PHOTOMETRY AND ALBEDO MAPS OF PLUTO AND CHARON. B. J. Buratti\(^1\), J. Hofgartner\(^1\); J. H. Hillier\(^2\), M. D. Hicks\(^1\), A. J. Verbiscer\(^3\), S. A. Stern\(^4\), H. A. Weaver\(^5\), C. J. A. Howett\(^4\), L. A. Young\(^5\), A. Cheng\(^5\), K. Ennico\(^6\), C. B. Olkin\(^4\), and the New Horizons Science Team. \(^1\)Jet Propulsion Laboratory California Institute of Technology (4800 Oak Grove Dr. Pasadena, Ca 91109; bonnie.buratti@jpl.nasa.gov); \(^2\)Grays Harbor College; \(^3\)University of Virginia; \(^4\)Southwest Research Institute Boulder; \(^5\)Johns Hopkins Applied Physics Laboratory; \(^6\)NASA Ames

**Introduction:** The acquisition of multispectral imaging observations with *New Horizons* during the flyby of the Pluto-Charon system in July 15, 2015 represents the first opportunity to study in detail the photometric properties of a body that is not rocky or water-icy. Pluto is covered mainly with methane and nitrogen – while Charon’s composition is mainly water ice [1, 2]. Combined with ground-based observations of the system at “true opposition” in 2018, the measurements of *New Horizons* during cruise and encounter provide a fairly complete solar phase curve that can be used for robust photometric modeling.

Here we report on the results of that modeling as well as the creation of albedo maps for both Pluto and Charon.

**Solar Phase Curves:** From Earth, the maximum observable solar phase curve of the Pluto-Charon system is less than \(2^\circ\). The minimum solar phase angle observed during the New Horizons flyby was \(11^\circ\). Thus, both ground-based and spacecraft data are required for a full photometric analysis of the system. Large solar phase angles are ideal for understanding macroscopic roughness and the directional scattering properties of the surface, while small solar phase angles are required to understand the textural nature of the surface. In 2018 observations from the adaptive optics system at Palomar that show a huge surge in brightness in the last tenth of a degree were successfully acquired [3]. These observations are especially key to determining the geometric albedo of an object, while the full excursion in solar phase angles is required to determine the phase integral. Combined, these two parameters yield a Bond albedo, which in turn is required to model volatile transport and thermal variations on the object.

Charon’s phase curve is straightforward to model because the moon is an atmosphereless body [4]. Photometric modeling shows that Charon is similar in its photometric properties to other icy moons, except that its single particle phase function is more isotropic, suggesting the Kuiper Belt may represent a new regime for surface alteration processes. Charon’s phase integral is \(0.70 \pm 0.04\) and its Bond albedo is \(0.29 \pm 0.05\).

Modeling of Pluto’s phase curve is more challenging as its surface is overlain by a thin atmosphere and a complete radiative transfer model such as that described by Chandrasekhar’s “planetary problem” is required. This work is ongoing.

**Albedo Maps:** Images were obtained by the Long Range Reconnaissance Imager (LORRI) of both Pluto and Charon [6]. These images have been used to construct maps of the normal reflectance of the surface, corrected for all effects of viewing geometry [7].

![Figure 1. The solar phase curve of Charon (large red and black dots) shown with data from *Cassini* of Dione (blue dots). The data at the very smallest solar phase angles (\(<10^\circ\)) is from [5]; while any data beyond \(10^\circ\) is from the LORRI instrument on *New Horizons* [4]. The red data is constructed from disk resolved images, while the black data is from full-disk images. The solar phase curve of Charon is from [4] and *Cassini* data is unpublished. No rotational corrections have been done for the Dione data. The similarity of Charon to an icy moon is apparent.](image)

Most of the changes in intensity on planetary surface are not intrinsic but rather due to changes in the radiance geometry. The medium and high resolution images of Pluto and Charon during the *New Horizons* encounter enabled the creation of maps of normal reflectance for both objects [6]. Charon shows albedo variations that are typical of other icy moons, but the albedo map of Pluto shows that it has the most extreme variations in albedo of any object in the Solar System except for Iapetus [8]. Pluto’s normal reflectance in the Cthulhu region is less than 0.10, suggesting a substate of polymerized molecules, while on Sputnik Plani-
tia it is nearly unity. This value is close to that of bright icy moons such as active Enceladus, suggesting ongoing geologic processes in that region of Pluto. Furthermore, this huge variation in albedo – an order of magnitude – translates to a temperature difference of ~20K, spawning such exotic phenomena as snow and high winds, with concomitant eolian processes.

Figure 2. A map of the normal reflectance of Pluto, showing more variations – a factor of an order of magnitude – than any airless body in the Solar System except for Iapetus. From [7].

Figure 3. A map of the normal reflectance of Charon, showing variegations that are more typical of icy moons. From [7].

Ground-based observations: The smallest solar phase angle obtained by New Horizons was 11°. Ground-based observations must be obtained by adaptive optics (AO) systems to resolve Charon from Pluto. Four nights were obtained on the AO system on the Hale Telescope on Palomar Mountain in 2018, when the smallest solar phase angle for 161 years was reached, showing a huge opposition surge for both objects [3].

Summary: When combined with ground-based observations, the New Horizons data at Pluto provides a full excursion in solar phase angles to perform photometric modeling. Work on Pluto is still ongoing as the removal of the atmospheric component requires that its properties be modeled separately. The albedo map of Charon is unremarkable, although the pole is darker, unlike most icy bodies where the pole is brighter as it is a cold-trap for volatiles. Pluto, however, exhibits an extreme range in albedos, consistent with its place as an active body with a fresh surface.


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