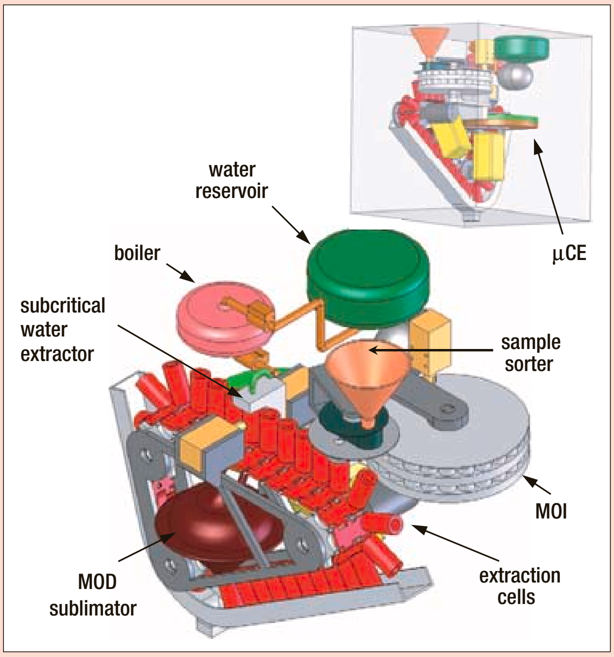
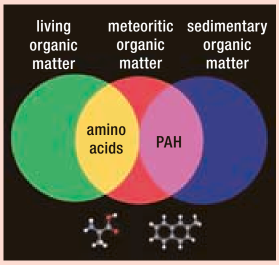
New strategies to detect life on Mars

If we are to find unequivocal evidence for life on Mars, we will need new ways to search for it. Jeff L Bada and the MOD team describe the innovative strategy developed for the ExoMars mission.

Abstract

The quest to determine whether life existed, or still exists, on Mars continues with several missions planned for the red planet by both the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) in the next few decades. One instrument designed for these missions is the Mars Organic Detector (MOD), which uses a new approach to achieve exceptionally high detection sensitivities and analysis capabilities for key bio-organic compounds. MOD is scheduled to fly in the ESA ExoMars mission early next decade and will attempt to answer the question of whether we are alone in the solar system. Here the MOD team explains why we have reason to be optimistic about uncovering the organic secrets of Mars.





1 (left): The Mars Organic Detector is a high-sensitivity instrument able to detect organic molecules and discriminate between those produced by life and non-biological process.

2 (above): Schematic representation of how the detection of amino acids and polyaromatic hydrocarbons (PAH) spans all organic assemblages likely to be found on Mars.

The detection of life on planets other than the Earth is a major goal of modern space exploration. In the first few decades of this century several spacecraft will venture forward with the objective of finding the first evidence of alien life. It is generally considered that the most likely host for life elsewhere in our solar system is the planet Mars, and both the ESA and NASA are developing mission concepts to explore the red planet for traces of life.

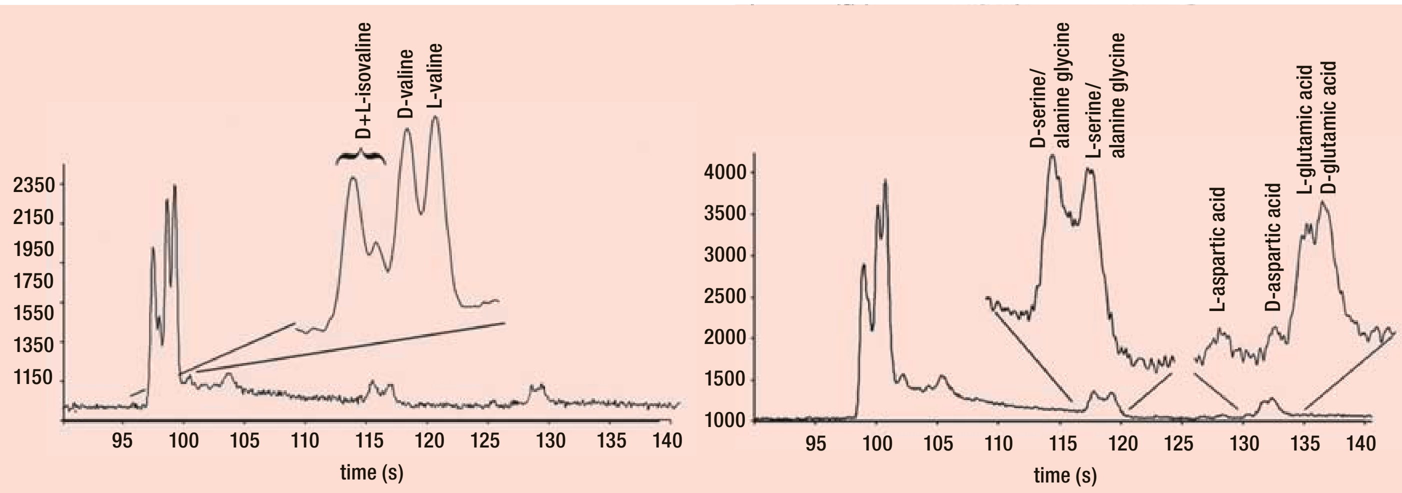
The detection of life on Mars, however, is unlikely to be straightforward. The Viking I and II missions in 1976 detected no organic compounds above a threshold level of a few parts per billion in near-surface samples (Biemann *et al.* 1976). But their early GCMS (gas chromatograph–mass spectrometer) instrumentation was not sensitive enough to detect ubiquitous biomolecules such as amino acids even if the sample contained several million bacterial cells per gram (Glavin *et al.* 2000). The lack of any organic matter was considered surprising in the light of the substantial amounts of organic molecules that have been delivered to the martian surface over billions of years by carbon-rich meteorites. It is estimated that each year, 2.4×10^8 g of organic carbon arrives on Mars (Flynn 1996). We now know that oxidation reactions involving organic compounds on the martian surface would either destroy organic matter completely or produce non-volatile products such as mellitic acid salts that also would not have been detected by Viking (Benner *et al.* 2000). Thus it appears that the absence of organic matter can be attributed to the presence of aggressive oxidants produced by the interaction of UV radiation with atmospheric components of the soil (Klein 1978). Clearly future Mars missions would have to dig deeper and achieve higher sensitivities to detect preserved key organic molecules.

Optimism surrounding the possibility of current life on Mars has been boosted by recent data from the red planet. Planetary missions such as Mars Global Surveyor, Mars Odyssey, Mars Express and the Mars Exploration Rovers have revealed extensive evidence of landforms and minerals produced by liquid water (e.g. Squyres *et al.* 2004, Murray *et al.* 2005). Moreover, methane, an important biosignature in terrestrial planetary atmospheres, has been detected by Earth-based and spacecraft observations in small quantities (Krasnopolsky *et al.* 2004, Formisano *et al.* 2005). Extreme public interest currently exists about whether life has been present in the past or still exists on Mars.

Advances in instrumentation

All known life is based on carbon; organic carbon to be specific. Although Mars contains a great deal of carbon we already know about, it is not directly related to life, but is in the form of atmospheric carbon dioxide, as well as perhaps surficial carbonate minerals. However, planetary scientists may not have to wait too long for unequivocal data related to martian life because there are now modern instruments suitable for spaceflight that display unprecedented detection sensitivities for organic matter. Furthermore, to avoid the problems of ambiguity when interpreting data, these sophisticated instruments include self-checking features that ensure analytical confidence in any results received.

The MOD (figure 1) instrument package searches for trace levels of specific organic molecules, amino acids and polycyclic aromatic hydrocarbons or "PAH" (figure 2), at demonstrated sensitivities more than 10^4 times greater than the Viking GCMS package (Kminek *et al.*



3: Results from the Mars Organic Detector capillary electrophoresis unit that can be used to analyse the composition and chirality of amino acids.

2000). These compound classes span all likely organic assemblages that may be detected on Mars. All life as we know it uses amino acids, while sedimentary (fossil) organic matter almost invariably contains some PAH; meteoritic organic matter contains both. Figure 2 shows how MOD has been designed to interrogate all possibilities. In MOD, the target compounds are liberated from their mineral matrix by heating at martian ambient pressure, a process that leads to their sublimation. Once in the gas phase the compounds are trapped on a cold finger and excited with a near-UV laser. Under these conditions the PAH fluoresce naturally and can be spectroscopically analysed directly. However, to facilitate detection of the non-fluorescent amino acids there is a portion of the cold finger coated with the chemical fluorescamine, which combines with the amino acids or any organic amine to form a highly fluorescent complex.

MOD is integrated with the Mars Oxidant Instrument (MOI), a chemometric array sensor designed to characterize the chemical species and reaction kinetics responsible for the highly reactive nature of the martian soil (Zent *et al.* 2003), and perhaps the alteration and depletion of organic compounds that comprise the evidence of putative martian life. In other words, if MOD does not detect organic compounds on Mars, MOI can tell us why.

Organic mixtures on Mars

A strength of MOD is the use of a strategically staged series of analyses. When the initial fluorescence analysis demonstrates the presence of significant volatile organic compounds, the sample is then routed via a "sipper" to a novel microchip capillary electrophoresis (μCE) system for confirmatory analysis. The μCE unit performs further detailed molecular analysis at part-per-trillion sensitivity levels. If amino acids are identified, the system then goes further by examining the handedness or "chirality" of the molecules (Skelley *et al.* 2005; figure 3). It is well known that terrestrial life is highly selective when it comes to using amino acids and, on Earth, uses only left-handed amino acids. By contrast, non-biological amino acids contain almost equal amounts of left and right-handed forms. Hence chirality detection provides an unambiguous way of detecting life (Bada and McDonald 1996) since living organisms can use only one of the handed forms. As well as amino acids and PAH, other compound classes such as carboxylic acids and nucleobases can also be detected with the μCE analyser. The first class represent important membrane molecules while the latter are used to produce nucleic acids, the carriers of life's genetic information.

4: The Atacama desert, a field testing site for the Mars Organic Detector and Mars Oxidation Instrument. (Courtesy of Jacek Wierzchos)

The martian environment is harsh for analytical equipment so in order to enhance and demonstrate the readiness of the MOD/MOI instrument for planetary exploration it has been field tested on one of the most challenging and Mars-like areas on Earth: the Atacama Desert in Chile (figure 4). MOD/MOI has been extensively used in various field sites and shown to operate perfectly in extreme conditions, producing composition and chirality analyses of samples containing 10 parts per billion amino acids (Skelley *et al.* 2005). Field operations at the Panoche Valley, CA, have shown that specific mineralogies associated with liquid water – such as the sulphate-rich mineral jarosite – are amenable to analysis and appear to preserve amino acids with high fidelity. Such mineral deposits, already discovered by the Mars Exploration Rovers, may thus be excellent sites to look for martian amino acids.

The ExoMars mission

As part of the recommended Pasteur life-detection package, MOD/MOI is a major instrument on the ESA ExoMars mission, the first flagship mission of the Aurora programme. Launching in 2011 or 2013, the instrument will seek evidence of past and present life on the martian surface and in the subsurface by analysing samples collected by a rover fitted with a drill. With more and more evidence of past liquid water on Mars and the development of spaceflight instruments with high levels of sophistication and sensitivity, the chances of answering the question "Is or was there ever life on Mars?" are better than ever. ●

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