Measurement of Pluto's Brightness Changes Using Spacecraft Observations Obtained From The New Horizons' Mission

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Abstract: New Horizons spacecraft updated and changed some of our preconceptions about this distant dwarf planet. It's active geology and complex composition can offer new insights in our understanding of planetary evolution, and hence that of our solar system. Data collected by the spacecraft was processed and analyzed in the effort to find a relationship between Pluto's phase angle and brightness. High phase angles were of utmost interest as such analysis had not been performed with close-range observations. Analysis of this measurement allows for a deeper understanding of Pluto's several physical parameters, such as optical depth, particle size and composition. Results revealed that forward scattering measured by the blue filter was dominant, compared to that of red filter. Whereas near-infrared and methane filters observed quite similar scattering properties. Pluto, however, was brightest in red and infrared wavelengths, whereas it's atmosphere alone, was brightest in blue and red wavelengths. Further analysis, using a radiative model, is needed for a stronger conclusion about the implications of these results.

I. INTRODUCTION:

Pluto, the first Kuiper belt object to be discovered smaller than our moon, and 7.5 billion miles away, was first spotted in 1930 by an astronomer named Clyde William Tombaugh. Pluto's orbit is inclined relative to the ecliptic by about 17° and is more eccentric than circular, unlike the first 8 planets. Because of its elliptical orbit a small region of its orbit lies closer to the Sun than that of Neptune's. After the 1992 discovery of the Kuiper Belt, and several objects of similar size in that region, and especially after the discovery of Eris, which is 27% more massive Kuiper Belt object, Pluto's status as a planet got questioned, and later reclassified as a dwarf planet by the International Astronomical Union in 2006. Nevertheless, Pluto does not fail to compete with the planets with its complex geology, atmosphere and weather, as later revealed by the New Horizon mission.

The New Horizon's journey began on January 19th, 2006 and it later uncovered mysterious and unexpected characteristics of the dwarf planet, such as its chemistry, active geology, and multi-layered haze-atmosphere which has been compared to that of Titan. It completed a close approach to the Pluto system on 14th July 2015 at a distance of 13,691 km from Pluto's center. Carrying an intricate suite of instruments including the Ralph multicolor/panchromatic mapper, it took a wide range of photographs of the dwarf planet through it's Clear, Red, Blue, NIR and Methane filters. Pluto's latitudinal band from about 25°S to 10°N features large low-albedo terrain, called the Chthulu Regio. The large, prominent high-albedo region of the New Horizons encounter hemisphere called Tombaugh Regio and measures about 1800 km east to west and 1500 km north to south. A large, level plains unit called Sputnik Planitia constitutes the west half of TR. Data from the mission has uncovered an existence of acetylene, ethylene, and ethane in Pluto's haze, as well as 20 distinct haze layers extending to a height of at least 200 km (Stern et al., 2015; Gladstone et al. 2016; Cheng et al., 2017).

In this research project, we have derived Pluto's brightness by analyzing data from the New Horizons spacecraft. This project is part of a larger effort in deriving the physical parameters of Pluto's haze layer, including its albedo, particle-size, and optical depth, using an existing radiative transfer model in which an optically thin atmosphere is defined by its single-scattering albedo, macroscopic roughness, and single-particle phase function (Buratti, 2017; Chandrasekhar, 1960; Hillier et al., 1990, 1991). Of particular importance was deriving the brightness characteristics of Pluto's atmosphere while in its high phase angle configuration, as the manner in which different light passes through can give important information about particle size and composition. The determination of the characteristic brightness of Pluto's haze is a contribution to the effort of deriving it's physical parameters.

II. OBSERVATIONS AND DATA ANALYSIS

Data used for analysis was that of Jet Propulsion Laboratory's New Horizons MVIC camera, and additional information from New Horizons' ephemeris. The images were of FITS format and calibrated without the removal of the background. The MVIC data used included images taken by five filters simultaneously, resulting in 90 images from each filter (clear, red, blue, near-infrared, and methane). These 90 images span from 2015-04-09 04:49:05.341 to 2015-07-19 23:39:25.948 UT (Universal Time) with integration time of 0.59s, and average apparent latitude (subject-observer latitude) of 43° at low phase angles, and -43 at high phase angles. Apparent longitude (or subject-observer longitude) varied from 0 to 360° due to the dwarf planet's rotation and spacecraft's changing position with respect to the subject.

The phase angle, or the angle formed by the geometric position of the sun, the target and the point of observation varied from 14.5° to 165° with a large gap between 38 and 165° as the latitude flips from being positive to negative within a time frame of 4 hours likely due to the spacecraft changing its position as can be indicated by the large change in longitude (168 to 313).

Since the values of longitude, latitude, phase angle and range that corresponded to each image from the MVIC camera were not included in the headers of these images, this information was obtained from the Jet Propulsion Laboratory's New Horizons Ephemeris and matched to its' Mission Elapsed Time value of each image (obtained from headers).

In order to measure the extent of the planet's brightness in each image, it was necessary to first minimize the effect of the background and the effect of the rotation of the planet.
The software used to accomplish this was the IRAF software because of its pixel adding and averaging functions.

(1)The effect of the background was minimized by pixel value addition and subtraction where the values of the pixels within an area in the background was averaged and subtracted from each pixel in the area encompassing the target, using the IRAF software. This technique accounts for the distinct camera-related patterns associated with each image.

(2)Next, to correct for any longitudinal brightness non-uniformities (effect of rotation), images with similar phase angle (within 1 degree) and varying longitudes were averaged. Similar correction was applied to the images with different phase angles and few longitudinal variations, but in this case, these values were rescaled to line up with the average brightness values.

(3)Finally, to obtain a brightness value for the planet, the total value of pixels from (2) were divided by the integration time and multiplied by range squared.

III. RESULTS + DISCUSSION

Phase Angle vs. Brightness								
Phase Angle	Red Filter Brightness	Red Filter Normalized Brightness	Blue Filter Brightness	Blue Filter Normalized Brightness	NIR Brightness	NIR Normalized Brightness	CH4 Brightness	CH4 Normalized Brightness
14.8	8.485E+18	0.9311	2.080E+18	0.9280	6.622E+18	0.9429	1.570E+18	0.9738
16.1	8.750E+18	0.9602	2.250E+18	1.0040	6.664E+18	0.9488	1.580E+18	0.9796
15.8	9.420E+18	1.0337	2.320E+18	1.0352	7.447E+18	1.0603	1.608E+18	0.9969
15.6	9.113E+18	1.0000	2.241E+18	1.0000	7.023E+18	1.0000	1.613E+18	1.0000
16.8	9.090E+18	0.9975	2.235E+18	0.9974	7.397E+18	1.0533	1.712E+18	1.0617
18.2	8.758E+18	0.9611	2.154E+18	0.9611	7.365E+18	1.0486	1.675E+18	1.0384
38.3	6.920E+18	0.7594	1.770E+18	0.7900	5.412E+18	0.7706	1.362E+18	0.8445
165.0	2.333E+17	0.0256	1.279E+17	0.0571	8.698E+16	0.0124	1.691E+16	0.0105
165.1	2.346E+17	0.0257	1.297E+17	0.0579	8.225E+16	0.0117	1.933E+16	0.0120
165.2	2.482E+17	0.0272	1.086E+17	0.0484	8.568E+16	0.0122	1.432E+16	0.0089
165.3	2.410E+17	0.0264	1.326E+17	0.0592	7.583E+16	0.0108	1.809E+16	0.0112
166.0	2.653E+17	0.0291	1.480E+17	0.0661	8.705E+16	0.0124	2.026E+16	0.0126
167.1	3.187E+17	0.0350	1.675E+17	0.0748	1.101E+17	0.0157	2.601E+16	0.0161
169.4	4.237E+17	0.0465	2.444E+17	0.1090	1.388E+17	0.0198	3.011E+16	0.0187

Table 1. This table shows the final values of brightness for each distinct phase angle per each filter.

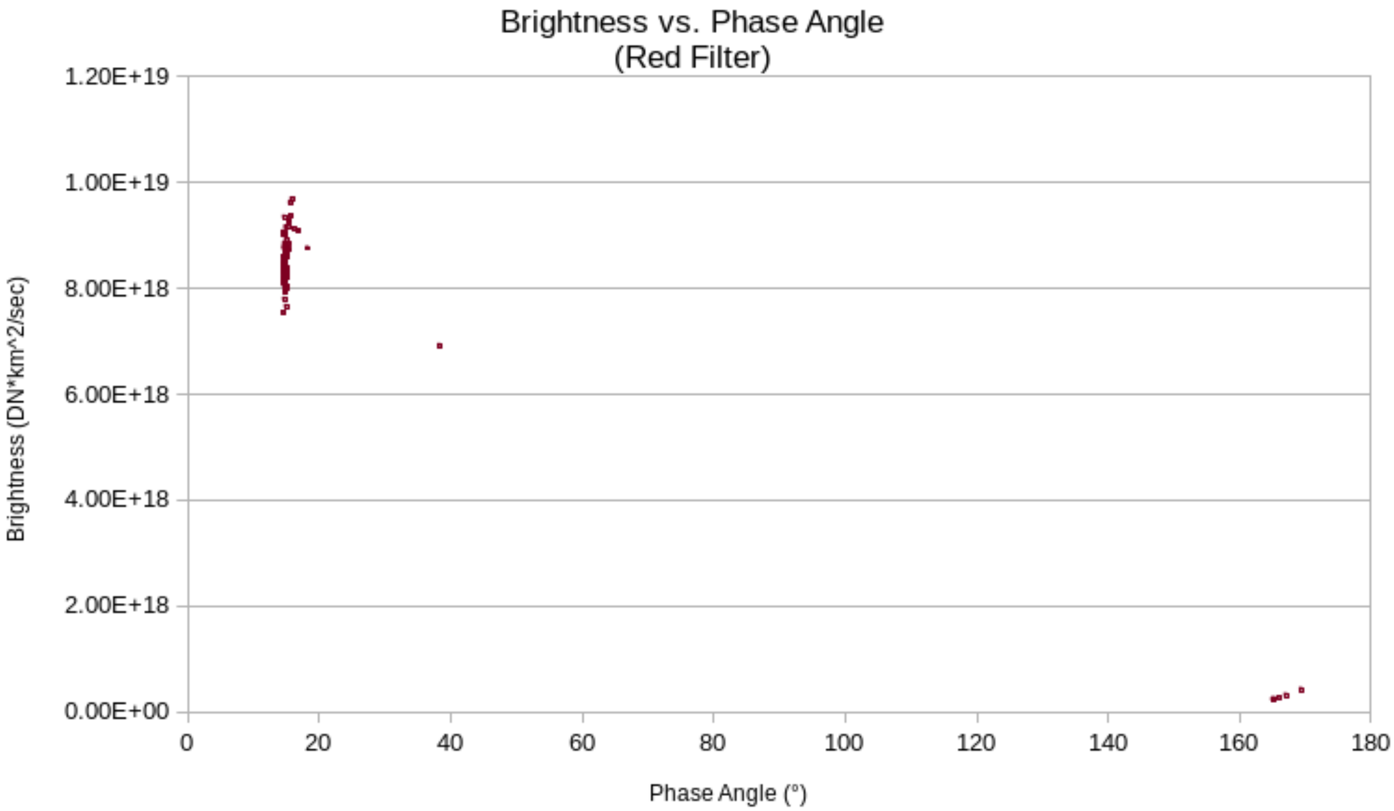

Figure 1. Above is the plot of the relationship of brightness vs phase angle. The effect of rotation is not minimized.

Table 1 is the collection of values obtained after all steps of analysis was performed. Using these values. Figure 1, in turn, is a phase curve of Pluto in the red wavelength. The effect of rotation is shown as the data points at less than 20° phase angle display a large variation of brightness that range between 8.00E18 and 1.00E19 (1/5 of an order of magnitude) The rotation of the planet is the reason behind the "vertical" lining up of these data points as in the beginning of the spacecraft's mission, Ralph had photographed Pluto from far distances, resulting in a very small variation in phase angle but large variation of longitudes (0 to 360). This effect was then minimized by averaging these values of brightness of same or very similar phase angle (within 1 degree).

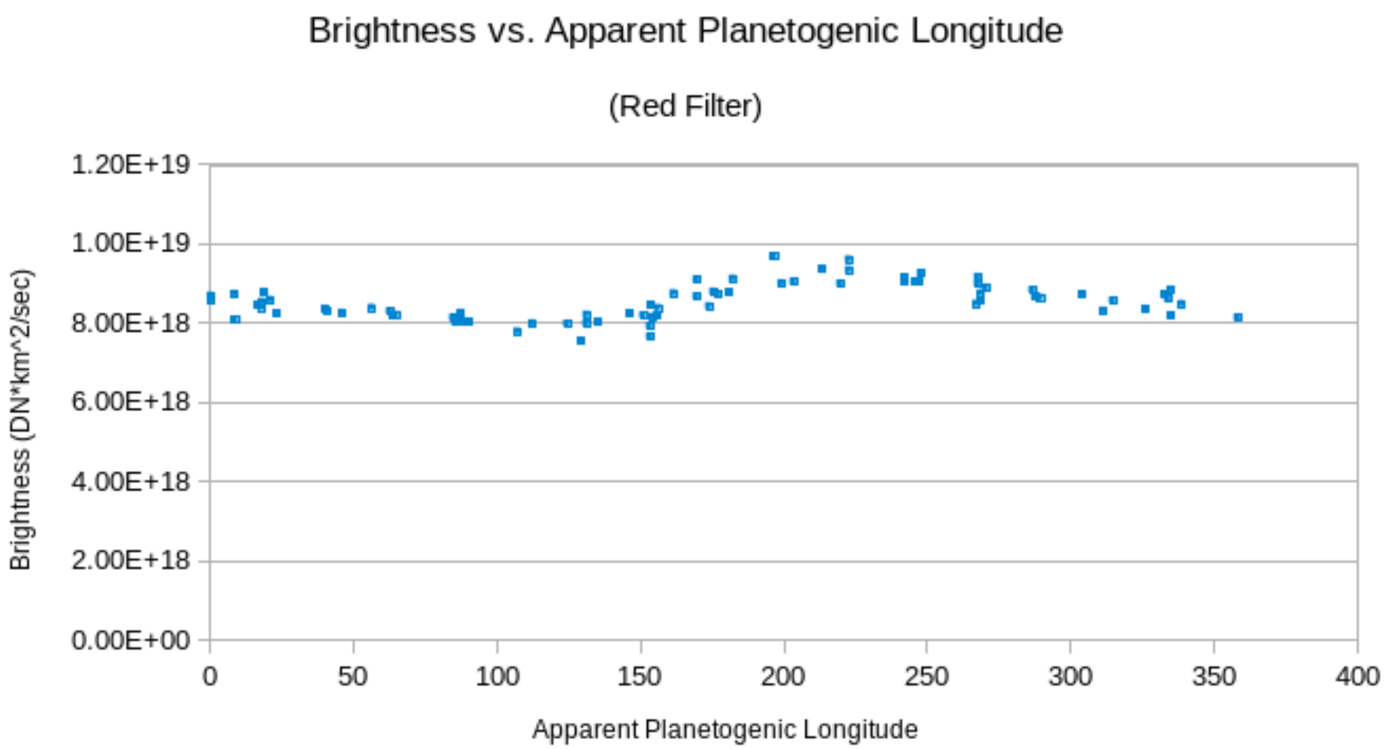

Figure 2. Above plot shows the variation of brightness with longitude. It’s one hemisphere is brighter than the other as can be observed through almost sinusoidal shape of this curve.

In figure 2, the inflection point at around 170° longitude can be due to the immediate change from Cthulhu Region to Sputnik Planetia. It turns out that Cthulhu region is indeed located at 90° longitude, and Sputnik Planetia around 180° longitude, where the inflection of the plot is very near. The variation in brightness, in this plot as well, is about 1/5ths of an order of magnitude. This can be due to the abundance of low-albedo tholins, which have the capacity of absorbing wavelengths of higher frequency due to more sites available for energy storage, and due to the Mie-Scattering effect, the light that is of smaller wavelength than the size of these molecules, can go through this atmosphere while larger wavelengths can be reflected or emitted.

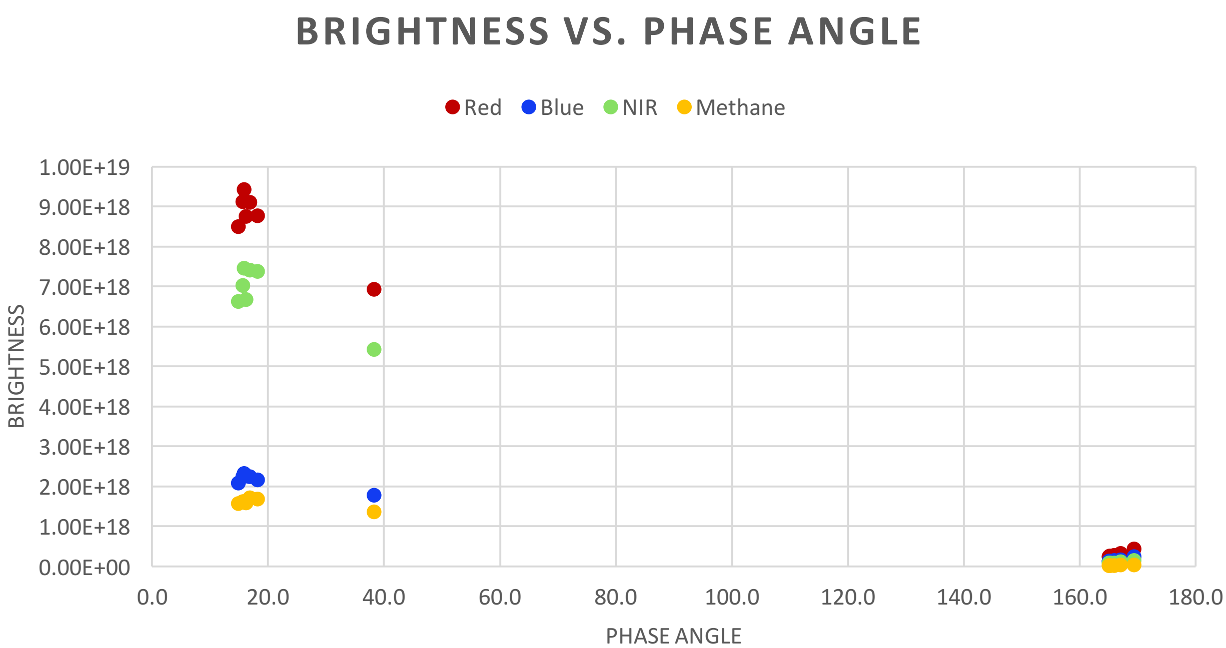

Figure 3. This plot compares phase curves of 4 different wavelengths. The rotation effect of the planet has been minimized, hence the fewer amount of data points.

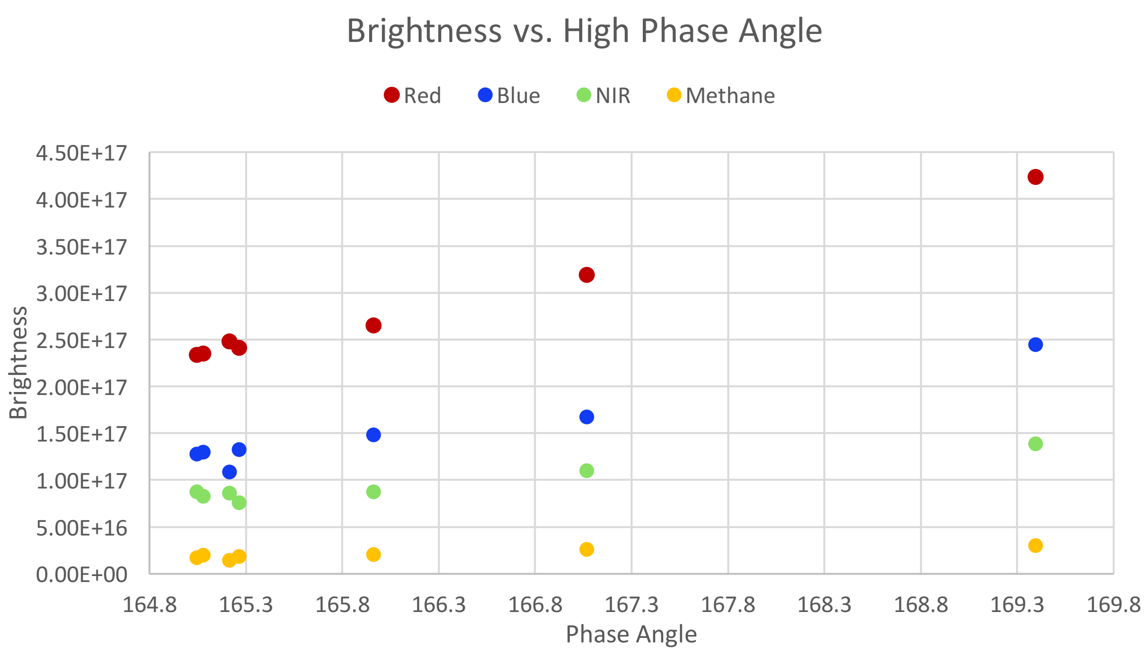

Figure 4. This plot zooms in on the larger phase angles for which there hadn't been any measurements obtained before. This shows not the reflectance but the forward scattering of the atmosphere as it is illuminated from behind.

Figure 3 plots brightness vs phase angle after applying rotation corrections. It's interesting that at lower phase angles, Pluto's brightness is greater in near-infrared than in blue, and at higher phase angles, the opposite is observed. This can be due to increased forward scattering in the red and blue wavelengths.

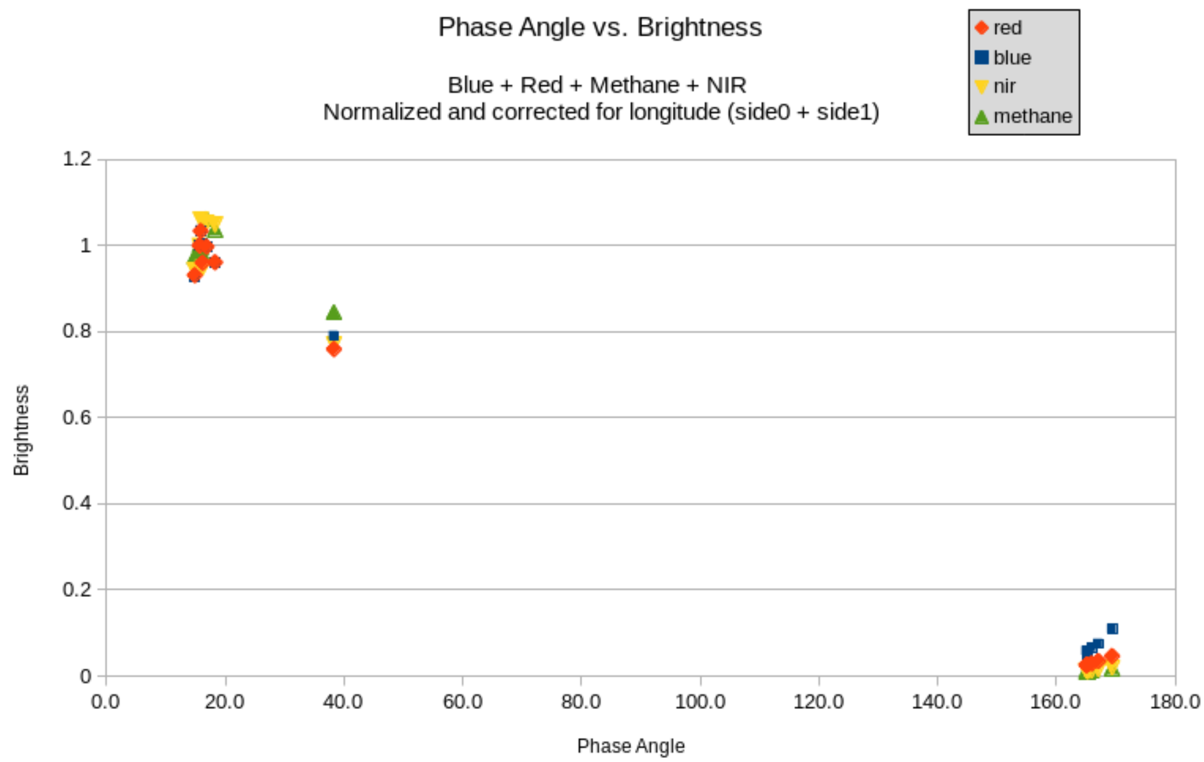

Figure 5. Above plot has been normalized by picking the value of brightness of 15.6° phase angle from each wavelength to have a value of 1. All other values are fractions of this brightness value. This allows to see how much the brightness has increased with respect to its own base value. There is some noise in the smaller phase angles likely due to being very far away from the planet, however, the closer observations seem to result very consistent results. The closest observations are those of the highest phase angles.

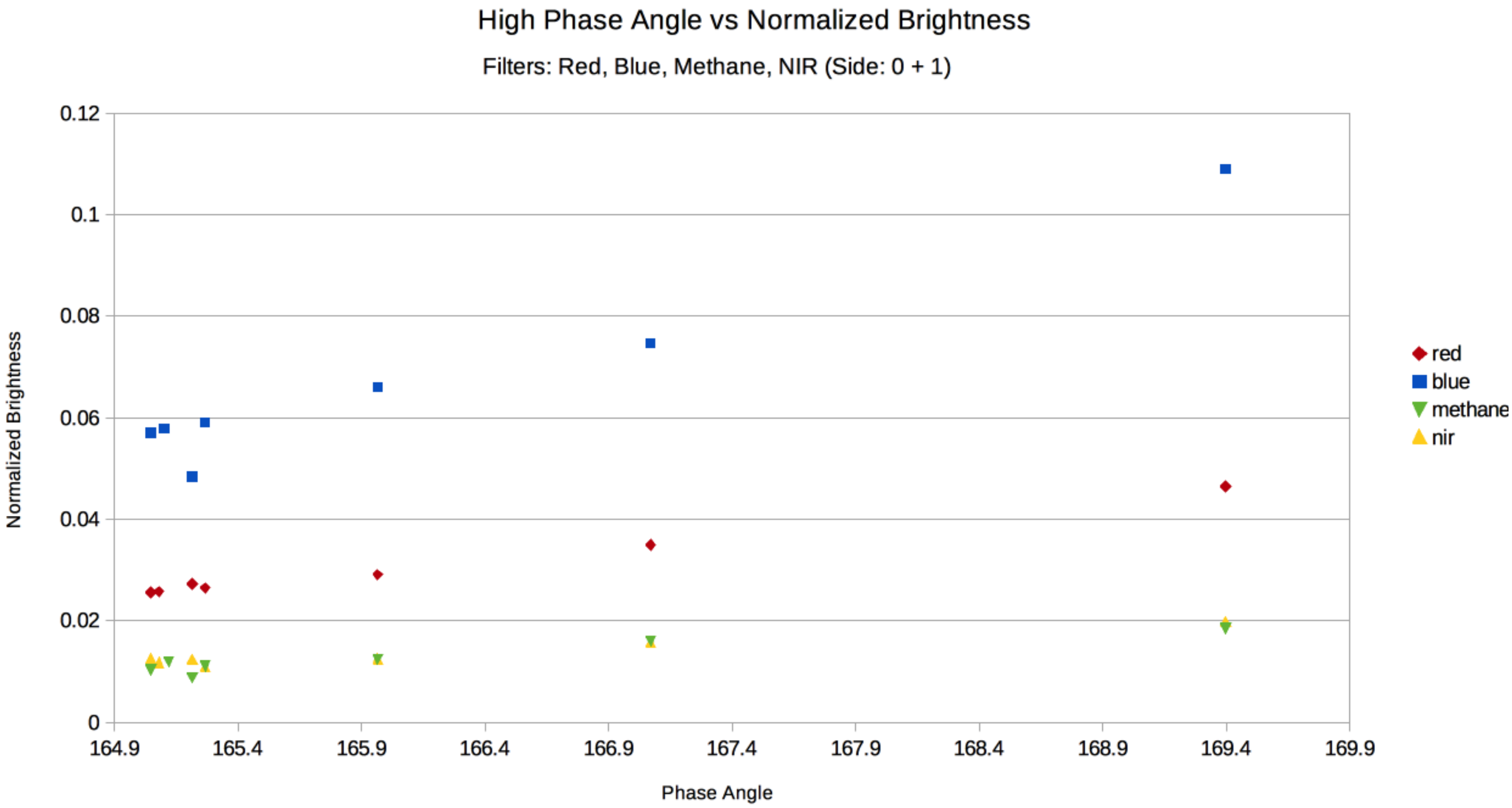

Figure 6. The plot above displays the normalized brightness of high phase angles. The atmosphere seems to be brightest in blue, yet NIR and methane seem hard to distinguish from each other. If the atmosphere is brightest in blue then the implications could be that there is more forward scattering in the blue wavelength than in red, as would be expected in the presence of large particles. This is an example of Mie scattering which in this situation can be due to Haze particles being comparable or larger than the blue wavelength or light and a little less comparable or larger than the red wavelength of light. In other words, this could be read as there are particles that are definitely larger than the blue wavelength, and larger than the red wavelength too. This comparison of scattering, thus, can be used in a more advanced program in determining a closer approximation of Haze particles.

IV. CONCLUSION:

In conclusion, Pluto's atmosphere seems to have forward scattering properties in the blue wavelength followed by the red, however it's brighter in the red wavelength. There seem to be close to no forward scattering properties in near infrared or methane, possibly indicating that the particles responsible for such scattering of light are more likely to be between blue and red wavelengths in size. This can be due to most particles being simpler gas molecules as opposed to large particles.

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