PHOTOMETRIC PROPERTIES OF PLUTO. M. W. Buie[1], S. A. Stern[1], L. A. Young[1], C. B. Olkin[1], H. A. Weaver[2], K. Ennico[3], W. M. Grundy[4], J. M. Moore[3], R. A. Beyer[3,5], P. Schenk[6] and the New Horizons Sceince Team. [1]Southwest Research Institute (buie@boulder.swri.edu), [2]Johns Hopkins APL, [3]NASA Ames Research Center, [4]Lowell Observatory, [5]Carl Sagan Center at the SETI Institute, [6]LPI

Introduction: From the first lightcurves taken of Pluto in 1954, it was clear that its surface had large stable regions of variegated albedo. Since that time, the variations have been studied to determine the properties of the surface, both in albedo (static or variable) and in composition.

The New Horizons flyby of Pluto provides a wealth of information for further refining our understanding of Pluto's surface[1]. Beyond the obvious value of increased spatial resolution, the geometries of the new data are considerably different from that afforded an Earth-vicinity view and significantly improve on our ability to extract surface photometric properties. These properties are essential for removal of illumination and viewing geometry effects that also appear to change the appearance of the surface but in themselves are confusing when trying to understand other properties of the surface; such as a principal component analysis of spectrophotometric data to look for compositional variations.

We have used a combination of historical measurments of Pluto with the New Horizons data to further refine our understanding of Pluto's surface. This is a very complicated problem that will take some time to unravel but here we report on initial efforts and some early results.

Method: The surface reflectance theory developed by Hapke is a powerful tool for the study of light reflected from a planetary surface[2]. This underlying methodology was used with earlier HST observations [3,4] to derive global photometric properties combined with a single-scattering albedo (w) map. The additional properties needed for a full description are: h – surface compaction parameter, $P(g)$ – single particle scattering phase function, B_0 – backscatter parameter, and θ – mean surface roughness. Single-scattering albedo is clearly a spatially variable quantity. The rest of the values are often determined as global quantities and applied to all terrains. This approximation is often needed since there is rarely enough information to permit their independent determination along with albedo. For most solid surfaces, treating these other values as global has worked reasonably well. The high degree of surface variations on Pluto is, however, a warning that such global treatments may work more poorly here than on other bodies. Nonetheless, we must start somewhere in our analysis.

From the earlier HST-based work, there were 6 sets of global parameters ($h,P(g),B_0,\theta$) identified[3,4]. These sets, labeled A-F, are equally able to match the observed variation in photometric properties of Pluto's surface from the restricted range of phase angle possible from Earth. The constrained range in this case is from 0.36 to 1.74 degrees. Rather than try to determine an actual function for $P(g)$, a constant was used over this phase angle range.

For this initial investigation, we have applied a simple process to the resolved New Horizons data. Given a set of global photometric parameters, each pixel in a New Horizons image that maps onto the surface of Pluto is inverted. This process takes the observed count rate, converts to absolute flux, then to bidirectional reflectance (r), and finally solving for the single-scattering albedo that gives the proper value of r. At that point, the illumination and viewing geometry effects inherent in the image have been removed. The image of w is then converted to a normal albedo chosen to be at normal illumination and viewing direction but at 1 degree phase angle. The slight shift in phase angle moves us off of the peculiar reluctance properties of particulate surfaces at ultra-low phase angles. We call this normal albedo even though it is technically not. The important thing is that this rendering lets us see something directly related to surface albedo without any geometric effects included.

To assess the quality of the inversion, a region was chosen in the north polar terrains of Pluto from N55–85 degrees. This region was extracted from 8 images ranging in time over the 6 days prior to close approach. The chosen terrain is thus seen to rotate under the spacecraft viewpoint and is always in view but with differing viewing geometries. The phase angle range for these observations is quite limited due to the encounter geometry and only spans 15.3 to 16.2 degrees. For this analysis, we thus chose a new value of P(g) to hold for this range and is reduced from the HST set by a reasonable amount (more on this later).

Since the goal of the inversion is to remove illumination and viewing geometry variations, the resulting inversion should give the same result for w on all 8 images and should do so over the entire region of interest. This region on Pluto has far less variation in albedo than any other region of this size that was seen on Pluto. Using this method we can then compare the trend of r versus the cosine of the emission angle (or incidence angle) to this same trend for normal albedo. A plot of *r* will show the ensemble limb-darkening behavior and the normal albedo should be flat.

Results: All six sets of photometric parameters were investigated along with some variations in the other parameters. Since these data are at a different phase angle than HST, a new value of *P(g)* was needed. The value chosen was *P(g)*=1.7 for sets A, B, C, and F; *P(g)*=1.5 for set D, and *P(g)*=1.9 for set E. These values were based on relative scaling for the phase function used for Triton. The training set is from LORRI monochrome imaging that has better longitude coverage. Of the six photometric sets, set C is clearly the best with the values of h=0.05, *P(g)*=1.7, B_0=1.0, θ=10. Note that this is using the formalism as published in the 1993 version of Hapke's book [3].

These parameters are effective at removing any limb-darkening effects for illumination and viewing directions within 78 degrees of the surface normal. At the highest angles from vertical, the inversion does not work as well. Part of this problem is due to local slopes being a more important correction nearer to the limb. We avoid this problem by excluding these regions from the training set.

We investigated the sensitivity of all photometric parameters on this inversion process by perturbing one parameter at a time. For h, *P(g)*, and B_0 the result is to change the single-scattering albedos independent of viewing geometry within a give set, though each set has its own limb-darkening behavior. The mean-surface slope value does significantly affect the limb-darkening and a range from 5-30 degrees was investigated. The previously adopted value of 10 degrees was the best value, despite the fact that the prior HST maps provided essentially no constraint on this quantity and the value was adopted from a similar type of analysis for Triton.

Using the best set (C), we then converted the MVIC PCOLOR_2 data to w, then normal albedo. This gives us four distinct colors to compare and combine. All four MVIC filters (BLUE, RED, NIR, and CH4) reveal distinct surface properties. This much is already evident from false-color images but these data products now allow a more quantitative approach. This work is still on going but there are a few trends that are emerging.

Not surprisingly, the darkest near-equatorial regions (eg., Cthulu Regio) are well separated in albedo, color as well as in color ratios. Note that all feature names in this discussion are still informal. The dark unit is also very tightly clustered in albedo space compared to all other regions.

When viewed relative to the RED filter data, all other colors show a weak mixing line between the darkest and brightest end-members. However, most of the terrain is most likely to be at the ends of the range and the intermediate cases are very much less common. Additionally, the mixing line between the two end members is never seen to fall on a strictly linear trend.

In the monochrome LORRI data and MVIC NIR and CH4, the most reflective regions are the southern end of Sputnik Planum and the most neutrally colored portions of the north polar terrains. In the BLUE and RED MVIC filters the brightest north polar terrain is slightly less reflective than southern Sputnik Planum. The most neutrally colored regions appear to be the east side of Tombaugh Regio.

References:

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