WHAT WOULD CONSTITUTE EVIDENCE FOR LIFE ON ICY MOONS? A. Pohorille[1] and T.M. Hoehler[2],

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Introduction: For the first time since Viking, NASA is considering missions that would include life detection as a primary objective, making it critical to develop and evaluate a diverse set of strategies for seeking evidence of life. The central question is: what should be the target of our search that, if found, would constitute a near-certain evidence for life? Since life on icy moons might be quite different from terrestrial life, we should concentrate on features of biological systems that are considered universal and are unlikely to emerge through abiotic means.

Catalysts of biochemical reactions as signs of life:
All metabolic reactions (i.e. the network of chemical reactions that support life) require structured polymers that act as catalysts of these reactions. On Earth, these polymers are proteins, which are linear chains of amino acids. However, other polymers, also built of amino acids or structurally closely related imino acids have been synthesized and have been shown to exhibit catalytic activity. Therefore, they cannot be excluded as alternatives to proteins. Other polymers that also possess catalytic capabilities, such as RNA, do not seem to be sufficiently powerful and versatile catalysts to support complex life. For this reason, a promising strategy in search for signs of life is to concentrate on building blocks or small fragments of proteins or their analogs.

Nature and diversity of monomers. Compared to abiotic environments, it appears that a universal characteristic of environments in which life exists is the nature of building blocks of catalytic polymers. The number of different monomers is relatively small, but sufficiently varied in terms of their chemical structure to enable catalysis of many different reactions. Further, the suite of monomers forming catalytic polymers operating in an aqueous environment is expected to contain both polar and non-polar groups. Most likely some monomers also contain positively and negatively charged groups. On Earth, no matter where we sample, we mainly find 20 amino acids that support terrestrial life, while abiotic amino acids are largely absent. In contrast, many different amino and imino acids are found in abiotic samples from meteorites. If life exists on icy bodies, it is not expected to contain the same suite of amino acids as life on Earth, but their number and chemical diversity is not expected to be markedly different. Thus, characterization of the monomers, if found during a mission to an icy world, provides very strong clues as to their biological or abiotic origins.

Chirality. Homochirality of polymers is required for adopting well-defined structures, which in turn are the requisite for efficient and specific catalytic activity. Thus, homochirality is a strong signature of life, although abiotic synthesis of homochiral polymers cannot be excluded.

Evaluating whole organic sample for signs of life:
An approach based on targeting specific classes of compounds is very powerful when molecules belonging to this class can be isolated and evaluated in sufficient quantities, but it may prove challenging or intractable if the molecular patterns we seek are embedded within an overall high level of chemical complexity. Alternatively, one might attempt to detect and quantify all of the chemical compounds in a sample. For this purpose, the method of choice is mass spectrometry (MS). The goal is to distinguish reliably complex MS patterns of abiotic and biological origin. This is a very complex, high-dimensionality problem (see Fig. 1) that can be effectively handled with the aid of machine-learning (ML) techniques, provided that sufficiently large sets of MS spectra from both abiotic and biological sources are available for training and testing. Such large sets can be readily generated for biological but not for abiotic samples. The latter are available only from a small number of pristine meteorites or from relevant abiotic reactions such Miller-Urey synthesis, tholin synthesis, and ice irradiation. Since this is insufficient for a meaningful ML processing, one needs to turn to computer-generated samples for training. We are evaluating whether challenges associated with this approach can be overcome or create an overwhelming obstacle that requires the use of different techniques.
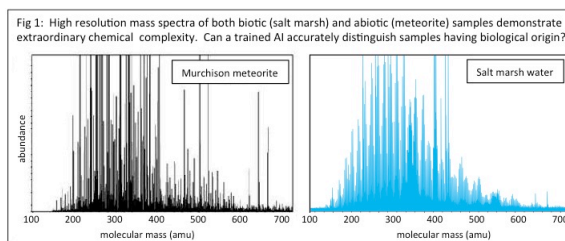

Fig. 1 High resolution mass spectra of both biotic (salt marsh) and abiotic (meteorite) samples demonstrate high chemical complexity. Can a trained Artificial Intelligence system distinguish samples of biological origin?

Conclusions: We propose two strategies for distinguishing biological and abiotic samples of extraterrestrial origin. One relies on analyzing the number, chemical diversity and chirality of building blocks and small fragments of proteins or protein-like polymers, which are likely universal catalysts of metabolic reactions. An alternative strategy is to analyze mass spectrometry pattern of a sample of all organic material collected in a mission. The advantage of this still unproven approach is that sample processing is considerably simpler and the amount and diversity of the analyzed material is markedly larger. We also argue that evidence for life should be evaluated in its totality rather than on the basis of a single property or molecule.