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Synthesis of Large Molecules in Cometary Ice Analogs: Physical Properties Related to Self-Assembly Processes

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The combination of realistic laboratory simulations and infrared observations have revolutionized our understanding of interstellar dust and ice, the main component of comets. Since comets and carbonaceous micrometeorites may have been important sources of volatiles and carbon compounds on the early Earth, their organic composition may be related to the origin of life (Thomas *et al.*, 1997). Ices on grains in molecular clouds contain a variety of simple molecules (Allamandola *et al.*, 1997). The D/H ratios of the comets Hale-Bopp and Hyakutake are consistent with a primarily interstellar ice mixture (reviewed by Bernstein 1999). Within the cloud and especially in the presolar nebula through the early solar system, these icy grains would have been photoprocessed by ultraviolet light producing more complex species such as hexamethylenetetramine, polyoxymethylenes, and simple ketones (Bernstein *et al.*, 1995).

We reported at the 1999 Bioastronomy meeting laboratory simulations studied to identify the types of molecules which could have been generated in precometary ices. Experiments were conducted by forming a realistic interstellar mixed-molecular ice (H_2O, CH_3OH, NH_3, and CO) at $\sim 10\,K$ under high vacuum irradiated with UV from a hydrogen plasma lamp. The gas mixture was typically 100:50:1:1, however when different ratios were used material with similar characteristics was still produced.

The residue that remained after warming to room temperature was analyzed by HPLC, and by several mass spectrometric methods. This material contains a rich mixture of complex compounds with mass spectral profiles resembling those found in IDPs and meteorites. Surface tension measurements show that an amphiphilic component is also present. These species do not appear in various controls or in unphotolyzed samples.

Residues from the simulations were also dispersed in aqueous media for microscopy. The organic material forms 10–40 μm diameter droplets which flu-

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oresce at 300–450 nm under UV excitation. These droplets have a morphology and internal structure which appear strikingly similar to those produced by extracts of the Murchison meteorite (Allamandola *et al.* 1997; Deamer 1985).

Together, these results suggest a link between organic material photochemically synthesized on the cold grains in dense, interstellar molecular clouds and compounds that may have contributed to the organic inventory of the primitive Earth. For example, the amphiphilic properties of such compounds permit self-assembly into the membranous boundary structures that required for the first forms of cellular life.

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