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In-Situ Resource Utilization Experiment for the Asteroid Redirect Crewed Mission

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Abstract

The Asteroid Redirect Crewed Mission (ARCM) represents a unique opportunity to perform in-situ testing of concepts that could lead to full-scale exploitation of asteroids for their valuable resources [1]. This paper describes a concept for an astronaut-operated "suitcase" experiment to would demonstrate asteroid volatile extraction using a solar-heated oven and integral cold trap in a configuration scalable to full-size asteroids. Conversion of liberated water into H_2 and O_2 products would also be demonstrated through an integral processing and storage unit. The plan also includes development of a local prospecting system consisting of a suit-mounted multi-spectral imager to aid the crew in choosing optimal samples, both for In-Situ Resource Utilization (ISRU) and for potential return to Earth.

1. Introduction

Use of asteroid-based resources represents a truly "game-changing" strategy for the extension of human presence into space. The costs to launch resources from Earth to low-Earth-orbit (~$10,000/kg) and to loft them out of Earth's gravity well (~$30,000/kg) are high and likely to remain so considering that there have been no revolutionary advances in space launch capability in the past generation. High launch costs result in prohibitively high costs for advanced exploration missions that must carry all of their consumable resources (e.g., fuel and life support) from the Earth's surface. The Asteroid Redirect Robotic Vehicle (ARRV) is designed to retrieve as much as 1000 tons of volatile-rich asteroid into an accessible high orbit in the Earth–Moon system [1]. If 250 tons of volatiles could be extracted from such an object, and if ARRV-like vehicles could be refueled in orbit with 10 tons of propellant to perform each retrieval, then the cost of the resulting volatiles in high orbit would be $400 per kilogram – almost 2 orders of magnitude less costly than current practice. Such an advance would remove or reduce the cost of volatile transport as a significant barrier to human exploration of the Solar System.

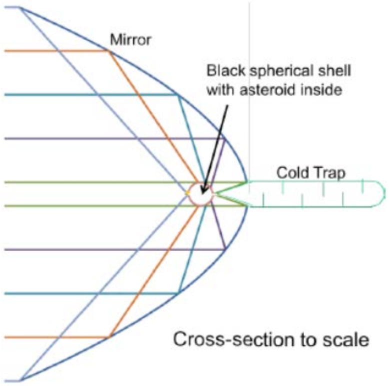

Figure 1: Mirror concentrates sunlight uniformly over sealed black sphere containing a sample (for the 1:75 subscale experiment) or an entire 10 m volatile-rich asteroid (for full-scale ISRU). The black sphere heats up to ~1100 K and "cooks" volatiles (mostly water) out of the asteroid. Hot volatile gases pass through a hole in the black sphere into a long coldtrap in the shadow of mirror that radiates into space to condense volatiles. Baffles in the cold-trap create graded-temperature zones for separation of volatile species.

Water is of primary interest as an in-situ resource. Typically ~10% of the mass of C-type carbonaceous asteroids is believed to be water in the form of hydrated minerals. Water can be used to produce hydrogen and oxygen required for chemical rockets. Hydrogen can also be used as propellant in nuclear-thermal or solar-thermal rockets. Both water and hydrogen also make excellent radiation shielding, and water and oxygen are essential for life support.

In 2013 and 2014, we built an experimental apparatus to heat samples in vacuum and to condense the volatiles in a cold trap and successfully tested the apparatus in the laboratory using a sample from the Murchison volatile-rich meteorite. For ARCM [2], a sub-scale (1:75) version of the full-scale apparatus depicted in Figure 1 would be deployed and operated by astronauts along with a resource processing and storage unit and an EVA-suit-mounted prospecting instrument.

2. Approach

2.1 Prospecting

Terrestrial field geologists (including those prospecting for resources) do not carry their laboratories into the field with them. Instead they select, acquire, and transport samples from the field to their laboratories for detailed analysis, and ARCM follows this same philosophy. However, field geologists and prospectors always bring a minimum set of portable instruments into the field to optimize sample selection (to be representative, avoid duplication, and capture the mineralogical diversity) and to document the context from which the samples were acquired. No geologist would think of leaving their hand lens, rock hammer, or acid (test for carbonates) behind, and modern additions to this standard field kit have also been proving their worth.

Infrared spectral imaging has a proven ability to assess and map mineralogy on Earth, the Moon, Mars, and the moons of Jupiter and Saturn. For ARCM extravehicular activities (EVAs), a suit-mounted multispectral infrared camera would map the mineralogy of the EVA workspace to improve sampling efficiency and optimize the value of the small set of samples that can be acquired in the limited time available. Cameras using infrared super-Bayer-patterned filters with custom spectral passbands (developed at JPL) acquire a complete multispectral ‘image cube’ in a single ‘snapshot’ – a capability essential for acquiring data from a freely-moving ‘platform’ (EVA crew in this case). The camera would operate continuously—placing no requirements on the crew. Data would be downlinked to the Mission Control Center, interpreted (with “back room” support) and used to guide the crew to select an optimal set of samples. Data rate would be similar to that of a visible color (RGB) video camera (more spectral bands but slower frame rate). The multispectral imagery would reveal the mineralogical diversity present in the EVA workspace and enable selection of samples that include at least one of each significant mineral and resource class present in the workspace, and would also document the context from which the samples were acquired.

2.2 Volatile Extraction and Separation

This experiment would demonstrate a subscale system based on the concept depicted in Fig. 1, carried on the ARCM in the Orion vehicle. The subscale apparatus would have a black spherical shell about 20 cm in diameter that opens like a clamshell and into which a crew member would insert the asteroid sample. The shell would seal when closed, with the exception of a single opening as a path for volatiles to escape to the cold trap/condenser tube. Volatiles liberated from the asteroid sample would successively condense along the length of the cold trap, according to their boiling points. Volatile composition would be measured by a mass spectrometer. Experiments at JPL support the hypothesis that volatiles will likely include numerous species in addition to water, so it is critical that the water collected in the cold trap be separated during the volatilization process, and subsequently collected in a manner that avoids cross contamination. One possible way to accomplish this separation involves a heating ring that would be mounted around the cold-trap to progressively transit forward from the back of the cold-trap to warm up and remove each of the collected species in sequence. A water electrolysis stack would be employed to splitting water into hydrogen and oxygen.

Acknowledgements

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