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Origin of the water content of Europa : Evidence for pebble accretion ?

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Abstract

Despite the fact that the observed gradient in water content among the Galilean satellites is globally consistent with a formation in a circum-Jovian disk on both sides of the snowline, the mechanisms that led to a low water mass fraction in Europa ($\sim$8%) are not yet understood. Here we show that the water mass fraction of pebbles, as they drift inward, is globally consistent with the current water content of the Galilean system. This opens the possibility that each satellite could have formed through pebble accretion within a delimited region whose boundaries were defined by the position of the snowline.

1. Introduction

The Galilean satellites (Io, Europa, Ganymede and Callisto) are thought to have formed within a disk surrounding Jupiter at the end of its formation. Within this frame, accounting for the bulk composition of Io, which is essentially rocky [5], requires that it fully accreted inside the position of the snowline from water-free material. On the other end, Ganymede and Callisto, both containing $\sim$50% water by mass [5], should have accreted from ice-rich material beyond the position of the snowline. Accounting for Europa's $\sim$8% water by mass is not as straightforward. So far, the only explored scenario is the growth of the protosatellite both inward and outward of the snowline due to either/both disk cooling over time or/and protosatellite migration [1, 2]. Here we study the compositional (i.e., ice-to-rock ratio) and dynamical evolution of solid particles accounting for aerodynamic drag, turbulent diffusion, surface temperature evolution and sublimation of water ice. We show that Europa's water content could be the result of the accretion of partially dehydrated building blocks just inside the snowline rather than its formation within different environments.

2. Method and Results

In our model we track the evolution of individual particles (i.e., lagrangian integration). We integrate the equation of motion together with the equation of surface temperature evolution and ablation rate due to sublimation of water ice for each particle. We also use a Monte-Carlo scheme to account for the turbulent diffusion of the particles [3]. These particles are embedded in a gaseous circum-Jovian disk which is modeled with simple prescriptions giving the gas density and temperature distribution as a function of the mass accretion rate onto Jupiter [4]. When performing our simulations, we release particles of a given size at the midplane of the disk beyond the position of the snowline and let them evolve due to gas drag (inducing inward drift) and turbulent diffusion.

We find that large planetesimals (D$\gtrsim$10 km) are able to retain much more water than smaller ones in a given environment due to the efficient cooling of their surface temperature through water sublimation. Small dust grains (D$\leqslant$1 mm) have very short sublimation timescales and are not able to retain water inside the position of the snowline. The pebbles, solids with typical sizes of 0.01–1 m, are able to transport water inside the position of the snowline as they gradually sublimate while rapidly drifting. This is illustrated on Figure 1 where we present the ice mass fraction of these solids as a function of the distance from Jupiter. Due to the very fast inward motion of the pebbles induced by gas drag, we re-injected the particles that crossed the inner edge of the disk set at 3 R_{Jup} to obtain the curves drawn on the figure.

3. Discussion

Our results suggest that the direct capture of large icy bodies (D$\gtrsim$10 km) on heliocentric orbits towards the circum-Jovian disk could be problematic to form a water-free body such as Io and a Europa with low water content. Instead, the pebbles (0.01–1 m) define three distinct regions in term of composition that

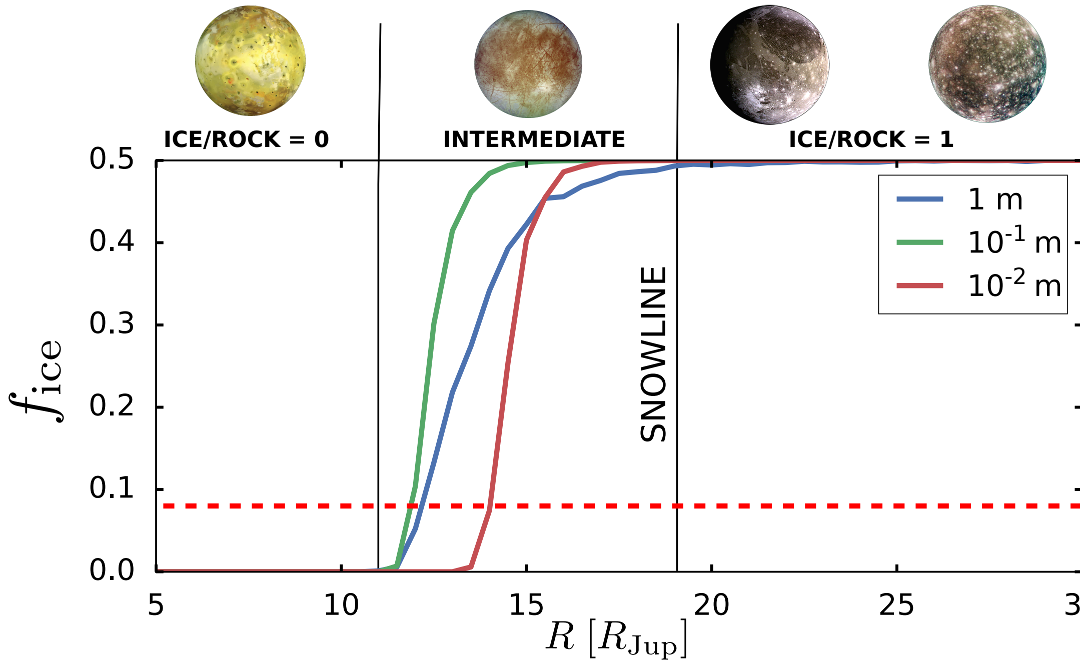

Figure 1: Average water ice mass fraction of solids as a function of radial distance from Jupiter. 10^4 particles of each size have been released in the 25–35 R_{Jup} region. The horizontal dashed line corresponds to Europa's estimated water mass fraction.

are globally consistent with that of the Galilean system. If indeed these solids were the building blocks of the satellites, the formation of Europa could have been restricted to the "intermediate" region just inside the snowline (Fig. 1). There, it would have accreted from partially dehydrated, drifting material, rather than having cross the snowline during its growth. We can note that within this frame, Europa could have formed with any water mass fraction between 0 and 0.5. As migration of the satellites and cooling of the disk likely occured during the formation of the Galilean system, this scenario further implies that the migration of Europa was tied to the evolution of the position of the snowline so that it fully accreted in the intermediate region.

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