**LRO INVESTIGATIONS OF VOLATILES PROCESSES AND THE SPACE ENVIRONMENT OF THE MOON.**

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**Introduction:** The Planetary Science Decadal Survey, Visions and Voyages [1] sets characterization of the lunar volatile cycle as a top priority for lunar exploration, seeking to address questions dealing with the sources of volatiles, if and how they migrate across the surface, and what is their ultimate fate. The Lunar Reconnaissance Orbiter (LRO) has been gathering data to address these questions for 12 years and, in that time, has revolutionized our understanding of lunar volatiles. Despite these advances, many fundamental questions remain unanswered. To address these questions, the LRO team is focused on new global-scale measurements characterizing diurnal variability and the exosphere and the space environment, as well as focused measurements of regions of high interest in the lunar poles, including polar craters.

The transport of volatiles across the surface of the Moon plays a critical role in the distribution of volatiles, both as a function of depth and of location on the surface. After several years of investigations by LRO and other spacecraft, major questions remain about how volatiles are transported and the role of the space environment in volatile production and evolution. Thus, LRO is investigating global volatile processes using a multi-instrument approach.

LRO is uniquely situated to study lunar exosphere processes [2-3] and the radiation environment surrounding the Moon. LAMP and CRaTER observations during this extended mission enable the first comparison of how the Moon's atmospheric and radiation environments respond to the changing solar activity in two subsequent solar cycles. There is new evidence that the Sun is moving into a grand minimum, that is, a series of weak solar cycles, like the Maunder, Dalton, or Gleissberg minima [4-5]. Ongoing observations provide important information to understand and predict how this variability will affect the atmospheric and radiation environments.

**Ongoing LRO Science:** The LRO team is using a multi-instrument approach to address identified high-priority science questions in volatile science and the interaction of the lunar surface with the space environment. For example, LRO instruments are investigating the mobility of hydration as a function of local time, latitude and depth, as well as terrain type. Grava et al. [6] used LAMP observations to confirm that solar-derived alpha particles (He++) are the main source of lunar exospheric helium. Looper et al. [7] used CRaTER to show that, after a decline during the middle of the solar activity cycle, cosmic ray radiation intensity has risen back to exceed the historically high levels seen at the start of the mission. This suggests that the sun is not in another historic minimum, however more work remains to fully confirm.

The nature of PSRs and the presence or absence of volatiles is being investigated across the team. Studies by Jozwiak et al. [8] and Sefton Nash et al. [9] examined the large PSRs Cabeus and Amundsen to explore differences in water-ice signatures measured in these craters. Jozwiak et al [8] combined observations from multiple instruments and suggests differences might be related to the nature and distribution of ices, and/or the different thermal and surface environment of the craters. Ongoing studies continue to evaluate this in detail. Measurements from Diviner showed doubly-shadowed regions that are much colder than surrounding areas (micro-cold traps) within Amundsen [9]. Measured emissivity differences are thought to be from 1) The abundance of sub-FOV doubly-shadowed terrain with ultra-cool temperatures, and 2) The thermophysical gradient in the uppermost layers of PSR regolith that may be caused by a thin veneer of water ice.

**Plans for ESM5:** The LRO extended mission #4 is scheduled to end in September 2022. There are still many outstanding questions related to volatiles and the lunar exosphere which can be addressed by LRO in a fifth extended mission, which would span September 2022-September 2025. This time frame will see the landings of several Commercial Lunar Payload Services (CLPS) providers as well as the Artemis III South Pole landing, which will change the composition of the lunar exosphere. LRO is currently the only spacecraft orbiting the Moon capable of directly measuring the neutral lunar exosphere, and LAMP is well situated to study this environment in its pristine state. The LRO orbit will also be passing over Cabeus crater again, allowing more detailed analysis of Cabeus and how it compares to other PSRs. Diviner, LAMP, LROC, LOLA, and Mini-RF are poised to examine seasonal differences on volatile distribution and migration. The new solar cycle presents another opportunity to better understand the suns influence on the lunar exosphere and space radiation. LRO remains viable and ready to continue providing new insight into our Moon.

**References:** [1] Planetary Sciences Decadal Survey (2011); [2] Stern, A. et al. (2012) *Geophys. Res. Let.* 39; [3] Stern et al. (2013) *Icarus, 226*; [4] Rahmanifard, F. et al. (2017) *Astrophys. J.*, 837; [5] Schwadron et al. (2018) *Space Weather*, 16; [6] Grava et al. (2020) *Month. Not. Royal Ast. Soc., 501*(3); [7] Looper et al. (2020) *Space Weather*, 18(12); [8] Jozwiak et al. (2019) *AGU Fall Meeting, #P51D-3403*; [9] Sefton Nash et al. (2019) *Icarus*, 332, 1-13.