CONSTRAINING PLUTO'S ESCAPING N_2 ATMOSPHERE USING NEW HORIZONS LEISA OBSERVATIONS OF CHARON J. C. Cook[1], S. A. Stern[1], O. J. Tucker[2], A. Verbiscer[3], L. A. Young[1], [1]Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder CO 80302, [2]University of Michigan, Ann Arbor, MI 48109, [3]University of Virginia, Department of Astronomy, Charlottesville, VA 22904. (jccook@boulder.swri.edu)

Background: The majority of Pluto's known atmosphere prior to the *New Horizons* flyby is comprised of N_2, with minor ($<1\%$) amounts of CH_4 and CO [1, 2]. The atmospheric escape rate has been estimated between $\sim10^{27}$ to $\sim10^{28}$ N_2 particles s^{-1}, depending on solar activity and heliocentric distance (*i.e.*, [3]). As has been suggested by various works since the 1980s, some of the gas leaving Pluto may reach Charon. Recently, [4] has shown that some of that N_2 may form a weak atmosphere around Charon, and become temporarily bound to Charon's surface. Ground based observations of Charon by [5] suggest an N_2-ice detection, but it has never been confirmed. This year, the *New Horizons* spacecraft will make a close encounter with Pluto and its satellite system. Using the instruments aboard *New Horizons*, observations are planned to examine the surfaces of Pluto and Charon, the atmosphere of Pluto and search for an atmosphere around Charon down to the $\sim$nbar level. Here we examine a combination of ground-based observations of Charon's sub-Pluto hemisphere from [6] and use spectral models to further constrain or detect the abundance of N_2-ice. Then we determine what abundances are necessary for *New Horizons* to detect N_2-ice or gas at Charon.

Motivation: The atmospheric models of Charon presented in [4] suggest under nominal solar conditions a column density of $\sim$2-3$\times10^{22}$ N_2 molecules cm^{-2}. This is below the sensitivity of 10^{23} molecules cm^{-2} for a 3σ detection using *New Horizons*' Alice UV spectrograph operating in solar occulation mode [7]. However these results are highly sensitive to surface temperature, and if the surface is only a few degrees warmer, then the column densities do become significant enough to detect. Under the conditions assumed by [4], N_2 will freeze onto the night-side surface. Once reintroduced to solar heating at sunrise, sublimation of N_2 will occur. This makes the dawn terminator a prime place to look in the Charon solar occulation data for its atmosphere. However, if the surface is colder than expected, then the N_2 may form a detectable frost layer. If this is the case, the detection of N_2-ice may be possible, but again isolated to regions around the pole and dawn terminator.

Past Observations: In 2005, [6] obtained high SNR (50-100) spectra of Charon using Gemini North with the NIRI and Altair (adaptive optics) instruments. Observations were made in H-band (1.50-1.80 μm) and K-band (1.95-2.40 μm) at a resolving power ($\lambda/\Delta\lambda$) of $\sim$500. Observations were made within 10° of Charon's sub-Pluto (0°) and anti-Pluto (180°) hemispheres. Fig. 1 shows the sub-Pluto K-band spectrum of Charon. These spectra showed the absorption bands at 1.5, 1.65 and 2.0 μm due to crystalline H_2O ice seen previously by [8, 9, 10]. Another previously seen band near 2.21 μm, was definitively identified as ammonia hydrate [6]. Water ice and NH_3-hydrates have been seen in spectra of Charon at all observed longitudes [11, 12].

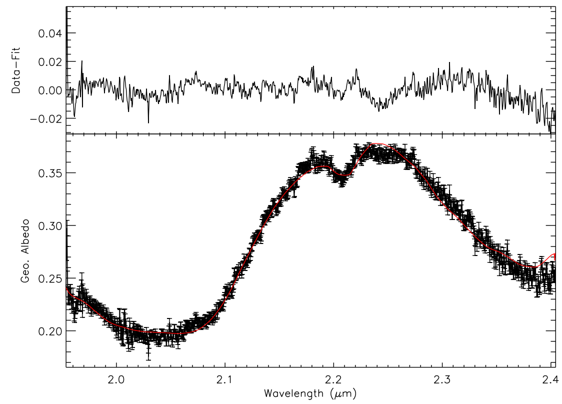

Figure 1: Gemini North/NIRI+Altair observations (black) and Hapke model (red) of Charon (bottom) and residuals (top).

Future Observations: With the arrival of *New Horizons*, new spatially resolved spectra of Charon will be obtained using the LEISA instrument, the near-infrared spectral imager [13]. The instrument is designed to make spectral maps of the surface of Pluto and Charon. LEISA performs in a push broom fashion, building a 256 (spectral) $\times$ 256 (spatial) $\times$ n (spatial) image cube, where n is an arbitrary length. Spectra from LEISA have a resolving power of $\sim$260 from 1.25 to 2.50 μm and resolving power of $\sim$560 from 2.10 to 2.25 μm [14]. We will use the high-resolution spectra to determine the shape and variations of the 2.15 and 2.21 μm bands of N_2 and NH_3-hydrate, respectively. Starting weeks before closest approach, *New Horizons* will make regular observations of Charon to make hemispheric maps of the surface at resolution of 8 km/pix. These observations will be useful in determining the global distribution of numerous species, including N_2. At closest approach, smaller regions of Charon will be observed at up to 4.7 km/pix resolution. Shortly after closest approach, Charon will occult the sun from the viewpoint of *New Horizons*. *New Horizons* will perform the Charon occultation to look for an atmosphere in absorption.

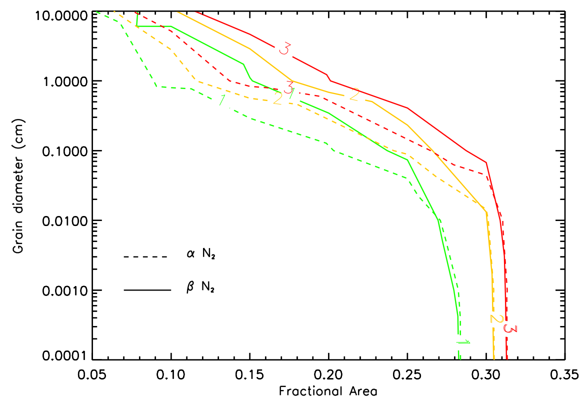

Figure 2: Limits on α (dashed) and β (solid) phase N_2 on Charon. Each contour line represents where $\Delta\chi^2_\nu$ is 1 (green), 2 (yellow) and 3 (red).

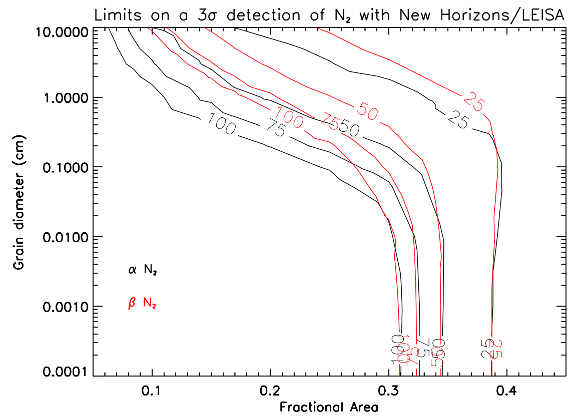

Figure 3: Signal-to-noise estimates for the 3σ detection of α (black) and β (red) N_2 on Charon.

Modeling Spectra: We use Hapke's theory to produce model spectra of Charon that matches the data in Fig. 1. We assume two spatially separated spectral units. The first unit is an intimate mixture of pure crystalline H_2O ice at 40 K and kaolinite, a phylosilicate with a blue spectral slope. [9] noted that pure crystalline H_2O ice does not match spectra of Charon at longer wavelengths, and that a blue neutral absorber was necessary. In our experience, kaolinite produces the best match in K-band. The second spectral unit is an intimate mixture of ammonia hydrate ($NH_3{\cdot}H_2O$) and ammonium hydroxide (NH_4OH), both of which produce absorption features at 2.21 (stronger) and 1.99 (weaker) μm in addition to the crystalline H_2O ice bands. Given this composition, the best-fit model is about 36% (first unit) and 64% (second unit) of the observed surface. We then rerun the model including a third spectral unit of pure N_2-ice. N_2 has two phases of ice. The hexagonal, β phase, that forms at temperatures $>$35.6 K and the colder, cubic, or α phase. Figure 2 shows that if N_2 grains are 1 μm in diameter, then it covers $<$31% of the observed surface regardless of ice phase. If, however, the grain sizes were similar to those found on Pluto (1-10 cm), then the upper limit on the observed surface area is 12-20% for β N_2 and 8-14% for α N_2.

Modeled LEISA data: We rebin the Gemini data from Fig. 1 to the spectral sampling of the high-resolution segment of LEISA as a proxy. We find the 3σ limit for the detection of α and β N_2 for data of different SNR levels over the wavelength range 2.10 to 2.18 μm. These results are shown in Fig. 3. For large grain N_2-ice, the α N_2 is detectable if covering $>$10% of the observed area for high SNR ($\sim$100) data. However, for finer grains the ability to detect either form of N_2 becomes more difficult and would need to cover $>$30-40% of the observed area. In addition, the ability to distinguish between α and β N_2 becomes impossible for grain diameters $\lesssim$300 μm.

Discussion & Conclusion: The close proximity of Charon to Pluto means that Charon is capable of capturing gas that has escaped from Pluto. Recently, [4] showed how Charon may have a weak N_2 atmosphere and some N_2-ice. If the surface temperature of Charon is as [4] modeled, then the atmosphere is too weak for *New Horizons* to detect. However, small differences in the surface temperature (*i.e.*, few K warmer) may produce a detectable atmosphere. But, if conditions are colder than expected, then N_2 will remain bound to the surface. Since the detection of either an atmosphere or N_2-ice is so sensitive to temperature, the observations made by *New Horizons* will be critical in understanding the role atmospheric escape from Pluto may have on Charon, such as the formation of nitriles. In addition, since *New Horizons* will obtain spatially resolved spectra of Charon, mapping the distribution of N_2-ice may help to determine the origin of N_2 on Charon, *e.g.*, either from Pluto, or delivered from cometary impacts [7].

References: [1] Young, L. A., et al. (1997) *Icarus* 127:258. [2] Lellouch, E., et al. (2009) *A&A* 495:L17. arXiv:0901.4882. [3] Tucker, O. J., et al. (2012) *Icarus* 217:408. arXiv:1111.2808. [4] Tucker, O. J., et al. (2015) *Icarus* 246:291. [5] Verbiscer, A. J., et al. (2007) *LPI Contributions* 1357:144. [6] Cook, J. C., et al. (2007) *ApJ* 663:1406. [7] Stern, S. A., et al. (2015) *Icarus* 246:298. [8] Brown, M. E., et al. (2000) *Science* 287:107. [9] Buie, M. W., et al. (2000) *Icarus* 148:324. [10] Dumas, C., et al. (2001) *Astron. J.* 121:1163. [11] Merlin, F., et al. (2010) *Icarus* 210:930. [12] DeMeo, F. E., et al. (2015) *Icarus* 246:213. [13] Stern, A., et al. (2003) *Earth Moon and Planets* 92:477. [14] Reuter, D. C., et al. (2008) *Space Sci. Rev.* 140:129. arXiv:0709.4281.