Lunar Volatiles as a Resource for Science and Exploration

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LEAG — LUNAR · EXPLORATION · ANALYSIS · GROUP

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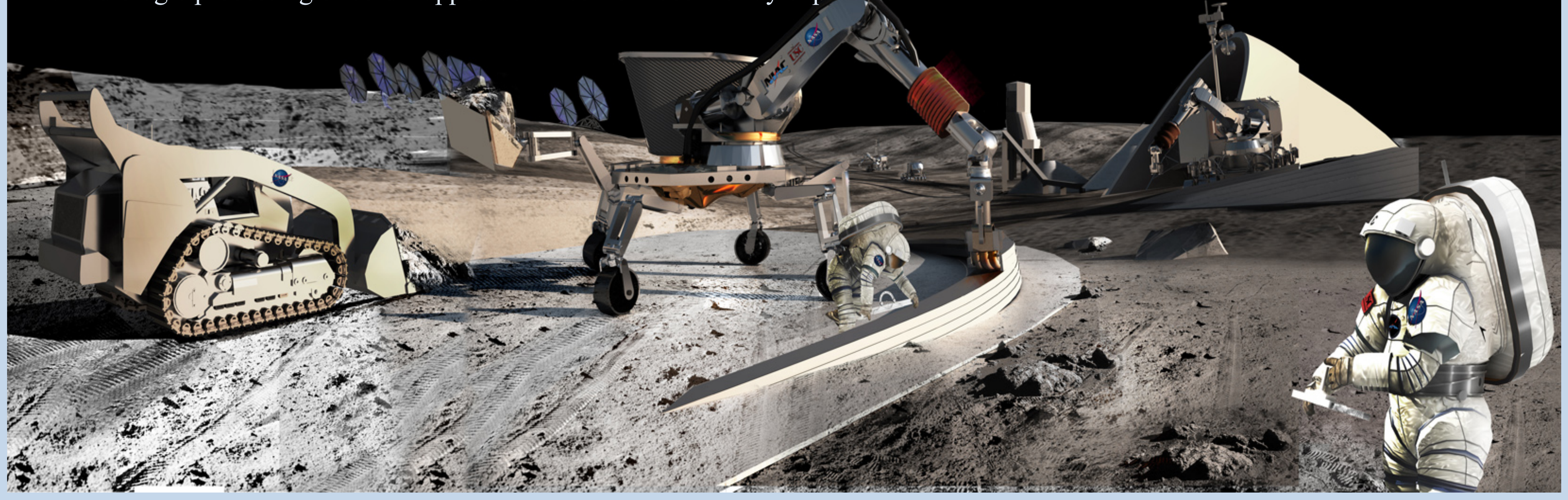
VISION 2050: LUNAR VOLATILES

In 2050, the proposed Moon Village [1] will be at some stage of implementation. Therefore, the Moon will host a combination of activities from a diverse set of nations and commercial groups. Lunar volatiles will be in regular use for exploration efforts. Commercial entities will be harvesting the volatiles and improving production strategy. The Moon will be a testing ground for ISRU efforts on asteroids and Mars.

Scientifically, much work will have been done to understand the sources, sinks, age, and redistribution of volatiles on the Moon. Ongoing work will use the Moon as a baseline for comparison of volatiles on other airless bodies such as Mercury, asteroids, and the Martian moons. Scientific work will focus on interactions between volatiles and external drivers especially in PSRs, where the cold temperatures retain the more volatile compounds. Ongoing research will explore prebiotic organic synthesis by radiologic processing of cold-trapped volatiles from cosmic-ray exposure.



THE IMPORTANCE OF LUNAR VOLATILES

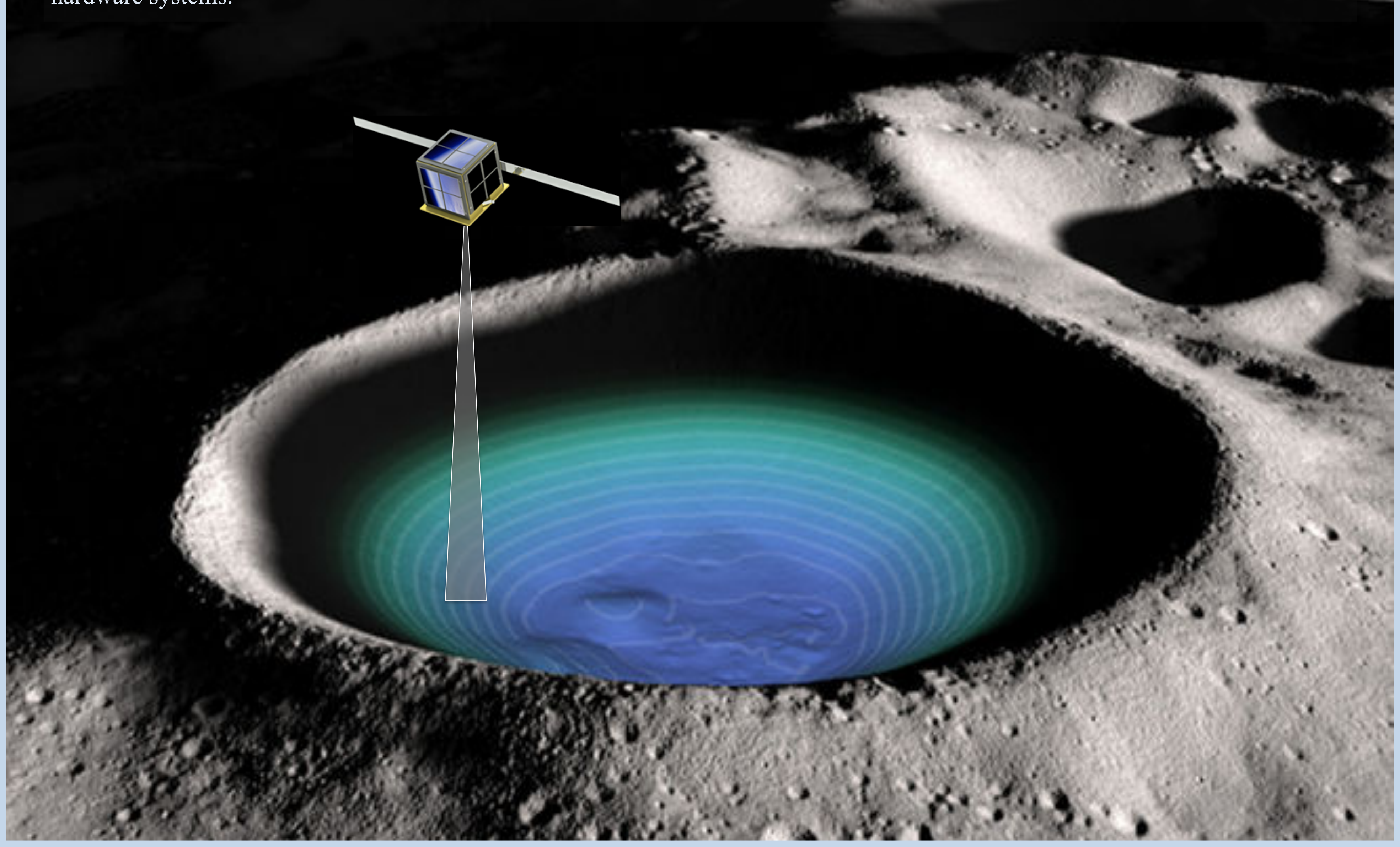
There is great scientific significance to lunar volatiles. The volatile content of the Moon is the balance of sources and losses of volatiles to the Moon over history. As such, it is an accessible reservoir holding insight into the history of volatiles in the Inner Solar System. Human exploration is facilitated by in situ resource utilization (ISRU). Production of consumables on site reduces the amount of material that must be launched from Earth's deep gravity well. Water is a valuable resource because it can be used to produce propellant and staples of life support.

Abundance: The abundance of water is the most important constraint on the viability of using the resource.
- Defines the absolute limit to the availability of the desired products.
- Related to the original abundance and the retention efficiency, and therefore can be used to infer the inventory of volatiles in the Inner Solar System over time.

Distribution: Data already indicate that volatiles have a heterogeneous distribution both in depth and lateral extent.
- The size scale of the heterogeneity determines the amount of mobility
- Depth distribution defines subsurface access needed to extract the volatiles.
- Relating the external conditions to the distribution will enable the best application of remote sensing and reconnaissance data to predict the presence of the resource on ISRU operational scales.
- Understanding the processes that modify the distribution over time can indicate its stability and renewability.

Physical Form: At grain-size scales, the physical form of water is another variable in the distribution.
- There are multiple potential physical forms of water, including ice, frost, hydrated minerals, adsorbed molecules, and ice-soil mixtures.

Composition: Includes the elemental and mineralogical constituents and isotopic ratios.
- The collection of constituents and isotopic data provide clues as to the original source, and therefore the renewability of the resource.
- Analysis of the composition reveals the presence of contaminants, which may be critical for designing and operating ISRU hardware systems.



PATHWAY

Multiple documents already exist containing suggestions for the roadmap for lunar research [2-6]. Here we highlight some aspects that will enable scientific progress and exploration goals, and also reflect the LEAG Lunar Exploration Roadmap implementation plan [3].

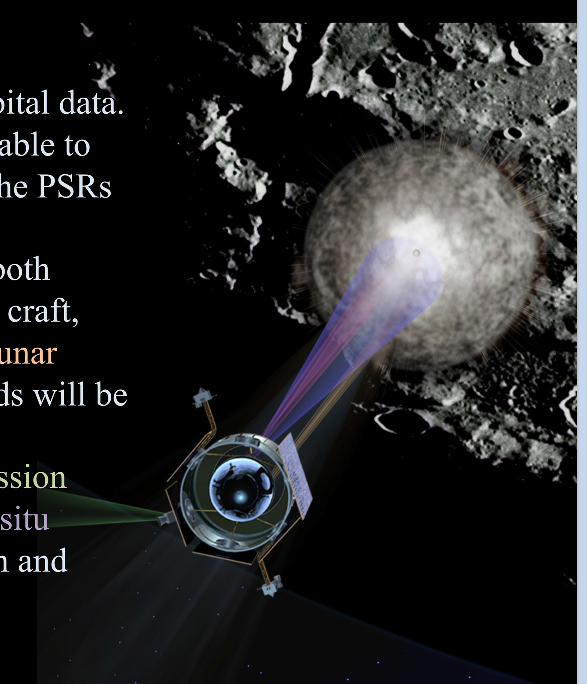
2020s: Lunar remote sensing can still provide a wealth of information on lunar volatiles: monitoring sources, sinks; mapping distributions; determining composition and physical form; and quantifying abundances. Cubesat and smallsat opportunities provide a low-cost method to perform targeted investigations of single pieces of the system. A dedicated long-lived volatiles orbiter mission could make significant progress at understanding the hydrological cycle on the Moon.

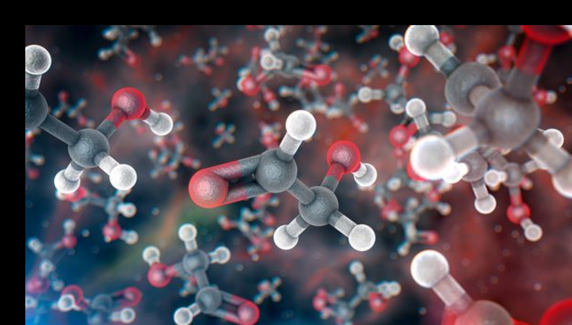
Many questions are, however, better answered by an in situ investigation. Landed missions to the surface of the Moon both inside and outside of the PSRs are required to provide ground truth to the remote sensing investigations and provide in situ subsurface data. Landed packages can inform on the composition of volatiles, the physical form, the abundance and the distribution. They can monitor ongoing processes. With commercial entities planning lunar landers, these investigations can be included as rideshares. Multiple dedicated missions offer efficient means to assess lunar volatiles in situ. These should address scientific and exploration objectives, which largely overlap in the early stages. Inclusion of ISRU demonstration packages is a necessary step toward regular production of resources from lunar volatiles.

2030s: The landed exploration with mobility will lead to understanding the magnitude, accessibility, form, and extractability of volatile deposits at multiple sites identified from orbital data. This in turn will lead to sample return, where the most sophisticated instrumentation is available to conduct the analysis. Cryogenic sample return of lunar volatiles from inside and outside of the PSRs will validate and extend the results from remote sensing and in situ analysis (see also [7,8]).

As humans become part of activities near and on the Moon, they can assist in furthering both science and exploration objectives. Their contributions may include tele-operation of landed craft, instrument deployment, production plant set-up and maintenance, and sample acquisition. Lunar ISRU will begin. Operations will develop on the Moon of increasing magnitude. The methods will be ported for potential demonstration on Mars and asteroids.

Investigations of comparable bodies including Mercury and asteroids will progress. A mission impacting into PSRs at Mercury will provide important constraints on the volatiles there. In situ analysis on asteroids will provide detailed analogous data for relating processes on the Moon and asteroids.





2040s: Asteroid and Martian ISRU operations expand and enable further exploration. Landed missions on Mercury and Ceres investigate sources, composition, and distribution of volatiles on those bodies. The overall understanding of volatile inventories of the Inner Solar System becomes more detailed in terms of relative importance of sources through space and time, roles of external drivers to alter the composition and distribution, radiation-induced and surface-catalyzed molecular synthesis.

CRITICAL ISSUES

While science and exploration have many aligned objectives, consideration must be made that they do not inhibit one another. For example, large-scale operations on the lunar surface will introduce volatiles into the lunar environment that can migrate to the PSRs. Scientific analysis should precede major utilization efforts to maintain the scientific integrity of the region. Fortunately, the scientific analysis enables the eventual utilization by providing the necessary prospecting and characterization to design the extraction technique.

The PSRs are an extremely challenging environment from an operational perspective. The low temperature and lack of solar power complicate the engineering and design of systems, particularly with respect to power. Some lunar PSRs not only lack sunlight, but Earth visibility as well, requiring communications via an orbiter. The lack of high-resolution images increases the uncertainty in surface operations.

Multiple nations are presently planning and conducting lunar programs. Coordination of those activities through ISECG or a similar organization can maximize the return for each participating nation, reduce reproduction of effort, and provide an array of resources for all involved. Policy for international cooperation and for private/public coordination is a critical component to development of lunar volatiles.

REFERENCES

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