Discovery of Remarkable Opposition Surges on Pluto and Charon. B. J. Buratti[1], M. D. Hicks[1], E. Kramer[1], J. Bauer[2]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; bonnie.buratti@jpl.nasa.gov; [2]University of Maryland Department of Astronomy, College Park, MD 20742

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]. Pluto is a dynamic body with the first-ever active glaciers observed outside the Earth, possible clouds, snow, seasonal volatile transport, and at least two types of the dark, elusive material that is ubiquitous in the outer Solar System and that may be tied to the origin of life on Earth. But as spectacular as this flyby was, it represented an instant in time, leaving out the long temporal baseline that is required to capture, understand, and model the seasonal events and the types of geologic processes that were observed on Pluto – and that happen on 100-year time scales, at least. As with most other flyby encounters, key viewing geometries were not attained.

One key observation that was not observed by *New Horizons* but was successfully captured this past year with the Palomar Observatory Hale Telescope adaptive optics (AO) is the Pluto-Charon system at true opposition: the lowest possible solar phase angle (0.0061°; 0.008° at Palomar). This geometry will not be repeated for 161 years. These observations represent both an augmentation of the *New Horizons* data set, and a test of the models that describe the character of the opposition surge in terms of the geophysical properties of planetary surfaces. This year (2019) we have received 6 more nights at Palomar, including two nights when the "heart" of Pluto (Sputnik Planitia) is at its smallest solar phase angle (0.018°).

Figure 1: Charon and Pluto from *New Horizons*. NASA/APL/SWRI

Observations: Our full request of four nights was assigned to this project in 2018 and observations in JHK wavelengths (1.2, 1.6 and 2.2 µm) were obtained on all nights. One night was slightly cirussy, and further data analysis beyond the usual pipeline processing [2] is required to fully reduce this data. Luckily, this night was the least critical, being slightly smaller in solar phase angle than our fourth night, which was obtained at our maximum phase angle.

Table 1-2018 JHK data obtained at opposition

Time (civil)	Solar phase angle (°)	Longitude (°)
July 11	0.008	35
July 12	0.022	340
July 29	0.51	105
July 30	0.53	50

Data Analysis: Figure 2 shows a typical image of Charon and Pluto fully resolved. We observed and obtained photometric data in all three JHK filters. Because Pluto is at opposition in the summer and the declination was about -20° at our location in the northern hemisphere, we observed for only about 4 hours each night. This span was sufficient to go through two full duty cycles encompassing all three filters.

Figure 2. A typical Palomar Hale Telescope AO image of Pluto and Charon, showing the two bodies clearly resolved.

In all cases, there were on-chip standard stars from the 2MASS catalogue that could be used for photometric measurements. We followed the standard analysis routines of flatfielding, subtracting all background signals, and performing aperture photometry on both objects [2]. The night of July 29 was cirrusy, during which most images did not show the system resolved. Further processing which will include selection of the best images and stacking, should result in useful data.

Pluto. Figure 3A shows an example of the results for Pluto. The surge is about twice as high as the 0.1-0.2 mag surges (depending on wavelength) observed previously [2,3].Note that the lowest point is at a solar phase angle that is greater than the projected radius of the Sun onto Pluto, which is the lowest theoretical value for this angle. Thus, there is no plateauing of the curve.

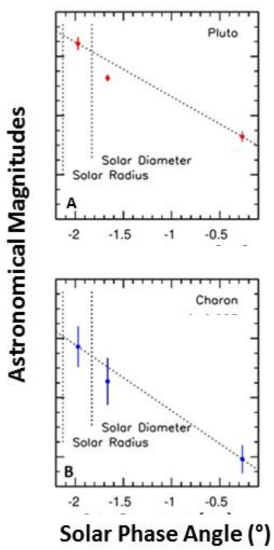

Figure 3. Observations for three nights around Pluto's "true opposition" in July 2018. Each division is 0.2 astronomical magnitudes and the x-axis is a log scale. These observations were obtained of the "anti-heart" hemisphere of Pluto. The "heart" (Tombaugh Regio) will be at its minimum in July 2019, enabling a comparison of the microstructure of the two hemispheres of Pluto (and Charon, as they are tidally locked).

Charon. Charon also exhibits a surge about twice as great as that extrapolated from ground-based observations [3]. However, its surge is substantially larger than that of Pluto.

Future Work: A complete capture of the opposition range visible from Earth will take an additional two years of observations. For the first half of 2019 we requested 6 nights from the Palomar Time Allocation Committee (TAC) and received our full request, which occurs during southern California's dry season. The observations span phase angles out to 1.5° on both hemispheres of Pluto/Charon. Larger solar phase angles will be visible later in the year and in 2020.

Discussion. The scientific goals of this project can be divided into two categories: 1) tests of models for the opposition surge; and 2) a study of the surface properties (porosity or "fluffiness" and particle size) of both hemispheres of Pluto within the context of *New Horizon's* high spatial resolution images and spectra of both hemispheres of Pluto and Charon. As such, our goal is to substantially enhance the return from NASA's first mission to a KBO in its environment.

This observational project not only captures the smallest possible solar phase angle for 161 years on Pluto, but one of the smallest in the Solar System, as the solar phase angle is limited by the angular size of the Sun. It is a unique opportunity to test the various models of the surge, some of which have become controversial [4,5]. In addition, previous studies have shown that the IR is a key spectral region for studying the surge, as it tends to change its character rapidly in the 2-3 µm region, possibly providing a sensitive probe to the size of surface particles [6]. Finally, this work is of a body (Pluto) that isn't rocky or water-icy: its study is a new opportunity for comparative planetology.

This work complements the *New Horizons* mission, as it covers viewing geometries that were lacking. But the ground-based data is not resolved: we will be able to model two hemispheres of Pluto and Charon, but not to map properties. However, putting the physical parameters – particle size, the porosity of the optically active region of the regolith, and albedo – within the context of detailed observations of geologic processes such as glaciation, snow, seasonal volatile transport, etc. is valuable. Our data will also enable a more accurate calculation of the geometric and Bond albedos at this wavelength, parameters that are critical for performing thermal modeling on these worlds, at least one of which is geologically active and both of which appear to have seasonal volatile transport [2,7]. This work will serve as a benchmark for future measurements mapping the transport of volatiles in the system. Finally, this project argues for the compilation of a solar phase curve in the near-IR, which proved to be so valuable to studies of the Saturnian moons [6] and which can be derived from the LEISA instrument on *New Horizons*. Our results can serve to support further calibrations to this instrument.

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