From Interstellar Ices to PAHs

A symposium to honor Lou Allamandola's Contributions to the Molecular Universe

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INVITED TALK

The Formation of Complex Organic Compounds in Astrophysical Ices and their Implications for Astrobiology

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Ices in astrophysical environments are generally dominated by very simple molecules like H_2O, CH_3OH, CH_4, NH_3, CO, CO_2, etc, although they likely contain PAHs as well. These molecules, particularly H_2O, are of direct interest to astrobiology in-and-of themselves since they represent some of the main carriers of the biogenic elements C, H, O, and N. In addition, these compounds are present in the dense interstellar clouds in which new stars and planetary systems are formed and may play a large role in the delivery of volatiles and organics to the surfaces of new planets. However, these molecules are all far simpler than the more complex organic compounds found in living systems.

Since astrophysical ices are usually at very low temperatures (10-100K), they are not expected to participate in an significant chemical reactions other than gas-grain surface reactions. Indeed it is these gas-grain reactions that are responsible for much of the original ice materials. The formation of more complex organics is inhibited by energy barriers. However, reactions in the ices can be induced if radiation in the form of energetic particles or photons is present. Such radiation can penetrate the ices and break bonds in the original ice constituents, resulting in the formation of radicals and ions. These radicals and ions can then react with neighboring species since these reactions can be barrierless.

This form of chemistry is far different from normal gas phase or liquid phase equilibrium chemistry. It is a 'chemistry of opportunity' in which species do not necessarily react with other molecules that will lead to the most stable products possible, but instead react with the nearest available neighbors for which a reaction is possible. Some of these reactions can occur during irradiation, but if a radical or ion is unable to react with any of its neighbors, it remained trapped in the ice matrix until it can be mobilized by some other process like warming of the ice. Thus, much of the chemistry that happens in irradiated ices occurs when the ice is subsequently warmed and/or the original volatile components sublime. As a result of these processes, ice irradiation experiments produce an enormous range of products even when the original ices only contain a modest number of simple molecules.

When ices that have been irradiated are warmed, the majority of their original molecular components are lost by sublimation, but many of the more complex species made during the irradiation and subsequent warming are sufficiently non-volatile to remain behind as a complex organic residue. Such residues can contain thousands of new chemical species. These residues are sufficiently complex that the majority of species in the residues currently remain unidentified.

While it is difficult to identify all the new products in these residues, it is somewhat easier to see if the residues contain specific molecules of interest. Since these residues may be analogs for the organic materials found in protostellar disks and subsequently delivered to planetary surfaces, there has been particular interest in searching them for molecules of astrobiological significance. In my talk I will discuss a number of types of organic species of astrobiological interest that have been identified in the irradiation products of relevant astrophysical ices. These include amino acids (the building blocks of proteins), amphiphiles (the building blocks of membranes and vesicles), nucleobases (the building blocks of RNA and DNA), quinones (molecules that mediate a host of biological processes), and sugars and sugar-like compounds.

Since the physical and chemical processes that produce these residues are expected to be present wherever new stars and planetary systems are formed, the production of such complex organic mixtures should be expected to be a fairly 'universal' occurance, i.e., these materials are likely to be present whenever new planetary systems are formed. Insofar as these materials play are role in the formation and subsequent evolution of life, these results suggest life may be relatively common in the universe.