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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 compute the thermodynamic evolution of these ice lines within Saturn's circumplanetary disk to investigate their potential role in the formation of Titan and Enceladus.

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 other volatile species of interest) in the protosolar and circumplanetary disk. Our goal is to determine these ice lines for separate species in the Saturnian subnebula and evaluate their enrichments over time in order to estimate their potential role in the formation of Titan and Enceladus. 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 derived from the approaches of Canup & Ward (2002) and Sakaki, Stewart, & Ida (2010). 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 $R_d = 150R_{Sat}$. The total rate of mass inflow is $F_p = \pi F_{\text{in}} r_c^2$. The infall rate decays exponentially with timescale $\tau_{Dep} = 3 \times 10^6 - 5 \times 10^6$ yr in the final state of the Saturnian case.

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

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

We consider the gas in a hydrostatic equilibrium in the vertical direction with zero vertical velocity, allowing us to focus on a 1D model. This allows us to add a prescription to compute the radial velocity of the CPD's gas and describe the interaction between the solids and the gas. 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.

3. Results

The sublimation temperatures are calculated from the temperature and the pressure at each point of the disk. For the purposes of accurate representation, we use the sublimation temperature of 143 K for water; i.e. 50.5 K for methane clathrate; 43.5 K for carbon monoxide clathrate; and finally 20.2 K for pure nitrogen condensate. We then look at the positions where the disk reaches that temperature in the orbit of Saturn according to our model. The intersection between the sublimation temperature and the disk temperature shows us the position of the ice line.

Species	$t = t_0$	t =2.10^{6}yr
H_2O	3.4 $R_{\rm sat}$	2.7 $R_{\rm sat}$
CH_4	13.5 $R_{\rm sat}$	10.8 $R_{\rm sat}$
CO	18.1 $R_{\rm sat}$	14.5 $R_{\rm sat}$
N_2	35.9 $R_{\rm sat}$	26.7 $R_{\rm sat}$

Table 1: Positions of the Ice Lines of the major species examined in the model. Enceladus is positioned at 4.1 $R_{\rm sat}$ and Titan orbits at 21 $R_{\rm sat}$.

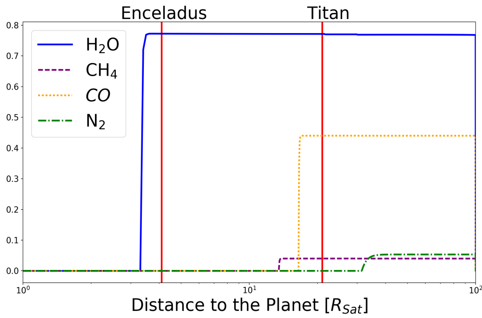

Figure 1: Initial concentrations of Water, Methane, Carbon Monoxide, and Nitrogen Ices, relative to protosolar abundances.

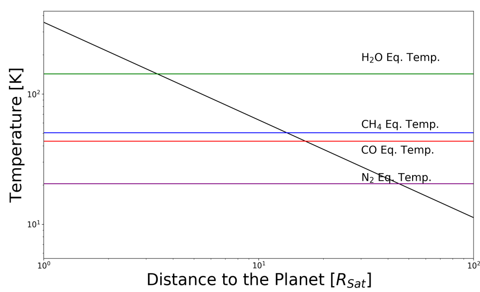

Figure 2: Positions of the Ice Lines of the major species examined in the model. The intersection between the sublimation temperature and the disk temperature shows us the position of the ice line.

4. Summary and Conclusions

Our calculations of the evolution of the various snowlines show that important volatiles enrichments (at least in the gas phase) happen at their locations. In our simulations, the disk is depleted in solids over a few hundred years, implying that moon formation must occur during this timescale, which is unlikely. A constant

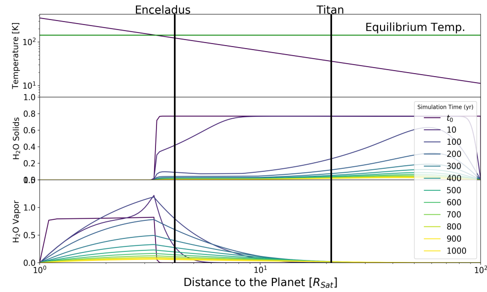

Figure 3: Evolution of water vapor and dust in the Saturnian system over a 1000 yr as a function of radius, scaled to the protosolar abundance. The intersection of the 143 Kelvin line with the disk temperature slope indicates the position of the ice line. The dust and the vapor are normalized to protosolar quantities in the PSN. After a thousand years, almost no dust or vapor remain.

source of solids would need to be injected into the disk for it to be sustainable.

Acknowledgements

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References

[1] Canup R.M. and Ward W.R. (2002) *Formation of the Galilean Satellites: Conditions of Accretion*, AJ, 124:3404–3423

[2] T. Sasaki, G. R. Stewart, and S. Ida, (2010) *Origin of the different architectures of the Jovian and Saturnian Satellite systems*, A&A, 714:1052–1064