

RESOLVE: Bridge between early lunar ISRU and science objectives

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THE NEED FOR RESOURCES: When mankind returns to the moon, there will be an aspect of the architecture that will totally change how we explore the solar system. We will take the first steps towards breaking our reliance on Earth supplied consumables by extracting resources from planetary bodies. Our first efforts in this area, known as In-Situ Resource Utilization (ISRU), will be to extract the abundant oxygen found in the lunar regolith. But the "holy grail" of lunar ISRU will be finding an exploitable source of lunar hydrogen. If we can find a source of extractable hydrogen, it would provide a foundation for true independence from Earth. With in-situ hydrogen (or water) and oxygen we can produce many of the major consumables needed to operate a lunar outpost. We would have water to drink, oxygen to breath, as well as rocket propellants and fuel cell reagents to enable extended access and operations on the moon. These items make up a huge percentage of the mass launched from the Earth. Producing them in-situ would significantly reduce the cost of operating a lunar outpost while increasing payload availability for science.

PROSPECTING: The Lunar Prospector found evidence of elevated hydrogen at the lunar poles, and measurements made at these locations from the Clementine mission bistatic radar have been interpreted as correlating to water/ice concentrations. At the South Pole, there is reasonably strong correlation between the elevated areas of hydrogen and permanently shadowed craters. However, there is considerable debate on the form and concentration of this hydrogen since the orbiting satellites had limited resolution and their data can be interpreted in different ways. The varying interpretations are based on differing opinions and theories of lunar environment, evolution, and cometary bombardment within the lunar Science community. The only way to

truly answer this question from both a Science and resource availability perspective is to go to the lunar poles and make direct measurements. With this in mind, NASA initiated development of a payload named RESOLVE (Regolith & Environment Science and Oxygen & Lunar Volatile Extraction) that could be flown to the lunar poles and answer the questions surrounding the hydrogen: what's its form? how much is there? how deep or distributed is it? To do this, RESOLVE will use a drill to take a 1-2 meter core sample, crush and heat sample segments of the core in an oven and monitor the amount and type of volatile gases that evolve with a gas chromatograph (GC). RESOLVE will also selectively capture both hydrogen gas and water as a secondary method of quantification. A specialized camera that is coupled with a Raman spectrometer will allow core samples to be microscopically examined while also determining its mineral composition and possible water content before heating. Because RESOLVE is aimed at demonstrating capabilities and techniques that might be later used for ISRU, a multi-use oven is utilized with the ability to produce oxygen using the hydrogen reduction method.

SCIENCE BENEFITS: In the process of answering the hydrogen question, the RESOLVE instrument suite will provide data that can address a number of other scientific questions and debate issues, especially the sources of volatiles and reactions that might take place in cold traps. It should be noted that the original instrument suite for RESOLVE was selected to accomplish the largest number of ISRU and science objectives as possible within the limited funding available. Complementary instruments are noted when additional science objectives can be accomplished. Incorporation of these new instruments into RESOLVE and potential partnerships is an area of near-term interest.

Sources of Volatiles: The main proposed sources are episodic comet impacts, more-or-less continuous micrometeorite (both comet and asteroidal) impacts, solar wind bombardment, occasional volcanic emissions from the interior, and episodic delivery of interstellar volatiles from cold molecular clouds. These sources leave distinctive signatures, many detectable by RESOLVE. Comet impacts are likely to produce coherent layers of ice (probably reduced to pebbles and boulders by subsequent small impacts, and buried); these would be detected by imaging and Raman spectroscopy, the high water (H₂O) signal measured by the GC, and possibly by changes in the drilling rate or torque. More continuous delivery mechanism theories would not produce layers or boulders of ice, but might bond regolith grains together. Continuous sources might be distinguished by H/H₂O ratios and the abundances of other volatiles. Hydrogen isotopic composition would provide additional important information because these sources have distinctive D/H ratios, so one enhancement to RESOLVE would be an incorporation of a mass spectrometer with the existing GC.

Reactions in the Polar Regolith: Billions of years of micrometeorite bombardment, irradiation by cosmic rays and interstellar Lyman-alpha ultraviolet, and the presence of carbon-, hydrogen-, oxygen-, and nitrogen-bearing volatiles might have led to the production of organic compounds, a process that has been demonstrated experimentally. Heating by micrometeorite impacts might drive reactions involving water to produce phyllosilicates (clay minerals). If abundant enough, these reaction products could be observable by Raman spectroscopy and GC analysis. Thus, the polar cold traps are natural laboratories for the study of processes operating in interstellar space, and the RESOLVE suite of instruments can shed light on those processes.