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Comparative Planetology of the Origin of Nitrogen on Titan, Pluto and Triton

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Abstract

Stable isotope ratio measurements combined with modeling of isotope evolution help us to understand the origin of volatiles throughout the solar system [see 1 and references therein]. The evolution of the nitrogen isotope ratio, $^{14}N/^{15}N$, in the atmospheres of Titan, Pluto and Triton compared to measurements throughout the solar system (Fig. 1) can be used to determine the origin of nitrogen in each atmosphere. The goal is to determine if this nitrogen originated as N_2 or is derived from NH_3 in the protosolar nebula (PSN). The origin of Titan's nitrogen has been well constrained [2], but uncertainties due to lack of measurements and poor understanding of photochemistry and other processes leave Pluto [3,4] and Triton unconstrained. Therefore, our goal in this work is to provide guidance on measurements needed by a future Ice Giants mission to study Triton and any mission to follow New Horizons and Cassini in exploring Pluto and Titan.

1. Introduction

This work is part of an ongoing study to determine the origin of nitrogen in atmospheres throughout the solar system [2,3,4,5,6]. Measurements of $^{14}N/^{15}N$ throughout the solar system allow us to map out the origin and history of nitrogen in the solar system, as illustrated in Fig. 1 [adapted from 4, see references therein for individual measurements]. $^{14}N/^{15}N$ measured in the solar wind and the atmospheres of Jupiter and Saturn are presumed to be representative of N_2 in the PSN because the most abundant form of nitrogen in the PSN was N_2. Trace amounts of HCN and NH_3 were also present in the PSN, and $^{14}N/^{15}N$ for these constituents measured in comets are presumed to represent their primordial ratio.

On the other hand, $^{14}N/^{15}N$ measured in the atmospheres of the terrestrial planets, Titan and the lower limit for HCN in Pluto are known to have evolved from their primordial ratio over the history of the solar system. Modelling how the ratio changes over time helps us to understand the origin of nitrogen in these bodies. Our most recent work has evaluated Triton as a follow-up to our studies on Pluto [5,6] and Titan [2,3].

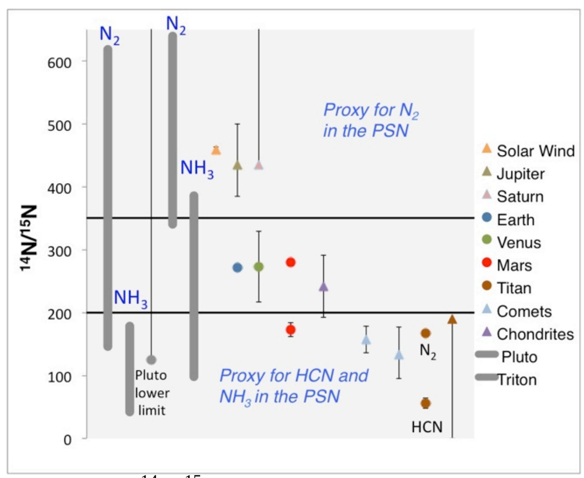

Figure 1: $^{14}N/^{15}N$ measured throughout the solar system [see 4 and refs. therein]. Triangles are primordial values while circles are ratios that have evolved. Estimated range of values for Pluto (left grey bars) and Triton (right grey bars) are also shown

2. Lessons from Pluto and Titan

2.1 Escape

Escape preferentially removes the lighter isotope from the atmosphere, reducing the ratios illustrated in Fig. 1 over time. The higher ratio for Mars is thought to represent a primordial value that decreased through escape over time to the current ratio [see 6 and refs. therein]. However, escape from Titan's very dense atmosphere is not effective at changing $^{14}N/^{15}N$ [2,6]. We determined an upper limit for primordial $^{14}N/^{15}N$ similar to the $^{14}N/^{15}N$ in cometary NH_3 [2]. Hydrodynamic escape of nitrogen was predicted for

Pluto's atmosphere prior to the *New Horizons* flyby. This would have a major impact on the isotope ratio over time [3]. However, observations by the *New Horizons* Alice UV spectrograph presented a much cooler atmosphere with nitrogen escaping rates that are orders of magnitude lower than predicted [7]. This significantly reduces the impact of escape on $^{14}N/^{15}N$ in Pluto's atmosphere [4].

2.2 Photochemistry

The difference in $^{14}N/^{15}N$ in N_2 and HCN in Titan's atmosphere (Fig. 1) is due to extreme fractionation by photochemistry in Titan's atmosphere [8]. Our preliminary study modelling the photochemistry of Pluto's atmosphere [4] does not find the same effect and is supported by the lower limit reported for $^{14}N/^{15}N$ in HCN [9]. It is unclear at this time why Pluto is so different from Titan, and more work needs to be done on this topic.

2.3 Other processes

When evaluating photochemistry in Pluto's atmosphere, we also simulated the loss of HCN by condensation and sticking to aerosols [4] and found that this process appears to have a major impact on $^{14}N/^{15}N$ in HCN that does not agree with the lower limit [4,9]. This means that we have a poor understanding of the impact of these processes on $^{14}N/^{15}N$ and that more work is also needed.

3. Application to Triton

Updated estimates for Triton's atmospheric structure and the rate of nitrogen escape have been provided based on what has been learned about Pluto's atmosphere from *New Horizons* [10]. We apply these results and estimates for photochemical fractionation to determine the range of ratios that could be measured by a future Ice Giants mission to explore Triton (Fig. 1). Improved studies on photochemistry and other processes at Pluto will play an important role in reducing the uncertainty in these results.

4. Summary and Conclusions

Measurements of $^{14}N/^{15}N$ in planetary atmospheres can be used to determine the origin of nitrogen for these bodies. We have determined that Titan's nitrogen originated as NH_3 in the PSN [2] and are working on constraints for current $^{14}N/^{15}N$ in the atmospheres of Pluto [3,4] and Triton in anticipation of future missions capable of making these measurements.

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