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Understanding the Hydrocarbon Lakes and Seas on Titan

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Abstract

We have performed laboratory experiments and chemical modeling to understand methane and ethane stability in the presence of a nitrogen atmosphere with respect to surface conditions on Titan.

1. Introduction

Many outer solar system bodies are likely to have a combination of methane, ethane and nitrogen. In particular, the atmosphere and lakes and seas of Titan are known to consist of these species. Understanding the past and current stability of these lakes requires characterizing the interactions of methane and ethane, along with nitrogen, as both liquids and ices. Previous studies have shown that the freezing point of methane is depressed when mixed with nitrogen [1, 2]. Northern Arizona University (NAU) hosts one of a handful of laboratories around the world devoted to studies of astrophysical ices and liquids [2, 3]. Our cryogenic laboratory setup allows us to explore ices down to 30 K through imaging, and Raman and transmission spectroscopy. Our recent work has shown that although methane and ethane have similar freezing points, when mixed they can remain liquid down to 72 K [4].

The lakes and seas of Titan are composed primarily of methane and ethane, with the concentration of dissolved nitrogen from the atmosphere dependent on the ratio of methane to ethane, the temperature, and pressure. Models have predicted the existence of two liquid layers in equilibrium with the vapor phase under certain temperature and pressure conditions [5, 6]. Our experiments have confirmed the presence of the two liquid phase at colder temperatures and higher pressures than what exists on the surface of Titan.

Titan's atmosphere is composed of ~1.47 bar of mostly nitrogen. Methane and ethane are quite soluble into each other, and nitrogen is known to be highly soluble into methane, depending on temperature and pressure; however, nitrogen is less soluble into ethane [e.g. 5-7]. To fully understand the stability of the lakes and seas of Titan, we need to map out the phase diagram for the ternary system of nitrogen, methane and ethane. Recent thermodynamic modeling of the ternary liquid of nitrogen-methane-ethane suggest that at higher pressures, such that might exist at depth of a Titan sea, it is possible for a liquid-liquid-vapor equilibrium to occur [3, 5, 6]. Our laboratory work confirmed that two liquids can exist in the conditions predicted by [5] and [6]. We will show how nitrogen affects the freezing points of methane and ethane when mixed under Titan surface conditions, in addition to the solidus points. Further, we explore the stability and chemical properties of the lakes and seas on Titan, as well as comparing laboratory experiments to thermodynamic models.

2. Experimental Setup

In the Astrophysical Materials Laboratory at Northern Arizona University, volatile ices are condensed within an enclosed cell. Cooling is provided by closed-cycle helium refrigerators, within vacuum chambers for insulation. Cryogenic ice samples are studied via various analytical techniques including visible and infrared transmission spectroscopy, Raman spectroscopy and photography. Mass spectrometers are capable of monitoring changes in composition.

To test the properties of Titan lakes, we first mixed methane and ethane in the gas mixing chamber, condensed them to a liquid in the sample cell at the desired temperature, waiting 20 minutes for equilibrium, then closed the valve between the cell and the mixing chamber. We pumped out the remaining hydrocarbon gas in the mixing chamber. We slowly opened the valve to allow nitrogen into the sample cell until the desired pressure was reached. In all experiments, once the desired T and P conditions were met, we agitated the sample to ensure full mixing, waited 20 minutes for equilibrium, agitated again, then visually inspected the sample, taking photographs and videos. Raman spectra are taken in 1 mm increments from the bottom of the cell to 1 mm above the liquid to ensure the gas phase was also sampled. This allows us to monitor the composition as temperature and pressure were varied.

3. Experimental Results

Two Liquid Layers

In all experiments performed so far, the lower layer is enriched in nitrogen and methane, while the upper layer is enriched in methane and ethane, although both layers have all three species present. The initial ratio of methane to ethane will control the relative volumes of the two liquids, though it does not appear to affect their compositions. We will present these experimental results detailing the conditions under which the two liquid phases form, as well as the composition of the liquids. These results can inform whether they might occur on Titan.

Stability of Methane and Ethane in the Presence of Nitrogen

We have undertaken a systematic study of the effect of nitrogen on the methane-ethane system. We have previously shown that methane and ethane form a eutectic system, as do methane and nitrogen. New results show that ethane will preferentially freeze when there is enough nitrogen dissolved into the ternary system. We will present experimental results on the phase diagram of the methane-ethane-nitrogen system.

4. Modeling

We have undertaken computational molecular dynamics simulations to examine the molecular origins of the behavior we have observed. Simulations of the pure species reveal densities that deviate from experiment by 8%, 1%, and 27% for methane, ethane, and nitrogen at 100 K. Simulations of methane, ethane, and nitrogen mixtures have then been used to predict properties of Titan lakes and seas. For example, in the two liquid layer models, estimated compositions of each layer provide densities that justify layer order, which are found to be in general agreement with predictions by [5] and [6].

We next plan to undertake simulations of the two liquid layers in contact with each other. This will permit characterization of molecular behavior in the whole system, including interfacial organization of the molecules, molecular flux across the boundary, and other characterization of the two-phase equilibrium.

5. Implications

Our experiments show that within the depths measured in the seas and temperatures and pressures expected there, two liquid layers are possible on Titan today. Some interesting questions that are raised are what happens when considering the circulation patterns of the largest seas, how the “pure” methane rain (saturated with nitrogen) or the rivers would affect the delicate equilibrium necessary for two liquid layers to occur. Additionally, ice and/or secondary liquid formation happens under a narrow range of conditions, depending on the position within the lake, temperature, pressure, and composition. We will discuss how this all might impact understanding of previous mission results from Cassini, as well as future missions, and guide current theoretical models

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References

[1] Prokhvatilov & Yantsevich (1983) Sov. J. Low Temp. Phys. 9, 94-98. [2] Protopapa S. et al (2015) Icarus 253, 179–188 [3] Hanley J. et al (2019) LPSC Abstract #1712. [4] Hanley J. et al (2017) LPSC Abstract #1686. [5] Cordier D. et al (2017) Nat. Astro. 1, 0102. [6] Tan S. and Kargel J. (2018) Fluid Phase Equilibria, 458, 153-169. [7] Malaska M.J. et al (2017) Icarus 289, 94–105.