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Supplementary Materials for

Surface compositions across Pluto and Charon

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This PDF file includes:

Supplementary Text

MVIC radiometric calibration

MVIC throughput and I/F calibration were achieved through a combination of cruise stellar calibrations for absolute throughput of the RED channel followed by a channel-by-channel relative calibration using the global photometry of Charon as a calibration standard, matched to the global photometry of Charon derived from HST ACS HRC F435W and F555W observations (56). New Horizons observations used for calibration were geometrically corrected to re-weight the contribution of Charon's red polar spot given the sub-observer latitude of the HST observations. In addition to calibrating the system throughput, an additional instrument calibration was performed on the data presented in this paper: on approach, the gain of the NIR channel was found to change from scan to scan in a non-predictable fashion on one of the instrument's two power sides. The gain remained constant during each scan. The problematic power side was used for the P_COLOR2 Pluto observation described in this paper. In order to correct for this drift, earlier overlapping images taken on the alternate power side were used to bootstrap a gain correction. Sputnik Planum was used as the control region for this bootstrapped correction, for its nearly neutral color and relative lack of albedo contrasts. The PC_MULTI_MAP_B_17 observation obtained 2015 July 13 at 3:38 UT, at a scale of 32 km/pixel was used as the control data.

MVIC color CH_4 equivalent width

MVIC's CH4 filter is centered on the strongest CH_4 ice absorption band in MVIC's wavelength range, at 890 nm. We estimate the equivalent width of absorption in that band from MVIC's RED, NIR, and CH4 bands as follows. We start by forward modeling the parameter space of possible equivalent widths and spectral slopes, assuming reflectance is a linear function in wavelength with the addition of a perfect absorption band (zero reflectance) centered at 890 nm. This simple model is multiplied by a solar spectrum and sampled according to MVIC's wavelength-dependent filter transmissions, throughputs, and quantum efficiencies to compute a grid of synthetic CH4/NIR and RED/NIR ratio values as functions of slope and equivalent width. Equivalent width and slope maps can then be computed from actual MVIC CH4/NIR and RED/NIR ratio images, pixel by pixel, by interpolating the forward-modeled grids to retrieve the corresponding equivalent width and slope values. The equivalent width map is shown in Fig. 5 while the slope map is shown in Fig. S3.

Pluto normal albedo map

To map albedos or reflectances across a planet's surface, a photometric model is needed to account for changes in viewing and illumination geometry across the field of view of individual images and across multiple observations obtained at different times. We used this simple photometric model from (41):

$$I/F \;=\; A f(\alpha)\frac{\cos(i)}{\cos(i)+\cos(e)} \;+\; (1-A)\cos(i)$$

where I/F is the specific intensity, i is the incident angle, e is the emission angle, and $f(\alpha)$ is the surface solar phase function, which includes changes in intensity due to the physical character of the surface (roughness, the single scattering albedo, the single particle phase function, the compaction state of the optically active portion of the regolith, and coherent backscatter). The first term describes singly scattered radiation while the second term describes multiple scattering; *A* is a parameter that gives the fraction of each component. Fitting this function to the LORRI observations of Pluto's surface gives *A* = 0.7, in which 30% of the reflected photons are multiply scattered. This function is similar to those found for icy moons of Saturn (41). Because the images from New Horizons were obtained at solar phase angles of 11° and above, it is necessary to use ground-based observations to correct I/F to normal reflectance, which is the albedo for incident, emission, and solar phase angles all equal to 0°. To correct to 0° we used the phase behavior from ground-based observations below 2° (42,43) and full-disk New Horizons LORRI images at 11° and 14°.

Charon's NH_3 absorption

NH_3 ice has characteristic absorption bands at 2.00 and 2.22 µm (the exact wavelength ranges from 2.20 to 2.24 µm depending on the hydration state). The 2.00 µm band is hard to discern on Charon since the ubiquitous H_2O ice also absorbs strongly at that wavelength, but the 2.22 µm NH_3 band coincides with an H_2O continuum region. We mapped this band in LEISA data by computing *I*/*F* averages over wavelengths from 2.20 to 2.24 µm, covering the NH_3 ice absorption band, and also over adjacent continuum wavelengths from 2.10 to 2.17 µm and from 2.26 to 2.29 µm. Dividing the continuum average image by the band average image gives larger values where the NH_3 absorption is stronger. The resulting NH_3 absorption map is shown in Fig. S6. It is spatially fairly uniform, with only a few believable features rising above the noise, the most prominent of which corresponds to Organa crater at 310.9° E, 54.3° N. The region around Organa crater is enlarged in Fig. 8C.

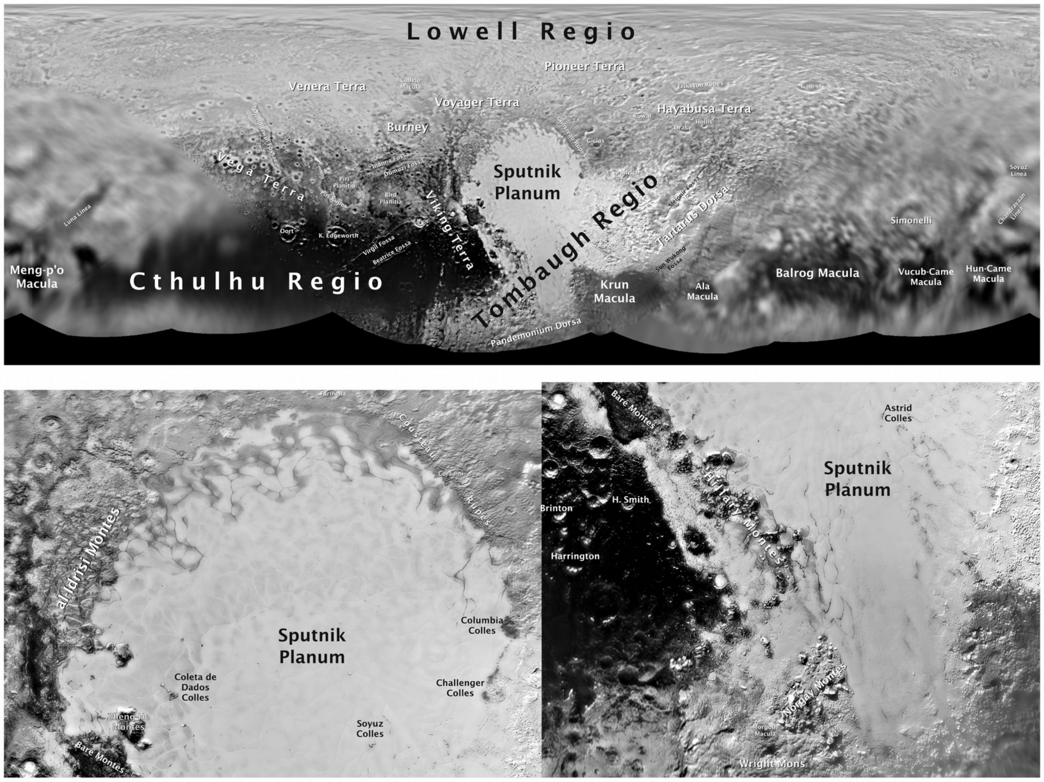

Fig. S1.

Nomenclature maps for Pluto. This figure is duplicated from Moore et al. (4). All names are informal.

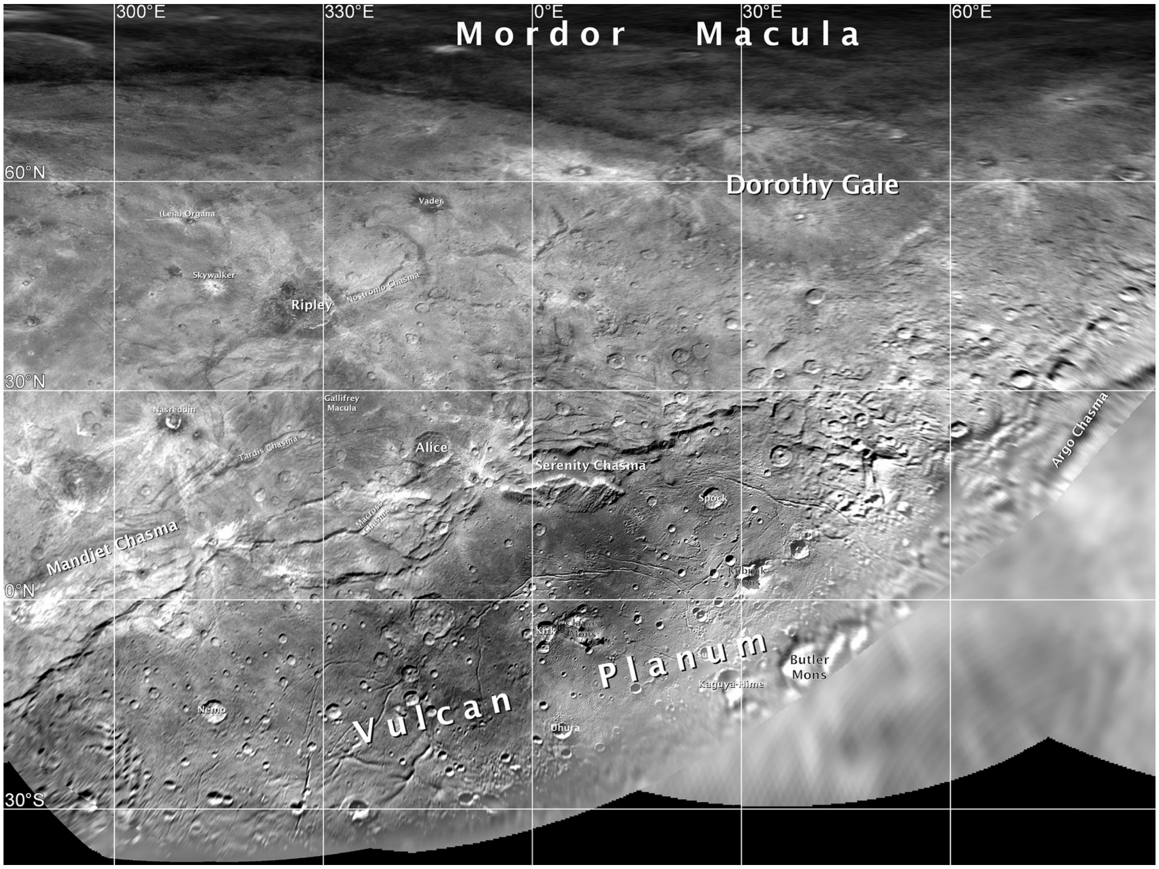

Fig. S2

Nomenclature map for Charon. This figure is duplicated from Moore et al. (4). All names are informal.

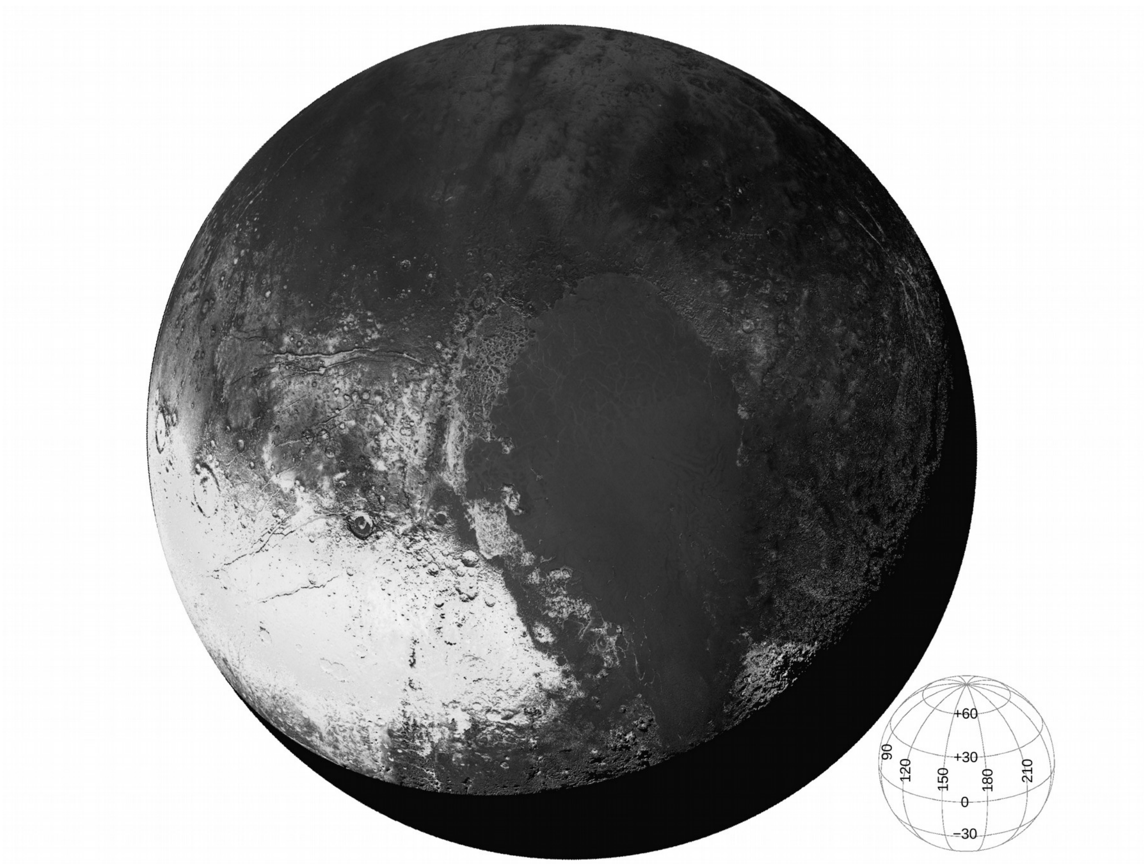

Fig. S3

Pluto spectral slope. This map is a computed in concert with the 890 nm equivalent width map shown in Fig. 5. Brighter areas correspond to redder spectral slopes over the 540 to 975 nm wavelength range sampled by MVIC's RED, NIR, and CH4 filters.

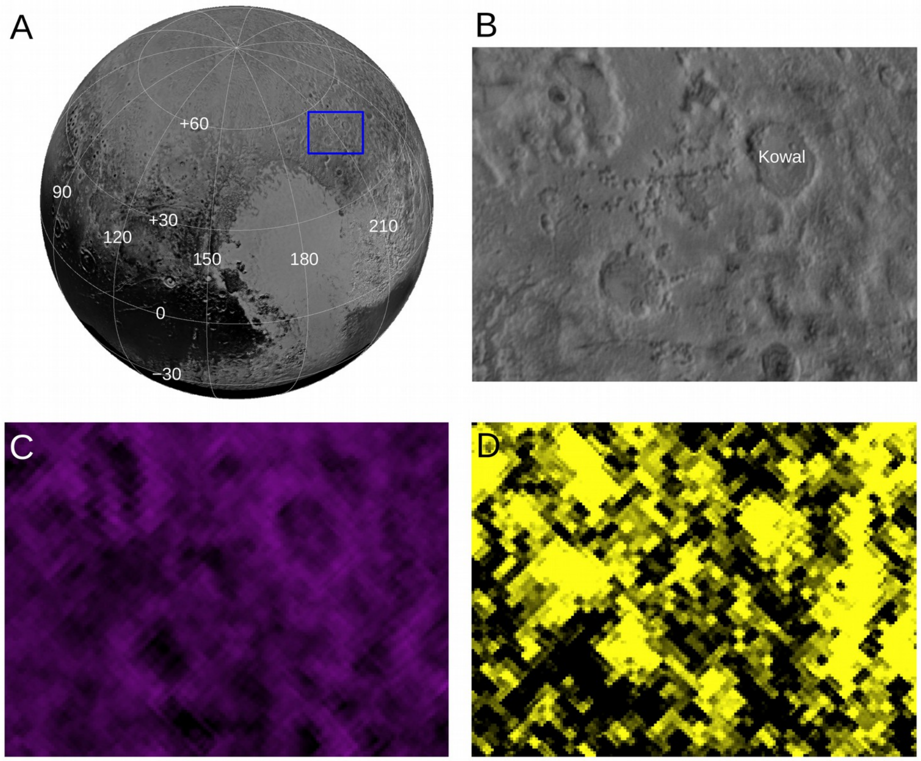

Fig. S4

Pluto's contrasting CH_4 and N_2 ice distributions. Panel A shows a LORRI base map for context, with a blue box indicating a region to be enlarged in the vicinity of Kowal crater. Panels B, C, and D zoom in on the corresponding area of the base map, the CH_4 map, and the N_2 map, respectively. At these latitudes, CH_4 ice absorption tends to be associated with ridges and crater rims, while N_2 ice absorption appears more prominent on crater floors. CH_4 ice accumulating on local topographic highs could be related to construction of edifices like the bladed terrain in Tartarus Dorsa.

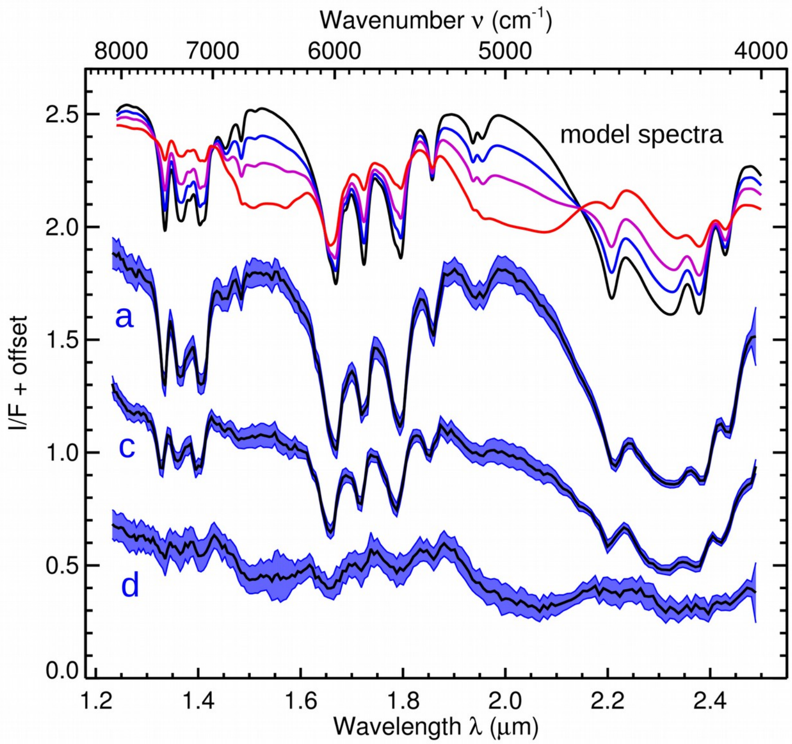

Fig. S5

Models of CH_4 plus H_2O compared with Pluto spectra. Pluto's near-infrared spectrum is dominated by the numerous strong absorption bands of CH_4 ice, making it difficult to detect absorbers with broad absorption features, such as H_2O ice. The H_2O correlation map in Fig. 2 highlights regions with the most conspicuous H_2O absorption bands, but many other areas show more subtle influence of H_2O absorptions via reduced albedos at 1.5 and 2 µm. These more subtle effects of H_2O absorption are illustrated with model spectra at the top of the plot, showing the influence of adding H_2O ice to a terrain that is spectrally dominated by CH_4 ice. The black model curve is for pure CH_4 ice. The colored model curves include various amounts of H_2O ice, ranging from the blue one having the least (20% H_2O ice in an areal mixture) to the red one having the most (70% H_2O in an areal mixture). Pluto spectra 'a', 'c', and 'd' are duplicated from Fig. 3B, corresponding to Lowell Regio, al-Idrisi Montes, and the H_2O-rich region around Pulfrich crater, with vertical offsets of +0.8, +0.3, and 0, respectively. The model spectra were offset by +1.6.

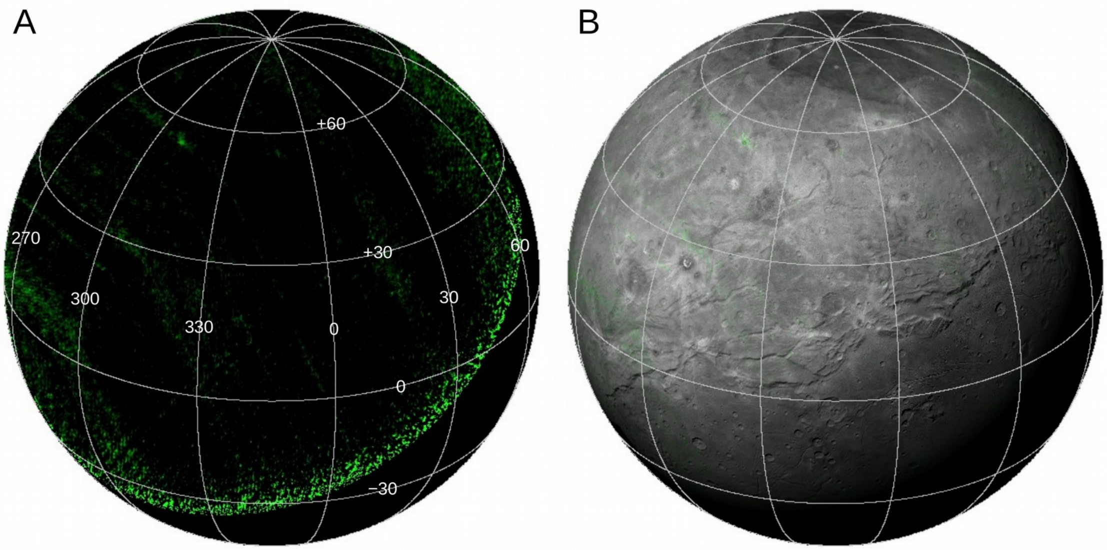

Fig. S6

Charon ammonia absorption map. This map highlights Charon's 2.22 µm NH_3 absorption band. The map is shown without accoutrements at left and coloring the reprojected LORRI base map at right.

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