THE SUBLIMATION OF WATER ICE AND ENCELADUS' PLUME. R. Hodyss[1], J. D. Goguen[1], P. V. Johnson[1], C. F. Campbell[2], I. Kanik[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 (Robert.P.Hodyss@jpl.nasa.gov), [2]California State University, Fullerton, CA 92831.

Introduction: The south polar region of Enceladus is the source for a plume of gas and water ice particles that are a source for Saturn's E ring [1]. The plume emanates from multiple locations on the surface that correspond to the fractures referred to as the "tiger stripes" [2]. INMS data show the plume is composed of 91 ± 3% H_2O, 3.2 ± 0.6% CO_2, 4 ± 1% N_2 or CO, and 1.6 ± 0.4% CH_4 [3]. Temperatures on Enceladus range from ~37 K in the north polar night to a diurnal range of 50-75 K at low latitudes to perhaps 145 K or more in the warmest surface area of the tiger stripes [4]. Within this large temperature range, water ice undergoes significant structural reorganizations which influence the inclusion, mobility, and escape of trapped gases [5; 6].

We have conducted preliminary experiments with ices similar in composition to the plume gases in order to assess the contribution of phase change and sublimation related gas release in the formation of Enceladus' plume. While this behavior may not completely explain the presence of the plume, it undoubtedly contributes to its formation.

Experimental: We performed temperature programmed desorption experiments on ice films deposited from a gas sample of composition 1.6% CH_4, 3.1% CO_2, 3.8% N_2, and 91.5% H_2O. The thickness of the ice film was approximately 0.15 μm, deposited at a rate of approximately 0.5 μm/hr. Samples were deposited at 20 K and 70 K and were warmed at a rate of 1 K/min. These deposition temperatures were selected to bracket the range of insolation driven temperatures on Enceladus.

Results: Figure 1 shows the results of our TPD studies. A number of desorption features are common to both the 20K and 70 K depositions. Desorption of N_2, CH_4 and CO_2 is seen at 42 K, 55 K, and 85 K, respectively. These desorptions correspond to the sublimation of these species from the surface of the highly porous, amorphous water ice film, and are consistent with the temperatures at which these molecules would desorb if deposited as pure films on water ice [7; 8].

At 131 K, a release of N_2, CH_4 and CO_2 is observed at the onset of H_2O sublimation in the ice deposited at 20 K. This is probably caused by a phase change within the water ice matrix. Specifically, 131K corresponds to the previously reported [9] change from an amorphous solid to a third amorphous phase or a 'strong viscous liquid.' As the structure of the ice reorganizes, trapped species become mobile and can escape. The ice deposited at 70 K does not exhibit this behavior; the transition may be unobservable in this case due to the much smaller quantities of volatile gas trapped in the ice.

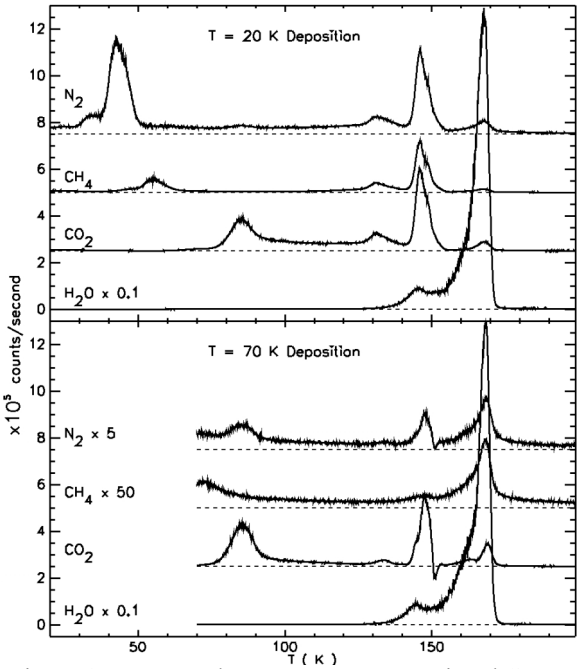

Figure 1. Measured mass spectrometer signal *S* vs. temperature for each of the 4 ice component molecules for ices deposited at T=20 K (top) and T=70 K (bottom). Traces are offset vertically for clarity.

At a temperature of ~145 K, significant amounts of N_2, CO_2 and CH_4 desorb from the ice. Again, this desorption is most likely caused by a phase transition in the water ice matrix, specifically crystallization to the hexagonal form. The quantity of highly volatile gas that remains trapped in the ice at these temperatures is surprising. Water is also beginning to desorb significantly in this temperature range. As the temperature increases, the rate of water ice desorption increases. Some of the more volatile gases are also released along with water as the rate of water sublimation reaches its peak. The water signal ends abruptly at ~170 K when the last of the water sublimes.

Although these data are relevant to many questions regarding the evolution of ices on Enceladus, we focus on their relevance to the plume. Consider the temperature range 135 to 155 K in the "instantaneous outgassing" plot Fig. 2. This is where the H_2O is just beginning to desorb while the other gases are still trapped

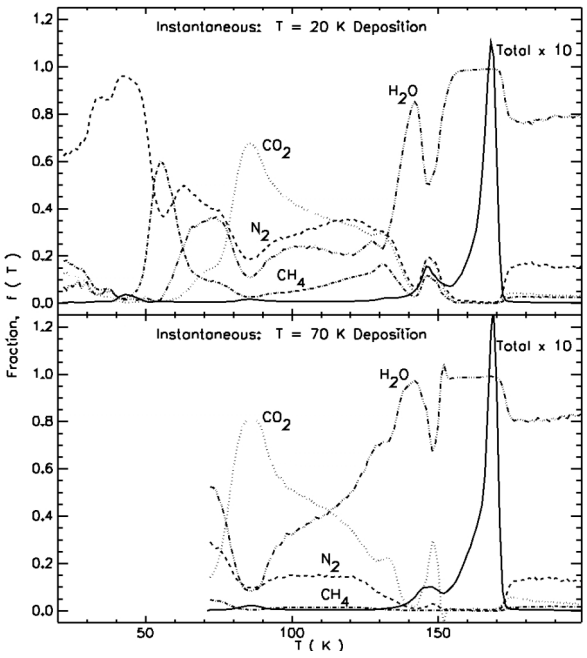

Figure 2. The "instantaneous outgassing" for ices deposited at T=20 K (top) and T=70 K (bottom). The ordinate value where a vertical line drawn at any T intercepts the $f_i(T)$ curves gives the instantaneous fraction of each component gas escaping during a $\Delta T = 1$ K interval. The solid lines labeled "Total" denote the fraction of all gas release that occurs within the $\Delta T =$ 1 K interval.

in significant amounts. This initial burst of outgassing results in a high fraction of H_2O plus significant quantities of CO_2, N_2 and CH_4. The T=20 K deposited ice could easily produce a plume-like mixture of gases if it were warmed to 135 to 155 K. The T=70 K deposited ice would be depleted in CH_4 and CO_2 would be enriched over N_2. Fig. 2 also shows that if ice deposited at either T=20 K or 70 K were warmed to T>155 K, then the escaping gas will be essentially pure H_2O because nearly all of the other trapped gases escape in the range from 135 to 155 K.

This 135 to 155 K temperature range is also precisely the temperature range that includes the CIRS measured temperatures of Enceladus South pole and Tiger stripes [4], which strongly suggests that the gas escape phenomena that we measure in our experiments are an important process for similar composition and temperature ices on Enceladus. Our results show that plume-like composition ices heated to the 135 to 155 K temperatures measured by CIRS will result in gases escaping with composition similar to the INMS plume composition. In contrast, similar ices heated to higher or lower T will not reproduce the measured plume composition.

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