PLUTO'S ATMOSPHERIC HAZE DISTRIBUTION TO ABOVE 600 KM: NO WINTER POLE N_2 CONDENSATION. A. F. Cheng[1], M. E. Summers[2], G. R. Gladstone[3], T. Lauer[4], L. A. Young[5], P. Lavvas[6], J. A. Kammer[5], C. M. Lisse[1], A. H. Parker[5], E. F. Young[5], S. A. Stern[5], H. A. Weaver[1], C. B. Olkin[5], K. Ennico[7]. [1]JHU/APL (andrew.cheng@jhuapl.edu), [2]George Mason University, Fairfax, VA, [3]Southwest Research Institute, San Antonio, TX, [4]NOAO, Tucson AZ, [5]Southwest Research Institute, Boulder, Co. [6]University of Reims, Reims, France. [7]NASA Ames Research Center, Moffett Field, CA.

Introduction: Haze in Pluto's atmosphere was detected by the New Horizons spacecraft in approach and departure visible imaging [1,2,3] as well as the UV solar occultation [4]. The haze was imaged by both the Long Range Reconnaissance Imager (LORRI) and the Multispectral Visible Imaging Camera (MVIC) on New Horizons, at solar phase angles ranging from ~20° to ~169°. The haze was detected to altitudes of at least 200 km above Pluto's surface [3] with both New Horizons imagers, which found the haze to be structured into as many as ~20 layers. The haze exhibited a blue color at visible wavelengths. A UV extinction attributable to the atmospheric haze was also detected by the ALICE ultraviolet spectrograph on New Horizons [4].

The haze is strongly forward scattering in the visible [3], and a microphysical model of haze reproduces the visible phase function just above the surface with 0.5 µm spherical particles, but also with fractal aggregate particles to fit the visible phase function at 45 km altitude and to account for UV extinction. The visible phase function at the bottom of the atmosphere has a back scatter lobe which is absent from the phase function measured 45 km above the surface, making the higher altitude phase function similar to that for haze in Titan's upper atmosphere [3]. Pluto's haze is found at altitudes where direct condensation of hydrocarbons is not possible, but the haze may form by similar processes to those responsible for the detached haze layer in the upper atmosphere of Titan. It is suggested that haze particles form fractal aggregates which grow larger and more spherical as they settle downwards through the bottom 15 km of the atmosphere. Haze particles settle onto Pluto's surface, at a rate sufficient to alter surface optical properties on seasonal (hundred-year) time scales [3], accumulating to an optically thick surface layer within thousands of years.

This picture of Pluto haze formation implies that haze in Pluto's atmosphere should extend to altitudes well above 200 km, as haze precursors form from methane photolysis whose rate maximizes around 250 km in the summer hemisphere [5,6]. We report new analyses of deep departure MVIC images in which Pluto haze is imaged to altitudes above 600 km. The haze brightness scale height at high altitudes >250 km is several times greater than the 40 – 50 km scale heights seen at low altitudes [2,3].

The Pluto atmospheric haze displays a pronounced hemispheric asymmetry, with substantially greater haze densities for northern compared to southern latitudes. This asymmetry, previously seen in both MVIC and LORRI images of haze below ~250 km [3], is now seen over the full altitude range extending to above 600 km. The observed distributions of Pluto haze are compared to predictions from Pluto Global Circulation models (GCMs) by Bertrand and Forget [6]. The observed Pluto atmospheric haze distributions strongly favor the GCMs without condensation of N_2 on the winter pole, which is the pole not observed by New Horizons during Pluto encounter.

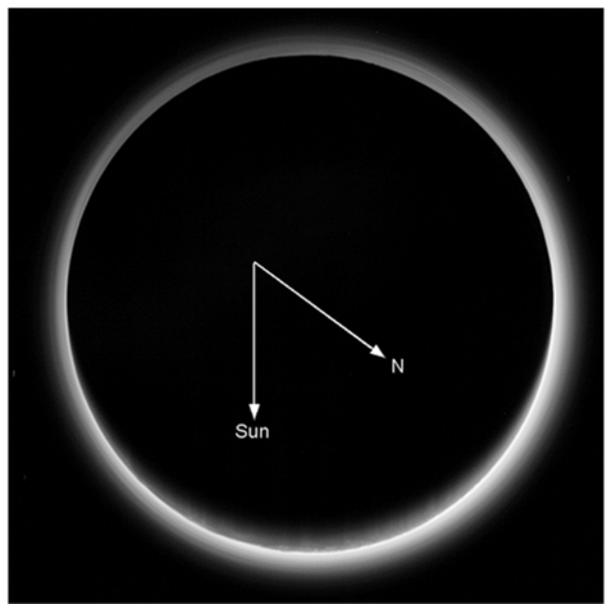

Figure 1. Stack of four LORRI images obtained July 15, 2015 at 3.83 km/px resolution and at phase 166°. Haze is present all around the limb, brightest toward Pluto N and not toward Sun, and layers are seen.

Observations: The atmospheric haze is seen to extend completely around the limb in full disk images of Pluto at high phase angles (e.g., Fig. 1). The haze is brighter than sunlit surface of Pluto for high phase angles >148° as seen by LORRI [3]. Haze layers can be discerned in LORRI and MVIC images obtained at sufficiently close ranges to achieve an image resolution of ~4 km/pixel or better. Layers are approximately horizontal, and they can be traced over horizontal extents of hundreds of km. and at a solar phase angle 166°. Also notable in the full disk images of haze completely around around the limb is that the haze is brightest to Pluto north and not to the subsolar direction [3].

Full disk images of Pluto were obtained by both New Horizons imagers at great ranges, too far from Pluto to be able to resolve haze layers. These images were searched for haze detections at higher altitudes than previously reported in order to study the haze distributions. Deep 10 sec exposures were obtained by the MVIC framing camera [7] on July 15, 2015 at 18:35:08 UT in the sequence O_RingDep_A_1 which was a high-phase ring search. These images were acquired at a distance of 1525316 km from Pluto, at a resolution of 30.2 km/px and at a solar phase angle of 165.5º.

The full disk Pluto image from O_RingDep_A_1 (Fig. 2) showed haze extending all around the limb to high altitudes, up to ~700 km over northern latitudes. Some image saturation and blooming artifacts are seen. The strong north-south asymmetry, with more haze in the north, is seen at both low and high altitudes, with a prominent change in scale height between low and high altitudes. The haze brightness scale height above ~250 km is 200-300 km.

Conclusion: The Pluto atmospheric global circulation models of Bertrand and Forget [6] predict the distributions of atmospheric haze. Two climate scenarios are presented for the GCMs: one without N_2 condensation at the winter (south) pole, and one with such condensation. The GCMs without N_2 condensation at the winter pole also have Sputnik Planitia as the only significant N_2 reservoir. These GCMs are consistent with the observed haze distributions (significantly more haze in the north than in the south, and no depletion of the lowest haze layer (below 20 km) in the summer hemisphere). Observations are inconsistent with the alternate scenario where N_2 condensation occurs at the winter pole.

References: [1] Stern S. A. et al. (2015) *Science,* **350**, aad1815. [2] Gladstone G. R. et al. (2015) *Science* 351, aad8866. [3] Cheng A. F. et al. (2017) *Icarus* 290, 112. [4] Young L. A. et al. (2018) *Icarus* 300, 174. [5] Wong M. L. et al. (2017) *Icarus* 287, 110. [6] Bertrand T. and Forget F. (2017) *Icarus* 287, 72. [7] Reuter D. C. et al. (2008) *Spa. Sci. Revs.* 140, 129.

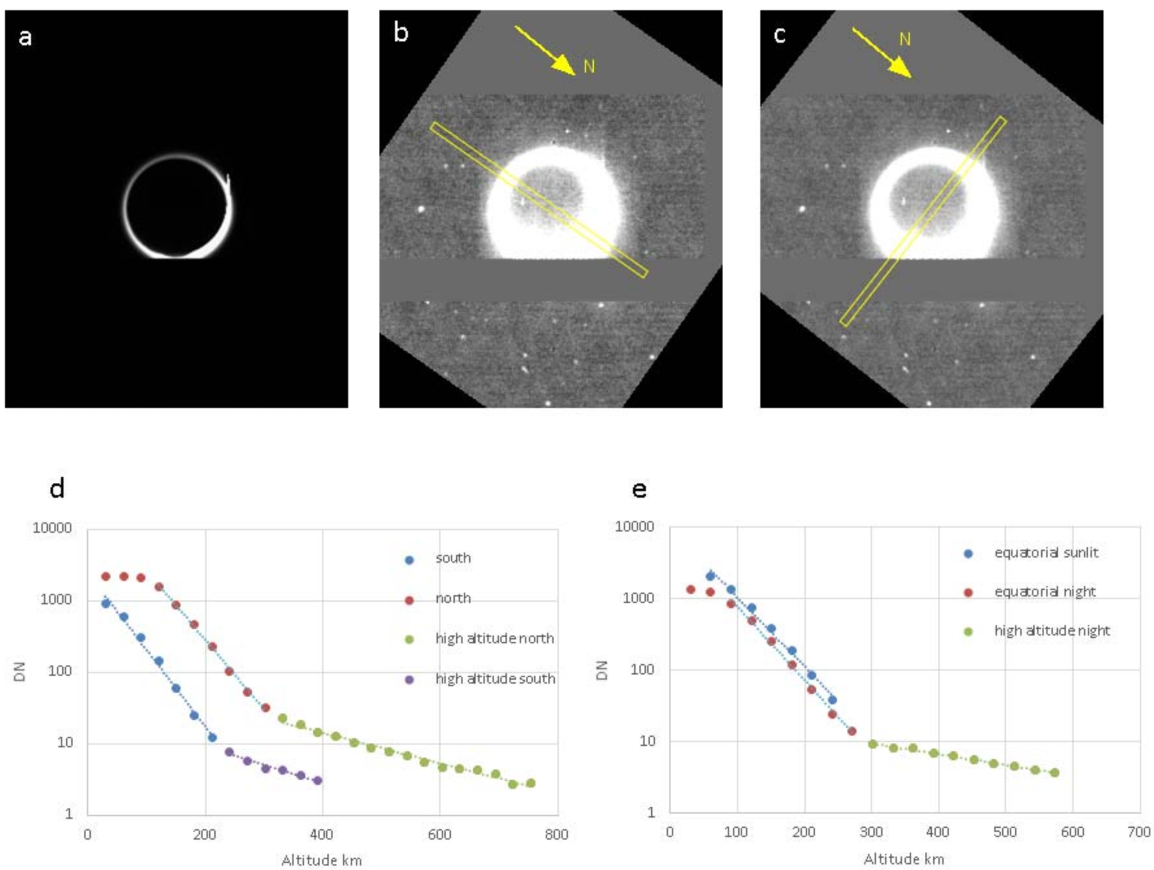

Figure 2. Pluto haze at altitudes up to 700 km. (a) Image resolution 30.2 km/px at phase angle 165.5° (b) Image stretched, with analysis box for profiles (d); north vs. south. (c) Stretched with analysis box for profiles (e); sunlit versus night.