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EXTRATERRESTRIAL ORGANIC CHEMISTRY: A SOURCE OF PREBIOTIC MOLECULES?

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Organic material appears to be abundant throughout the visible universe. The interstellar medium in external galaxies exhibits both the spectroscopic signature of gas phase organic molecules and thermal emission from warm dust which is at least in part carbonaceous. Since stars and planets form from such interstellar clouds, this organic matter provides at minimum an initial condition for the chemistry of pre-planetary material; in fact, it also plays an important role in the thermodynamics of collapsing protostellar cores, in the degree of ionization which controls coupling to magnetic fields, and probably in the "stickiness" of accreting grains in the preplanetary nebula. It is likely that some of this interstellar molecular material ultimately found its way to the primitive Earth.
The interstellar medium is most easily studied in our own Milky Way Galaxy. Here more than 100 molecular species, the bulk of them organic, have been securely identified , primarily through spectroscopy at the highest radio frequencies. These include species with up to 13 atoms and molecular weights up to about twice that of glycine. Recent assignments of emission features will be discussed. There is also considerable evidence for significantly heavier organic species, including polycyclic aromatics, although precise identification of individual species has not yet been obtained. The low temperature kinetics in interstellar clouds lead to very large isotopic fractionation, particularly for hydrogen; the D/H ratio in a specific molecule like cyclopropenylidene (C_3H_2), for example, can be 1000 to 10,000 times the cosmic D/H abundance ratio. This isotopic signature appears to be present in organic components of carbonaceous chondritic meteorites.
Simple organics such as nitriles have been identified in the atmospheres of the giant planets and of Saturn's satellite Titan, while organic material is generally thought to be present on the surfaces of many outer solar system atmosphereless bodies, including asteroids in the outer portion of the asteroid belt. Such asteroids are the probable parent bodies of the carbonaceous chondrites, meteorites which may contain as much as 5% organic material. This includes insoluble polymeric material reminiscent of terrestrial kerogen, as well as a wide range of amino acids, hydroxy acids, carboxylic acids, sulfonic and phosphonic acids, amines, amides, nitrogen heterocycles, alcohols, carbonyl compounds, aliphatic, aromatic and polar hydrocarbons, and other organic species. Richer in volatiles and

hence even less processed in the solar nebula than carbonaceous chondrites are the comets. *In situ* studies of Comet Halley showed that some half to two-thirds of the cometary nucleus consisted of solid "dust" particles of which perhaps one-quarter by mass was organic matter. The latter remains poorly characterized, with some agreement that it contains highly unsaturated polycondensates rich in C=C and C-O compounds. The volatile material, observed after sublimation into the cometary coma, includes such species as CO, CO_2, H_2CO, HCN, CH_3OH, H_2O, and H_2S.

There is at present a considerable fraction of the planetary science community which takes the view that most of the Earth's volatiles, including most water, carbon and nitrogen, were supplied by a "late" bombardment of comets and carbonaceous meteorites, scattered into the inner solar system following the formation of the giant planets. How much in the way of intact organic molecules of potential prebiotic interest survived delivery to the Earth has become an increasingly debated topic over the last several years. The principal source for such intact organics was probably accretion of interplanetary dust particles of cometary origin.