

Molecular isotopic structure as a biosignature and window on molecular origins

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The search for life on other solar system bodies calls for us unravel the precursors and formation mechanisms of prebiotic organics, and to identify and interpret biomolecules from natural environments.

Molecular ‘isotopic structure’ — the proportions of site-specific and multiply-substituted isotopic forms — is sensitive to isotopic contents and structures of substrates, mechanisms of formation and destruction, and conditions of synthesis, storage and/or destruction. Because most organic molecules exist in a vast number of isotopic forms, molecular isotopic structure has the potential to provide independent constraints on many of these details, and provides highly specific ‘fingerprints’ for forensic assignment and biogenicity.

Advances in analytical technologies over the last several years have enabled study of molecular isotopic structures at natural isotope abundances for a large number of compounds and isotopic forms, at sample sizes and types reaching down to pmol components of complex mixtures. The broadest capability of this kind comes from new methods of Fourier transform mass spectrometry. We will present recent findings from the application of these techniques to the study of abiogenic and biogenic amino acids from known chemical syntheses (e.g., Strecker synthesis and industrial syntheses), microbial cultures, in vitro enzymatic reactions and natural samples (including extracts from the carbonaceous chondrite, Murchison), and review related studies of other organic compounds.

Observed molecular isotopic structures reveal their power to discriminate biogenic from abiogenic syntheses, and to provide a guide to synthetic reaction pathways. The most striking example to-date comes from the site-specific ¹³C structure of meteoritic alanine, which reveals inheritance of amine carbon from the presolar CO pool; integration of this finding with compound specific $\delta^{13}\text{C}$ of Murchison organics permits construction of a detailed reaction model linking aldehyde and cyanide precursors, product amines, amino acids and monocarboxylic acids. We will discuss extensions of this approach to the study of nucleobases and other classes of organics of astrobiological significance.