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Experimental approach to the formation of organic molecules following vacuum-ultraviolet irradiation of interstellar ice

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Cosmic gases and dust grains ejected from dying stars gradually assemble under the influence of gravity to form interstellar clouds. Among these gases, heavy elements such as magnesium (Mg) and silicon (Si) are incorporated in dust. Lighter and chemically active elements (e.g., hydrogen, carbon, oxygen, and nitrogen; H, C, O, N, respectively) play important roles in the chemistry of interstellar clouds. After the temperature and photon field decrease when the density of dust particles increases in interstellar clouds, atoms (e.g., H, O, C, N) and molecules (e.g., CO) deposit onto the dust surfaces. Cold-surface reactions proceed on the grain surface, and an ice mantle, which is predominantly composed of H_2O combined with other molecules such as CO, CO_2, NH_3, CH_4, H_2CO, and CH_3OH, is formed.

The ice mantles are also subjected to substantial energetic processing by the prevailing ultraviolet radiation during the lifetime of a interstellar cloud. Followed by repeated processing when cycling between diffused clouds and dense clouds, new refractory organic molecules are formed in the ice mantles. The ice mantles undergo further photon radiations upon the formation of proto-planetary disks, and finally evolve to non-volatile complex organic residues by irradiation and thermal processing. However, the detail of the chemical evolution of the organic molecules has still been ambiguous. Although the previous laboratory studies using infrared spectroscopy can provide the presence of polar compounds such as amines, carboxylic acid or amides functions, it often suffers from the low sensitivity and the difficulty to obtain precise identifications of molecular species due to the overlapping of broad solid-state bands. Since dust grains and ice mantles are the precursors of planetary material, studying the photoprocesses is essential to understanding the origin of our solar system, and more powerful analytical techniques are required to unveil rich chemistry of the ices in interstellar clouds and protoplanetary disks.

Here, we are going to present a talk about a new apparatus which is now under construction to shed light on the chemical evolution of organic molecules in interstellar clouds and protoplanetary disks. The apparatus consists of three basic parts, i.e., a vacuum system, a copper-substrate equipped with a closed cycle helium refrigerator, and a vacuum ultraviolet source. Multi-component interstellar ice analogues are created on the cold (10 K) substrate by vapor deposition, and subjected to irradiation by the ultraviolet. The irradiated ice is subsequently heated up to 800 K. The gas composition desorbed from the ice during heating is analyzed by a high-resolution quadrupole mass spectrometer in the vacuum chamber. The survived organic residue from heating are studied using gas chromatography coupled to mass spectrometry (GC-MS) and high performance liquid chromatography coupled to mass spectrometry (HPLC-MS).

Keywords: interstellar cloud, protoplanetary disk, ice mantles, complex organic molecules