. The color of each spectrum and its label ($a$-$f$) correspond to the colors on the map.

In Fig. 2, we show the LEISA + MVIC spectrum for each cluster in Sputnik Planitia along with several preliminary Hapke models. In each cluster $CH_4$ is present. In several of the clusters, we also note the 2.148 $\mu$m-band due to $N_2$ is present. We also note the presence of the 1.57 and 2.35 $\mu$m-CO-bands. The band at 2.35 $\mu$m is somewhat blended with the adjacent strong $CH_4$ bands while the 1.57 $\mu$m-band is more notable, particularly in clusters $a$, $d$ and $f$. The presence of $H_2O$ is noted in clusters $b$ and $e$. All clusters except $b$ appear to have near-neutral colors in the MVIC channels and the choice of tholin has little effect on the modeled spectrum.

Figure 3 shows a map of the extracted spectra from each cluster in and around Cthulhu Macula. The LEISA spectrum for each cluster is shown in the lower part of Fig. 3. The colors used to show each spectrum and label ($a$-$g$) correspond to the colors used on the map.

In Fig. 4, we show the LEISA + MVIC spectrum for each cluster in Cthulhu Macula along with several preliminary Hapke models. Unlike the spectra from Sputnik Planitia, $CH_4$ is only prominently detected in two of the clusters ($b$ and $f$), which lie in the northeastern ($b$), and the southern boundary ($f$) of Cthulhu. The remain-

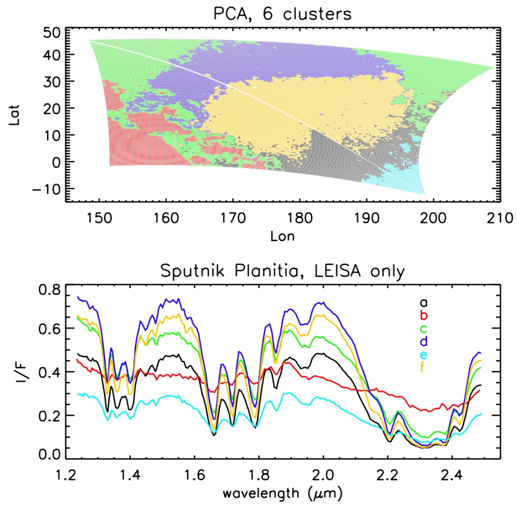


Figure 1: Cluster map (top) and LEISA spectra (bottom) of Sputnik Planitia.

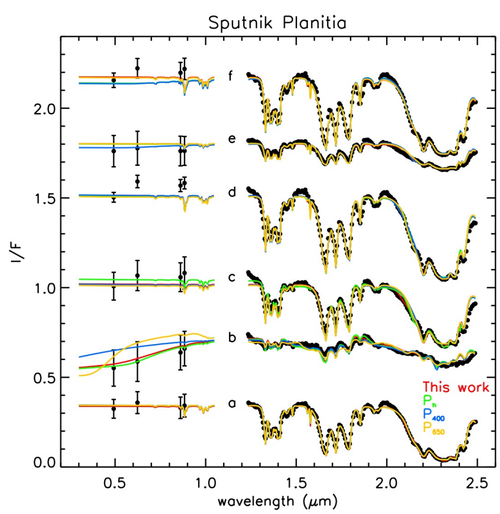


Figure 2: MVIC + LEISA spectra (points) and Hapke models (lines) from 6 spectral regions in and around Sputnik Planitia.

ing spectra show absorption features typical of both water (bands at 1.5 and 2.0 $\mu$m) and hydrocarbons larger than $CH_4$ (band $\gtrsim$ 2.3 $\mu$m).

At the meeting, we shall present our results in greater detail. We will expand our discussion to include spectral analysis using additional tholin we are currently developing. Finally, we will also include an analysis of Lowell Regio.

**Acknowledgements:** The authors acknowledge the support of the NASA ROSES NFDAP (NNH20ZDA001N) program.

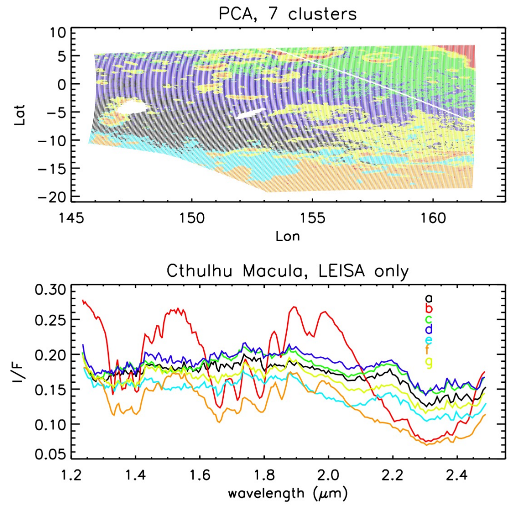


Figure 3: Cluster map (top) and LEISA spectra (bottom) of Cthulhu Macula.

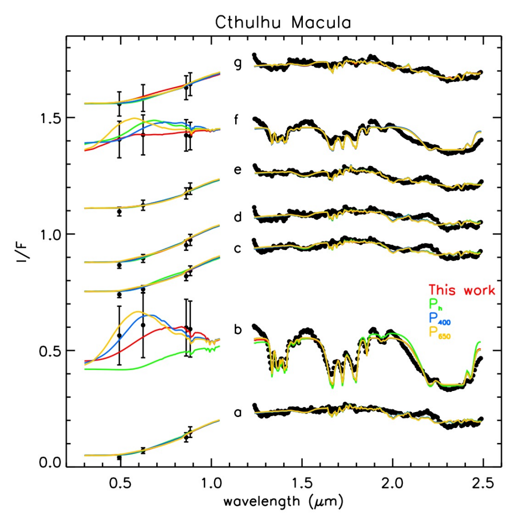


Figure 4: MVIC + LEISA spectra (points) and Hapke models (lines) from 7 spectral regions in and around Cthulhu Macula.

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