LOCATION OF SNOWLINES AND DISTRIBUTION OF WATER IN PROTOPLANETARY DISKS

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Introduction: Snowlines delineate regions of the disk where condensable volatiles are present as vapor and where they are present as ice, thus not only setting the stage for the formation of giant planets, but also establishing the inventories of volatiles and bioessential elements available for terrestrial planets. Beyond the water snowline, dust particles covered by an icy mantle are likely to more efficiently stick with each other to rapidly grow into larger and larger particles [1], and eventually larger planetesimals facilitated by pebble accretion [2]. Multiple snowlines of primary volatiles (H_2O, CO_2 and CO) located across the disk dictate the bulk abundances of volatiles in the feeding regions of the planets, and thereby the bulk abundances in the planets themselves [3].

Snowlines are complex regions in the disk whose location is not only dependent on temperature but also the inward and outward radial transport processes at the snowline such as the radial inward drift of icy particles and diffusion of vapor [4][5]. The motivation of this work is to understand why the earth appears to have a bulk abundance of water (>0.01 wt%)[6] much lower than that of C-type asteroids (~10 wt %)[7] present at ~2.7 AU, and what disk properties and processes shaped the final bulk water abundances of the terrestrial planets such as the earth.

In this work, we build on our previous disk models [8] that included for the first time both the effects of external photoevaporation and non-uniform α, which behave differently from traditional disk models, and investigate the volatile transport and the distribution of water in such disks.

Methods: We implement two different disk models with photoevaporation, based on the turbulent viscosity strength, α, as follows: i) by using an uniform constant α in disks, as is typically used in most disk models; and ii) by using a non-uniform α that varies throughout the disk, derived from magnetorotational instabilities. We determined in [8] that the later case has two significant effects on disk structure i) it steepens the surface density profile, and ii) the disk 'transition radius' (where the bulk disk mass flow changes from inward to outward) moves inward with time, rather than outward with time as expected in a viscously evolving disk [9]. We build over this disk model by adding vapor, icy chondrules (composed entirely of water), 'rocky' chondrules, icy asteroids (that grow from icy chondrules) and rocky asteroids (that grow from rocky chondrules) and follow the transport of each component to trace the water in the disk. In order to test the effect of photoevaporation that is likely to be diluted by the transport of rapidly drifting solids, we assume the 'Asteroids are Born Big' model of Morbidelli et al. (2009)[10], to neglect the presence of any fast migrators and account for only two slowly drifting populations of small particles (chondrule sized, 1mm) and large objects (asteroids).

We implement the volatile advection and diffusion equations from Gail (2001) [11], as described in [12], and the equations of Takeuchi & Lin (2002) [13] for radial drift of particles in the Epstein regime. Migration of asteroids is neglected in this work. We consider the disk to be accretionally heated, and implement the condensation and evaporation of volatiles by the saturation vapor pressure over ice at each radius r estimated from [14] and [15]. We evolve the disk over 5 Myr.

Results and Conclusions: We find that external photoevaporation and non-uniform α significantly influence the distribution of water in the disk, and concentrate the water in particular radial zones in the outer disk.

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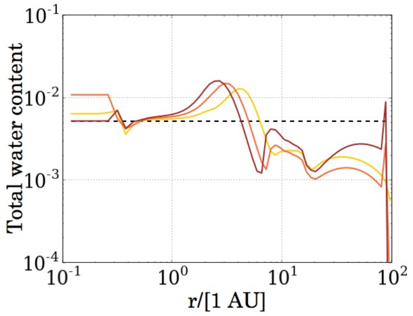

Fig.1: Total water abundance as ($\Sigma_{vapor} + \Sigma_{icychondrules} + \Sigma_{icyasteroids}$) / Σ_{gas} in a non-uniform α disk with photoevaporation over times 0 (dashed), 0.1 (yellow), 0.2 (orange), 0.3 Myr (brown).