Pluto, Titan, and Triton: How do their Haze Properties Compare? B. J. Buratti[1], J. D. Hillier[2], J. D. Hofgartner[2], M. D. Hicks[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; bonnie.buratti@jpl.nasa.gov; [2]Grays Harbor College, Aberdeen, WA 98520.

Introduction: The July 2015 encounter of the *New Horizons* spacecraft with Pluto brought a large Kuiper Belt Object into sharp focus for the first time [1]. Instruments on the spacecraft observed Pluto at solar phase angles not visible from the Earth, where the maximum solar phase angle is about 2°. The large solar phase angles (>150°), are especially useful for characterizing the properties of Pluto's haze. But key observations were not made during the encounter because of the fast nature of the flyby. These included the small solar phase angles observable from Earth. Thus, the best data set is one consisting of both spacecraft and ground-based data.

We have combined Earth-based observations, including those from the Palomar Adaptive Optics (AO) system, to construct a complete solar phase curve of Pluto. Using the classical radiative transfer model of Chandrasekhar's "Planetary Problem" (2,3) we have fit physical parameters to the surface and haze of Pluto. Comparison with the properties of Titan's haze shows that both worlds are factories for producing reddish, organic rich molecules.

Data: Both ground-based and *New Horizons* data were used in this analysis. For the small solar phase angles, Table 1 summarizes the data that were successfully obtained in 2018 and 2019 with the AO system at Palomar, which is capable of separating the disks of Charon and Pluto (see Figure 1). Observations between one and two degrees were not obtained because the system was down for refurbishment in late 2018 for several months to undergo a refurbishment. These data will acquired in late 2020.

Table 1 - Adaptive Optics Observations

Time	Solar phase angle (°)	Longitude (°)	Comments
July 7, 2018	0.008	35	
July 12	0.022	340	Lowest phase for 161 years
July 30	0.54	50	
June 13, 2019	0.85	118	
July 12	0.046	287	
July 13	0.0196	230	Lowest phase on "heart"

Figure 1: Charon and Pluto from the Palomar adaptive optics system.

Data from the spacecraft are summarized in Table 2.

Table 1- *New Horizons* Data used in this Study.

Image ID	Phase Angle	Subspacecraft Point
	16º	LORRI 1d2a: 42, 182
PC_COLOR_TIMERES	17º	LORRI TIMERES_3: 42, 170
P_COLOR1	18º	41, 161
P_LORRI	20º	40, 159
P_LORRI_STEREO_MOSAIC	25º	36, 160
P_LEISA_HIRES	30º	
P_COLOR2	40º	26, 168
P_MPAN1	50º	19, 174
P_MVIC_LORRI_CA	70º	1, 186
P_MP_Photslew	115º	-36,215
P_HIPHASE_HIRES	150º	-54, 255
PC_RALPH_CHARON_270DEG	165º	-44, 196
NAV_C4_L1_NONCRIT_1_02	165º	-44, 233
PC_MULTI_DEP_LONG_3	166º	-44, 290
P_LORRI_FULLFRAME_DEP	166º	-44, 289
PC_MULTI_DEP_LONG_2	167º	-45, 307
P_MULTI_DEP_LONG_1	169º	-46, 313

Analysis: A radiative transfer model based on Chandrasekhar's "Planetary Problem" in which a surface is overlain by an atmosphere which here is optically thin was fit to the data. The surface properties are macroscopic roughness, the single particle phase function, and the single scattering albedo. The haze properties are the single scattering albedo and the single particle phase function. With data from the multi-filter MVIC instrument, some constraints can be place on the spectrum, and thus the composition, of the haze.

Figure 2 shows the data with our model results. Observations from both the Long Range Reconnaissance Imager (LORRI) and the Multispectral Visible Imaging Camera (MVIC) were used, with the LORRI data being combined with the MVIC R-filter for the analysis.

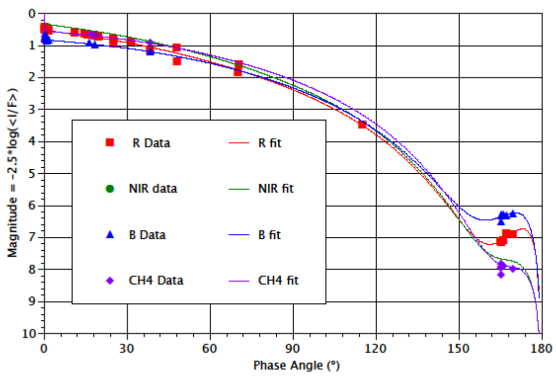

Figure 2. Our combined *New Horizons* and ground-based data with a preliminary radiative transfer model fit.

Results: For the surface, we find a macroscopic roughness on the low side (~18°) for icy surfaces. The single scattering albedo ranges from 0.95 in the red filter to 0.99 in the methane filter. The surface of Pluto is not as backscattering as those of the icy moons of Saturn and Jupiter (4). The haze optical depth ranges from 0.01 in the red filter to 0.006 in the methane filter, and the haze is strongly backscattering – more so than both Titan and Triton - with a Henyey-Greenstein g of about 0.8. Although the spectrum of the haze cannot be uniquely determined, it is consistent with a spectrum similar to Titan's. Our analysis of Titan's haze places a quantitative description of the haze layer imaged by *New Horizons* (Figure 3).

Discussion: Our ongoing analysis provides the first example of the photometric analysis of an object that is covered in ice that is not water ice.

The substantial haze layer on Pluto was an unexpected finding that places this Kuiper Belt Object more akin to Mars and Titan than to the family of icy moons (with the possible exception of Triton). The spectrum of this haze is similar to that of Titan (5), and likely rich in organics. By forming a patina of low-albedo, reddish, organic-rich surface material, the haze seems to play a substantial role in geologic processes on Pluto (6), similar to that provided by the grains of organic-rich sand that form dunes on Titan (7). The atmosphere of Pluto is thus an incubator for organic material, which, coupled a likely subsurface ocean on Pluto, provides a potentially habitable environment similar to that of Titan.

Figure 3. An image of New Horizons captured by New Horizons after the encounter showing the forward scattering nature of the planet's haze. Our model has quantified the extraordinary backscattering nature of the haze. Image courtesy of NASA/APL/SWRI.

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