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THE ROLE OF ICE LINES IN THE COMPOSITION OF SATURN'S MOONS

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Abstract. The presence of ice lines induces the creation of peaks of abundances of volatile elements in both protosolar- and circumplanetary- disks. The evolution of the abundance of volatile species in the protosolar nebula as a function of the migration of ice grains, their growth, and their evaporation have been modeled in order to understand the formation of the planets. These models have been taken to the protosolar nebula level to reproduce the enrichments measured in Jupiter's atmosphere. Yet as of today, no model has attempted to evaluate the ice lines of Saturn's circumplanetary disk to see how the known compositions of its moons could be reproduced. Here, we attempt to create a simplified description of Saturn's circumplanetary disk so as to try to bring a coherent vision of the formation of Titan and Enceladus with that of Saturn.

Keywords: snowline, ice line, Saturn, Enceladus, Titan, moon formation.

1 Introduction

The Ice Line, or Snow Line, is defined as the radius where the disk temperature is equal to the sublimation/condensation temperature of water-ice (or any species of interest) in the protosolar- and circumplanetary-disk. Our goal is to determine these ice lines for separate species in the Saturnian sub nebula and evaluate their enrichments over time in order to estimate how the moons of Saturn formed. This type of research has been done on the Jupiter system, but as of this moment there has been no study of this type attempted on the Saturnian system.

2 Circumplanetary Disk Model

We adopt the model of an actively supplied accretion disk by Canup & Ward (2002). The CPD is fed through its upper layers from its inner edge up to the centrifugal radius r_c by gas and gas-coupled solids inflowing from the protosolar nebula. This is set to $r_c = 30R_{Sat}$ and is limited by the outer radius $R_d = 150R_{Sat}$.

In this study we consider a disk based on the model by Sasaki et al. (2010). The total rate of mass inflow is $F_p = \pi F_{\rm in} r_c^2$. The infall rate decays exponentially with timescale $\tau_{Dep} = 3.10^6 - 5.10^6$ yr in the final state of the Saturnian case.

$$\Sigma_g \simeq \frac{F_p}{15\pi\nu} \begin{cases} \frac{5}{4} - \sqrt{\frac{r_c}{r_d}} - \frac{1}{4}\left(\frac{r}{r_c}\right)^2 & [r < r_c] \\ \sqrt{\frac{r_c}{r}} - \sqrt{\frac{r_c}{r_d}} & [r > r_c] \end{cases}$$

$$T_d \simeq 60\left(\frac{M_{\rm sat}}{M_J}\right)^2 \left(\frac{r}{20R_J}\right)^{-3/4} \exp\left(\frac{-t}{4\tau_{dep}}\right)$$

We consider the gas in a hydrostatic equilibrium in the vertical direction and the vertical velocity, therefore zero and allowing us to focus on a 1D model. This allows us to add a prescription to compute the velocity of the CPD's gas and describe the interaction between the solids and the gas in the radial direction. For each species of interest, we explore the sublimation temperature as a function of disk pressure. We solve the advection-diffusion equation at each radial distance in order to determine the abundance of species at the locations at which the Saturnian moons were formed.

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3 Results

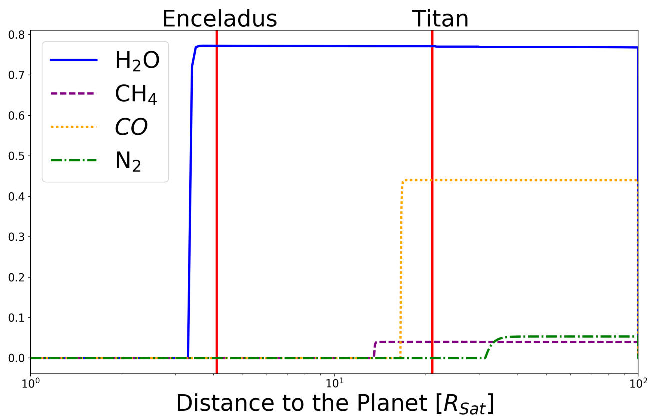

Fig. 1. Initial concentration of Water, Methane, Carbon Monoxide, and Nitrogen Ices, scaled to the protosolar abundances.

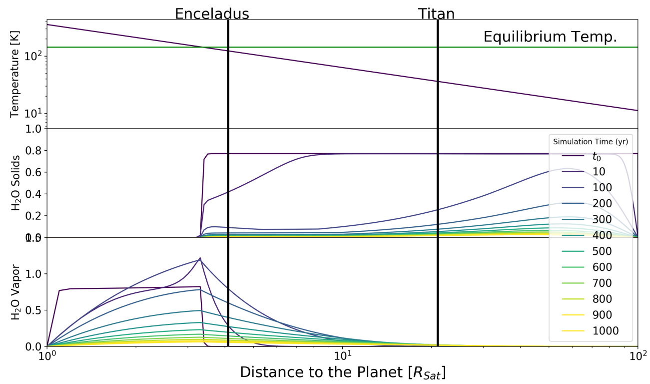

Fig. 2. Evolution of water vapor and dust in the Saturnian system over a 1000 yr as a function of radius, scaled to the protosolar abundance. The intersection of the 143 Kelvin line with the disk temperature slope indicates the position of the ice line. The dust and the vapor are normalized to protosolar quantities in the PSN. After a thousand years, almost no dust or vapor remain.

4 Conclusions

Enceladus would have formed in a location with water solids, which is supported by what we know of Enceladus's interior and composition, known to be over %90 water vapor. Titan would have formed with large quantities of solid carbon oxide and methane, however, the ice line of Nitrogen, of which Titan's atmosphere is comprised of %98, is out of reach for Titan's formation.

The disk is depleted in a few hundred years which means moon formation would be unlikely. A constant source of solids would need to be injected into the disk for it to be sustainable.

References

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