Origin of Water on Earth: A Diffuse Snowline Model from Computational Chemistry

Lise Boitard-Crépeau[1], Cecilia Ceccarelli[1], Piero Ugliengo[2], Pierre Beck[1], and Lionel Vacher[1]

[1] *Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France*
[2] *Dipartimento di Chimica and Nanostructured Interfaces and Surfaces (NIS) Centre, Università degli Studi di Torino, via P. Giuria 7, 10125, Torino, Italy*

The source of Earth's water —whether endogenous or delivered— is a key unresolved problem in our planet formation. There is consensus on the fact that water was mostly formed on micrometer-sized dust grains at the very beginning of the Solar System formation, in the molecular cloud and prestellar phase, where it remained frozen on the icy mantles enveloping the grains [e.g. 1]. With time, in the so-called Proto Solar Nebula (PSN: the protoplanetary disk of the Solar System), these grains coagulated and grew, forming planets, asteroids and comets. However, when the disk temperature increased with the formation of the Sun, water sublimated from the grain surfaces inwards the so-called snowline, depleting the inner disk of volatiles, including water, not trapped in larger bodies. Thus, standard Solar System formation models suggested that Earth accreted from the dry inner-disk material, questioning the origin of its water content [e.g. 2, 3].

The classical approach of the snowline based on a single condensation temperature of water has long been invoked to address this problem. However, the sublimation of a frozen molecule critically depends on the adsorption strength (in jargon called binding energy or BE) of the molecule onto the grain surface, and this value is not unique as it depends on the different orientation of the molecule on the several absorbing sites of the surface. Relevant to the water snowline, recent theoretical quantum chemical calculations have shown that the water BE on a icy surface has a gaussian distribution, with a non-negligible contribution of BE values larger than that usually adopted in PSN models [4].

In this work, we apply, for the first time, this water BE distribution to a simplified PSN thermal structure model. We show that the BE distribution implies a gradual, temperature-dependent desorption across the PSN disk— a *diffuse snowline* — rather than a sharp transition. Our model successfully reproduces the highest and lowest estimates of the Earth's water content [5] and matches the water content trends observed across chondrite groups at their expected formation locations [e.g., 6]. These results suggest that a significant fraction of Earth's water could have originated locally, without requiring delivery from beyond the classical snowline.

References

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