COMPARATIVE PLANETOLOGY OF THE ION CHEMISTRY AT PLUTO, TITAN, AND TRITON. K. E. Mandt[1] and A. Luspay-Kuti[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723 (Kathleen.Mandt@jhuapl.edu).

Introduction: Understanding the origin and evolution of volatiles in the atmospheres of small bodies in the outer solar system is critical for constraining conditions in the Protosolar Nebula (PSN) during the formation of the solar system. In previous work we have found that Titan's nitrogen originated as NH_3 in the PSN based on our understanding of how chemistry and escape fractionate the isotopes [1,2]. Our work with studying photochemistry and escape of Pluto's atmosphere found that the processes in Pluto's atmosphere are more complex, and current understanding about condensation and aerosol interaction prevent us from concluding what the source of Pluto's nitrogen was in the PSN [3]. Comparing processes that take place in Triton's atmosphere with what we know of Pluto's could provide valuable insight into this problem.

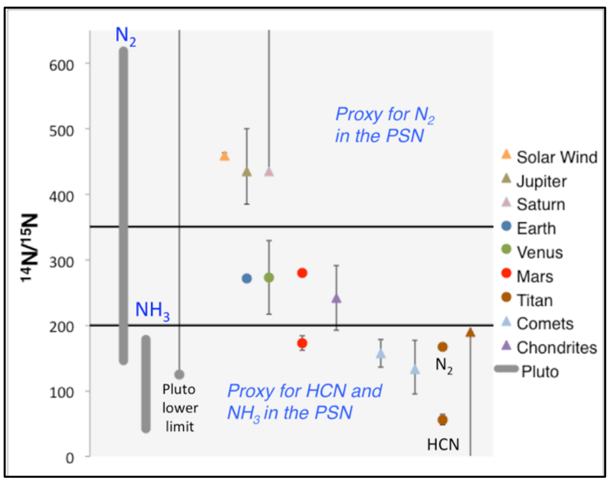

Figure 1 - $^{14}N/^{15}N$ throughout the solar system [3 and refs.]. Primordial values are shown as triangles and evolved ratios are circles. The large uncertainty for the possible evolved $^{14}N/^{15}N$ in N_2 at Pluto is due to uncertainties in the influence of condensation, aerosol trapping and sublimation on the isotopes. We have extended our work to evaluate the evolution of $^{14}N/^{15}N$ in N_2 in Triton's atmosphere.

Origin of Nitrogen: Nitrogen is a useful tool for understanding the conditions in the outer regions of the PSN because N_2 and NH_3 are incorporated into icy building blocks at different temperatures [2,4]. The nitrogen isotopes provide a clear separation between N_2 and NH_3 in the PSN as shown in Fig. 2, where we illustrate measurements of $^{14}N/^{15}N$ throughout the solar system. We divide them into two groups: primordial (triangles), or the value presumed to represent the value in the PSN; and evolved (circles), or a value that has changed over time due to atmospheric processes like escape and chemistry. Evolved observations of $^{14}N/^{15}N$ are not direct measurements of building block composition. This means that Pluto's current atmospheric composition cannot be used to make conclusions about Pluto's primordial composition. The evolution of the atmosphere must be evaluated to understand the origin of Pluto's volatiles.

Evolution of Atmospheres: The $^{14}N/^{15}N$ in planetary atmospheres evolve as a result of processes that affect each isotope differently. These processes include: atmospheric escape, photochemistry, electron-impact chemistry, condensation, sublimation, and aerosol trapping.

The atmospheres of Pluto, Titan and Triton are similar to each other in their general composition and in the types of processes at work in the atmosphere. However, the details of their composition, such as the methane abundance, and the rate at which each process works differs for each atmosphere. This means that different processes dominate in influencing nitrogen at Pluto compared to Titan and Triton. Photochemistry driven by solar photons combined with atmospheric escape are most important at Titan [1,2]. For Pluto, HCN is the reference gas for tracing evolution of nitrogen at Pluto. This molecule is strongly influenced by condensation and sticking to aerosols in Pluto's atmosphere and work is ongoing to understand the implications of this for the evolution of nitrogen at Pluto. As one step in trying to improve understanding of Pluto, we are using comparative planetology with Titan, which is well understood, and with Triton, which is currently poorly understood. We outline below a comparison with Triton.

Comparative planetology to understand the evolution of Pluto's atmosphere: The most notable difference between Pluto and Triton is the intensity of Triton's ionosphere compared to Pluto. The *Voyager* observations of Triton found that the peak electron density [5] is significantly greater than peak densities observed in Titan's solar-driven ionosphere[6], suggesting that energetic particles from Neptune's magnetosphere play an important role in chemistry in Triton's atmosphere. We illustrate in Fig. 2 the electron density observed at Triton compared to average dayside ion densities at Titan [6] and the upper limit for Pluto [7].

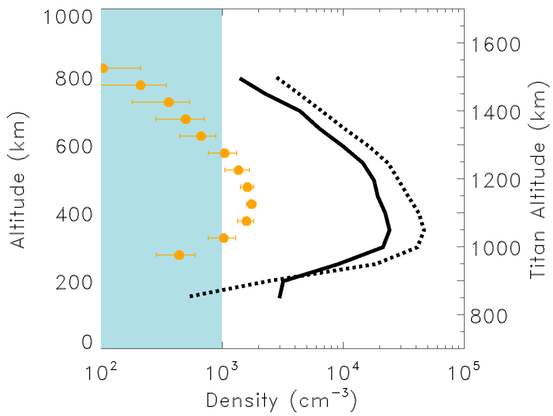

Figure 2 - Triton's total ionospheric electron density [5] at ingress (black solid line) and egress (black dashed line) is ~10x greater than Titan's peak daytime ion density (orange circles; [6]) and the upper limit for Pluto (cyan-shaded; [7]).

Ion chemistry and molecular growth: Ion chemistry at Titan is thought to play an important role in driving molecular growth that leads to the formation of organic hazes in Titan's atmosphere [8]. However, Pluto's haze layers [9] are more extensive than Triton's [10] even though Pluto's ionospheric density has an upper limit that is more than an order of magnitude lower than Triton's. This suggests that the processes driving molecular growth are more complex and by extension means that evolution of the atmosphere due to chemistry is also more complex.

Drivers of ion chemistry at Pluto, Triton, and Titan: The ionospheres of Pluto and Titan are both driven by solar photons ionizing atmospheric neutrals leading to complex chemistry. The total ion density in a solar-driven ionosphere is a result of the balance of production and loss processes. Titan is closer to the Sun and has higher ion production rates due to solar input than Pluto and Triton. These higher rates should lead to higher densities at Titan than at Pluto or Triton. This is the case for Pluto, but not for Triton. Modeling studies from the *Voyager* era found that the high electron densities in Triton's atmosphere required high ion production rates resulting from the input of energetic electrons from Neptune's magnetosphere [e.g. 11]. These models predicted that either N^+ or C^+ would be the dominant ion in Triton's ionosphere. However, the C^+ production in these models required assuming a high rate for a reaction that had not been measured in the laboratory [12]. Since these models were published, significant progress has been made in understanding the chemistry in atmosphere like Triton's thanks to comparisons made with observations by *Cassini* of Titan [e.g. 6,13] and *New Horizons* at Pluto [3,14]. To test if advances in photochemical modeling can explain the high electron density at Triton, we have adapted our Pluto Ion Neutral Photochemical (Pluto-INP) model to conditions at Triton (Triton-INP) and compare simulated atmosphere conditions with results from the *Voyager 2* flyby of Triton. Fig. 3 shows that the simulated total ion density (black line) using only solar input is ~6x lower than the electron density observed by *Voyager* confirming that Neptune's magnetosphere plays an important role in ion chemistry in Triton's atmosphere. However, the main ion produced in a solar driven ionosphere is HCO^+, and not N^+ or C^+, showing that what we have learned from Titan and Pluto is important for understanding Triton.

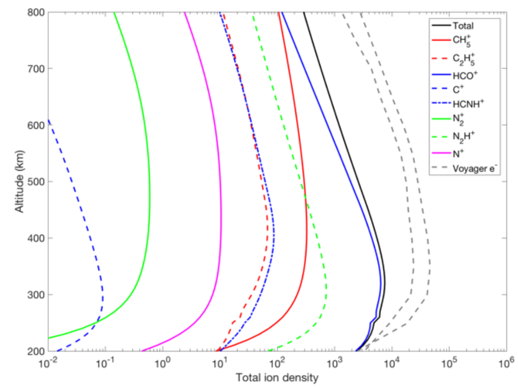

Figure 3 – Results of our ion chemistry pilot study [15] showing Triton-INP ion composition using only solar EUV as an energy source. Total ion densities (black solid line) are 3-6 times lower than observed electron densities (gray solid and dashed lines). The most abundant ion is HCO^+.

References: [1] Mandt K. E. et al., (2009) *PSS, 57,* 1917–1930. [2] Mandt K. E. et al., (2014) *ApJL, 788,* L24. [3] Mandt et al. (2017) *MNRAS*, 472, 118-128. [4] Mandt K. E. et al. (2015a) *SSRv, 197,* 297–342. [5] (Tyler et al., 1989) [6] Mandt K. E. et al. (2012) *JGR*, 117(E10). [7] Hinson, D. P. et al. (2018) *Icarus*, *307*, 17-24. [8] Wahlund et al. (2009) *PSS*, 57, 1857-1865. [9] Gao, P. et al. (2017) *Icarus*, *287*, 116-123. [10] Smith, D. B. et al. (1989) *Science*, 246, 1422-1449. [11] Krasnopolsky, V. A. & Cruikshank, D. P. (1995) *JGR*, 100, 21271-21286. [12] Lyons, J. R. et al. (1992) *Science,* 256, 204-206. [13] Krasnopolsky, V. A. (2009) *Icarus, 201*, 226-256. [14] Luspay-Kuti, A. et al. (2017) *MNRAS,* 472, 104-117. [15] Mandt, K. E. et al. (in prep.).