Background: The majority of Pluto’s known atmosphere prior to the New Horizons flyby is comprised of N₂, with minor (<1%) amounts of CH₄ and CO [1, 2]. The atmospheric escape rate has been estimated between ~10^{27} to ~10^{28} N₂ 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 N₂ may form a weak atmosphere around Charon, and become temporarily bound to Charon’s surface. Ground based observations of Charon by [5] suggest an N₂-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 ~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 N₂-ice. Then we determine what abundances are necessary for New Horizons to detect N₂-ice or gas at Charon.

Motivation: The atmospheric models of Charon presented in [4] suggest under nominal solar conditions a column density of ~2-3×10^{22} N₂ 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 occultation 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], N₂ will freeze onto the night-side surface. Once reintroduced to solar heating at sunrise, sublimation of N₂ will occur. This makes the dawn terminator a prime place to look in the Charon solar occultation data for its atmosphere. However, if the surface is colder than expected, then the N₂ may form a detectable frost layer. If this is the case, the detection of N₂-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 (λ/Δλ) of ~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 H₂O 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 NH₃-hydrates have been seen in spectra of Charon at all observed longitudes [11, 12].

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) × 256 (spatial) × n (spatial) image cube, where n is an arbitrary length. Spectra from LEISA have a resolving power of ~260 from 1.25 to 2.50 μm and resolving power of ~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 N₂ and NH₃-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 N₂. 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 1: Gemini North/NIRI+Altair observations (black) and Hapke model (red) of Charon (bottom) and residuals (top).
The first unit is an intimate mixture of pure crystalline H\(_2\)O ice at 40 K and kaolinite, a phyllosilicate with a blue spectral slope. [9] noted that pure crystalline H\(_2\)O 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 the spectral region of Charon, mapping the distribution of N\(_2\) on Charon. Each contour line represents where \(\Delta \chi^2\) is 1 (green), 2 (yellow) and 3 (red).

**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\(_2\)O and ammonium hydroxide (NH\(_4\)OH), both of which produce absorption features at 2.21 (stronger) and 1.99 (weaker) \(\mu\)m in addition to the crystalline H\(_2\)O ice bands. Given this composition, the best-fit model is about 36% (first unit) and 64% (second unit) of the observed surface. We then re-run the model including a third spectral unit of pure N\(_2\)-ice. N\(_2\) has two phases of ice. The hexagonal, \(\beta\) phase, that forms at temperatures >35.6 K and the colder, cubic, or \(\alpha\) phase. Figure 2 shows that if N\(_2\) grains are 1 \(\mu\)m 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 \(\beta\) N\(_2\) and 8-14% for \(\alpha\) 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 3\(\sigma\) detection of \(\alpha\) (black) and \(\beta\) (red) N\(_2\) on Charon.

**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:**