Temperature Dependence of UV Amorphization of Crystalline Water Ice

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[Introduction]

All of the icy satellites and Trans-Neptunian Objects (TNOs) observed with high signal-to-noise ratio, show existence of abundant crystallinewater ice on their surface. However, irradiation by ultra-violet (UV) photons and high energy particles changes the crystalline water ice to an amorphous one. The results of Kouchi and Kuroda (1990) suggests that the UV amorphization may be the main cause at TNO region(30-50AU), and that process is so fast that the surface of TNOs must be amorphous instead of crystalline which is actually observed.

[Experiments]

We have made laboratory experiments to determine the rate of UV amorphization process and its temperature dependences. We deposited about 30 mono-layers of water ice on a aluminum plate at 140 K in high vacuum, which formed Ic crystalline ice. Then we cooled it down to a temperature that we want to measure. An excimer lamp (wavelength:126 nm, FWHM=10 nm) was used for UV photon source, and its flux was 2e13 photon s^{-1} cm^{-2}. One second irradiation of our experiments correspond to 1-2 days of irradiation of Lyman alpha photons received from the sun at a distance of 40AU.

Infrared reflectance spectra (5500 - 650 cm^{-1}) were measured during the UV irradiation to see the change of the depth and profile of the absorption feature of water ice. We made another set of experiments using D_2O-H_2O layered samples in order to identify which depth the amorphization was occurring. We examined two set of samples: one was D_2O on H_2O and the other was H_2O on D_2O.

[Results and Discussions]

We found that the rate of UV amorphization highly depend on the temperature of the ice. There is a ”critical temperature”for UV amorphization. Amorphization occured in whole volume of ice if the temperature was below 30 K. However, the amorphization occured in a limited amount of ice, probably at its surface and/or near its surface, when the temperature was higher than 40 K. We observed two different amorphization processes which have different process rate and critical temperature. The absorption depth near 3300 cm^{-1} reduced immediately and rapidly after UV irradiation started (its time constat is a few minutes). This fast process was observed even at temperature higher than the critical temperature of bulk amorphization (˜35 K).

The rate of ”slow” process depends on the temperature. The amorphization completed almost in one hour at 10 K, whereas it took several hours at 30 K. If the temperature of ice was higher than 40 K, it was hard to identify the slow process. Our D_2O layered experiments suggest that the fast process is related to a process occurred at its surface and the slow process is related to that in the bulk. The critical temperature (˜35 K for our experiment) might depend on the UV photon flux, which should be examined experimentally.

Reference

Jewitt & Luu, “Crystalline water ice on the Kuiper belt object (50000) Quaoar,” Nature, 432, 731-733 (2004).

Kouchi & Kuroda, “Amorphization of cubic ice by ultraviolet irradiation,” Nature, 344, 134-135 (1990).