LIQUID-LIKE BEHAVIOR OF UV-IRRADIATED INTERSTELLAR ICE AT LOW TEMPERATURES

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Water-dominated ice is the most abundant solid in dense molecular clouds, and must have played a critical role in the planet formation in the early Solar System. UV irradiation of amorphous H_2O-dominated ice may also play a key role in synthesizing complex organic matter prior to the formation of cold small bodies. It is thus important to understand the formation and evolution of ice in molecular clouds and in protoplanetary disks. In this study, we performed low-temperature photolysis experiments on interstellar amorphous ice analog to understand physical and chemical properties of interstellar ice.

A mixture of H_2O-CH_3OH-NH_3 gas was deposited on a gold-coated cupper substrate at 10-15 K with simultaneous UV irradiation in the low-temperature photolysis apparatus (PICACHU) [1, 2]. After the deposition of several-μm-thick amorphous ice, the ice was observed in-situ by an optical microscope during warm-up. The photo-irradiated ice deposit cracked at ~60 K, and started bubbling of H_2 at ~65 K. The hydrogen bubbling continued up to ~140 K, where the ice crystallized. This observation indicates that the photo-irradiated vapor-deposited amorphous ice changed into a liquid-like low-viscosity material at temperatures below its crystallization temperature. The ice sublimated at ~180 K to form residual refractory organics. The viscosities estimated from bubble growth rates at ~88 and ~112 K are ~400 to 700 Pa s, which are much lower than the viscosity at the glass transition temperature (typically 10^{12} Pa s).

We also made in-situ morphological observation of UV-irradiated amorphous water ice using a low-temperature ultra-high vacuum TEM. We focused on the morphological change of several-tens nm-sized islands of amorphous water ice, and found clear wetting behavior of the amorphous ice islands at >50 K if the ice was photo-irradiated longer than 30 min at 10 K. The viscosity estimated from the morphological change of ice islands is $4x10^7$ Pa s that is also lower than that at the glass transition temperature.

Neither bubbling nor wetting behavior was observed for non-UV-irradiated ice deposit with the same gas compositions. These lines of evidences led us to conclude that UV-irradiated water-dominated amorphous ices composed behave like liquids over the temperature ranges of 50-150 K and that photo-irradiation is a key for the appearance of this liquid-like behavior. The low-viscous liquid-like ice may enhance the formation of organic compounds including pre-biotic molecules and the accretion of icy dust to form icy planetesimals at certain interstellar conditions.

References: [1] Piani L. et al. 2017. *Astrophys. J.* 837: 35–45; [2] Tachibana S. et al. 2017. *Sci. Adv.* 3: eaao2538.