# Icy grains are not spherical nor ellipsoidal


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In the astrochemical community, it has been assumed, without experimental validations, that ices on grains in molecular clouds and proto-planetary disks are formed by homogeneous layers regardless of their composition or crystallinity (Figure 1A). To verify this assumption, we investigated the $H_2O$ deposition onto refractory substrates and the crystallization of amorphous ices ($H_2O$, $CO_2$, and CO) using an ultra-high-vacuum transmission electron microscope [1]. Upon heating the samples deposited at 10 K, which are uniform layer of amorphous $H_2O$ (a-$H_2O$) on refractory substrates, amorphous CO on a-$H_2O$, and amorphous $CO_2$ on a-$H_2O$, we found that the uniform thin films of a-$H_2O$ and amorphous CO became three-dimensional islands of polyhedral crystals while amorphous $CO_2$ became a thin film of nano-crystalline $CO_2$ covering a-$H_2O$. Our observations indicate that crystal morphologies greatly depend on not only the ice composition but also the substrate material. Using experimental data and the crystallization timescale of amorphous ices, we conclude that icy grains in molecular clouds and proto-planetary disks are not spherical nor ellipsoidal; in molecular clouds, a-$H_2O$ covered the refractory grain uniformly, $CO_2$ nano-crystals were embedded in a-$H_2O$, and a polyhedral CO crystal was attached to a-$H_2O$ at temperatures as low as 10 K (Figure 1B); in proto-planetary disks, one thin $CO_2$ I crystal on a-$H_2O$ (1C) or one ice I crystal on organics (1D). Important implications for the chemical evolution of molecules, non-thermal desorption, collision of icy grains, and sintering will be presented.

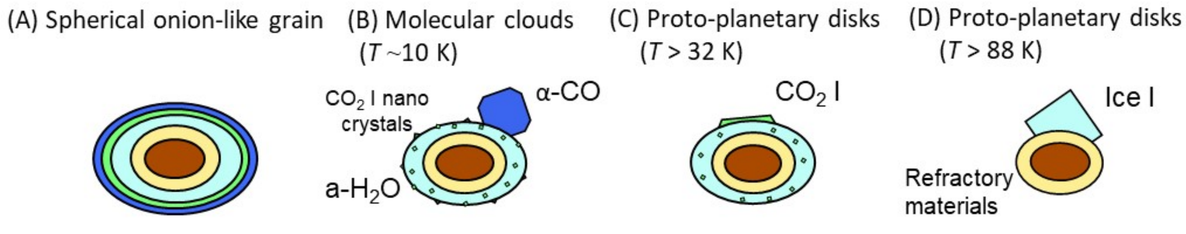


Figure 1: The schematic of icy grains (cross-section): (A) spherical onion-like grain as hitherto assumed, (B) in molecular clouds ($T$ ~10 K), (C) in proto-planetary disks ($T > 32$ K), and (D) in proto-planetary disks ($T > 88$ K). Respective colors show the chemical compositions: red—core; yellow—refractory material; green—$CO_2$; light blue—a-$H_2O$; dark blue—CO.

## Reference


[1] Kouchi, A., Tsuge, M., Hama, T., et al. 2021, ApJ, 918, 45