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The Biological Oxidant and Life Detection (BOLD) mission: A proposal for a mission to Mars

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ABSTRACT

The next step in the exploration of Mars should include a strong and comprehensive life detection component. We propose a mission called BOLD: Biological Oxidant and Life Detection mission. The scientific objectives of the BOLD mission are to characterize habitability of the martian surface and to search for evidence of extinct or extant life. In contrast to the Viking mission, which was designed to detect heterotrophic life on Mars, the BOLD mission incorporates a more comprehensive search for autotrophic microorganisms, as well as detecting a variety of biomarkers and understanding their environment. Six miniature landers are envisioned for BOLD that utilize either an orbital (e.g. Viking) or direct entry (e.g., MER, Phoenix) mission architecture. The number of landers will provide mission redundancy, and each will incorporate a Mars Soil Analyzer, a Multispectral Microscopic Imager, a Nanopore-ARROW that detects biopolymers with single molecule resolution, an Atmospheric Structure and Surface Environment Instrument, a Fluorescent Stain experiment, and a Chirality experiment. A terrain navigation system, coupled with robust propulsion, permits a landing accuracy on the order of meters if required to meet the science objectives. The probes will use existing orbiters for communication relay if the orbiter architecture proves too ambitious.

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1. Introduction

The primary goal of the Viking landers was to conduct life detection experiments on Mars. The consensus view is that Viking did not detect life, but instead observed reactive soil chemistry. This conclusion was based on the evolution of O_2 upon wetting the soil, the apparent absence of organic molecules in the soil, and the weakly positive result of the single control test in the Pyrolytic Release experiment (Klein, 1999). However, recent findings raise questions about the certainty of these interpretations (e.g., Houtkooper and Schulze-Makuch, 2007). For example, a re-analysis indicated that the Viking gas-chromatograph mass spectrometer was much less sensitive than originally assumed, due to interference with minerals in the martian soil among other factors (Navarro-González et al., 2006).

More recent missions that studied the martian surface include the NASA Pathfinder, the Phoenix lander, and the on-going Mars

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Exploration Rover (MER). Focusing on geology and environmental conditions, these studies are confirming that favorable habitable conditions existed on early Mars, possibly large standing bodies of water (Scott et al., 1995; Fairén et al., 2003; Schulze-Makuch et al., 2008). The next mission to Mars is the NASA Mars Science Laboratory (MSL) which was launched late in 2011. The MSL will test the habitability of Mars, both in regard to possible future human colonization and endemic martian life. The European Space Agency ExoMars mission is planned for launch in 2018. However, since the Urey package (Aubrey et al., 2008) has been dropped from the mission due to budgetary pressures, no currently scheduled future mission contains a life detection component.

Thus, despite past and current missions, the possibility of extant life and biological activity remains an open question. Large deposits of water ice have been found on Mars (Malin and Edgett, 2000; Boynton et al., 2002; Feldman et al., 2002; Mitrofanov et al., 2002), as well as evidence of contemporary liquid water (Malin et al., 2006; McEwen et al., 2011). Methane has been detected in the martian atmosphere, perhaps as a product of biological activity (Formisano et al., 2004; Krasnopolski et al., 2004; Mumma et al., 2004), and there are also indications of contemporary hydrothermal activity (Schulze-Makuch et al., 2007a). The proposed *Biological Oxidant and Life Detection Mission (BOLD)* will search for evidence of biological activity in these martian environments and determine the nature of the unknown oxidizers.

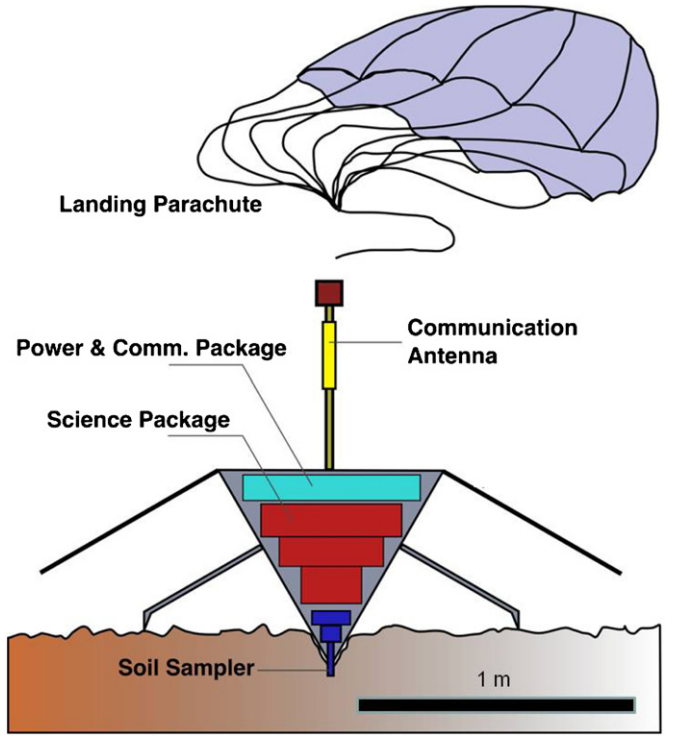

Fig. 1. BOLD probe, schematic overview. Six of these landers are planned to be deployed.

2. General mission design

The BOLD mission will characterize the habitability of the martian surface by searching for oxidants, particularly hydrogen peroxide and perchlorates, and probing for biosignatures near the martian surface (Schulze-Makuch et al., 2007b). The BOLD mission will conduct a more comprehensive search targeting autotrophic microbes, as well as generic biomarkers indicative of the possible presence of life. The mission will carry six probes to provide redundancy in case some of them do not land successfully or fail. A terrain navigation system, coupled with a closed-loop guidance system (Head et al., 2005; Furfaro et al., 2012) and sufficient propulsion capability to correct navigation and guidance errors permits landing precision on the order of 10 m. The probes will require an orbiter for communicating data to Earth. This could be an existing spacecraft such as NASA Mars Reconnaissance Orbiter, ESA Mars Express, or another spacecraft orbiting Mars at that time.

The BOLD mission will use an optical guidance system and employ live telemetry during the descent of the probes. The probes will be powered by batteries and are light-weight, with a science payload of about 7.8 kg, ~10% of the landed mass. The lander system uses a crushable shell behind the heat shield instead of landing gear. The mission duration for each landing probe is anticipated to be a minimum of 2 Sols (martian days), but may be extendable to 10 Sols or more. A schematic view of a landing probe is shown in Fig. 1.

Various designs of the landing probe are under consideration. One possibility is to have the probe in the shape of an inverted pyramid descending on a small parachute for probe orientation and landing velocity control. The envisioned landing conditions are far less stressing than previous missions or concepts (Smrekar et al., 1999; Smith et al., 2011). The impact will push the probe a few tens of centimeters into the martian regolith. After impact, a sampling mechanism (spring-action sampler) will be activated, which both collects and delivers near-surface materials to instruments located in the center of the probe. The sampler will have moisture and temperature sensors, as well as the capability to collect and return material to the interior of the landing probe for further analysis. The hollow-stem penetrator of very narrow diameter could be assisted by a pressurized device (volatile cartridge with regulated pressure). The design of the sampler and of the landing probe will be optimized for the environmental and surface conditions likely to be encountered. The design will be based on tests where pyramidal shape, mass, and impact velocity will be varied to determine on how deep the probe might penetrate under what soil conditions. The sampling mechanism is within current capabilities, but can only be activated once for each probe. The pyramidal design eliminates the need for a drill, but is limited to use on soft sediments rather than rocky materials. Remote imaging of the prospective landing sites such as through the High Resolution Imaging Science Experiment (HIRISE) combined with high precision landing capability will reduce the chances of landing on hard surfaces. The probes' hardiness is determined by prior landing simulations on Earth and by optimizing the design. In addition, the mission risk associated with landing on undesirable surfaces is reduced by probe redundancy: If the probability of landing success for each probe is 50%, the chance that at least one of the probes will succeed is $>98\%$.

3. Previous mission studies involving probes and penetrators

As discussed above, the BOLD mission has been uniquely conceived to deploy a set of six (6) probes equipped with instruments packages for a detailed study of the martian surface habitability. Over the past decades, a few mission concepts for deep space exploration that involve probes and/or penetrators have been proposed and/or flown. In this section, we briefly review three of such mission concepts to highlight similarities and differences with the BOLD mission architecture.

The concept of deploying probes on the martian surface is not new. For example, the ill-fated Mars Polar Lander (MPL) carried

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