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Scientific and Exploration Potential of the Lunar Poles

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Abstract

When we began this integrated research project, the lunar polar regions were regarded as "*Luna incognita*", the unknown Moon. During the last four years we have striven to further our understanding of the polar regions so that they are now as well known, and in some case better known, than the rest of the Moon. "*Luna incognita*" has become "*Luna cognita*".

1. Introduction

The goal of our team was to advance our scientific understanding of the Moon's poles and to fill in strategic knowledge gaps that facilitate the robotic and human exploration of these areas. One aspect that could not have been predicted is the wealth of new data that have become available since we began. These new data produced by an armada of spacecraft, including India's Chandrayaan-1, Japan's Kaguya mission, and NASA's LRO, provide new insight into the processes and history of the lunar poles. Our research has been divided into three themes:

(1) Lunar Polar Environment,

(2) Surface Characterization

(3) Surface Science, Instrumentation, and Operations.

By design, there was substantial overlap across topics, with each providing information to the others to facilitate a deeper, more thorough understanding of the questions that are posed.

2. Lunar Polar Environment

This theme includes: geology, illumination, volatile transport modeling, volatile-regolith laboratory studies.

2.1 Polar Geology

We have conducted several studies designed to elucidate the geological histories, nature and origin of the polar deposits. Using new spacecraft optical and radar images and Earth-based radar images, we have re-investigated and mapped the geology of the south pole.

In response to the assertion by the Augustine Commission that a return to the Moon is unaffordable, we investigated a possible architecture that extends human reach beyond low Earth orbit by creating a permanent space transportation system with reusable and refuelable vehicles.

2.2 Polar Illumination

The availability of high-resolution topography, combined with a high-fidelity simulation tool has allowed polar illumination conditions to be well characterized, including the ability to determine data useful for planning future lander missions. We have developed a simulation tool called LunarShader that uses topography data and a user-selected Sun position to precisely determine which areas of the lunar surface are illuminated. In addition to characterizing the polar illumination conditions we also discovered that permanent shadow can exist at latitudes as low as 58°.

2.3 Polar Volatiles

Our research has analyzed data regarding lunar volatiles and conducted modeling to support interpretation of the volatile data. This work includes atmospheric modeling to consider volatile transport and space weathering to follow volatile retention. We have simulated the evolution of an ice layer over time and compared the model results as they would be observed in neutrons, FUV, radar, and in situ. This work enables a self-consistent interpretation of the seemingly disparate data on the distribution and abundance of volatiles in lunar polar regions coming from LRO, LCROSS, and Chandrayaan-1.

2.4 Volatile-Regolith Modeling

We have conducted laboratory and modeling experiments to better characterize and understand the nature and evolution of H_2O, hydroxyl, and other volatiles potentially at the poles. We are conducting Temperature Programed Desorption measurements on lunar analog materials to determine the thermal stability of both molecular water and hydroxyl on the surface. We also characterize these adsorbed species with UV through IR reflectance measurements under appropriate pressure and temperatures.

3. Surface Characterisation

We have been using the latest data to study lunar surface characteristics. We have determined that self-secondary cratering on the continuous ejecta is a significant factor during an impact event. Such self-secondary craters are in part buried by melt and bouldery ejecta facies indicating that they formed concurrently with ejecta emplacement. Since the lunar chronology is tied to the crater frequencies of the Copernicus and Tycho ejecta blankets, if those frequencies do not represent the impact flux, the chronology will be incorrect.

4. Surface Science, Instrumentation, and Operations

This theme consisted of diverse objectives with the common thread that they either uniquely use the lunar poles and/or are enabled by a lunar polar location.

4.1 Excavation & Mobility Modeling

We have developed physically based discrete element method (DEM) models of excavation and mobility problems on the Moon. We have: (1) conducted physical testing of wheel digging, static and percussive excavation, penetration, and geotechnical tri-axial strength tests on lunar simulants (primarily JSC-1a); (2) developed DEM model capabilities; (3) validated model capabilities by simulating physical tests using the models.

4.2 Ground Penetrating Radar

Ground-Penetrating Radar (GPR) data from terrestrial analog environments can help constrain models of the evolution of the lunar surface, help predict the nature of subsurface properties, and aid in interpretation of orbital SAR data. By comparing analysis of GPR with the known local stratigraphy, we have shown that GPR can be used to probe the subsurface and help constrain the physical properties and setting of near surface materials.

4.3 Neutron Studies

We have conducted a reexamination of the hydrogen abundance sensitivity limits of orbital neutron data. A wet-over-dry, two-layer stratigraphy has been modeled for the first time using neutron transport codes. Application of this effort to Goldschmidt crater reveals that it may have an enhanced hydrogen content of 0.1-1% water equivalent hydrogen. We have also studied data from the Lunar Exploration Neutron Detector (LEND) in order to better understand how these data provide information of lunar surface hydrogen abundances.

4.4 Earth Observation

Our goal was to examine the potential for a long-term full-disk Earth observing instrument on the Moon that would characterize the remotely detectable physical and biological signatures of the Earth as a function of time. A lunar polar vantage point is unique, making it possible to track Earth's ever-changing photometric, spectral and polarimetric signatures in a manner analogous to future observations of terrestrial planets orbiting other stars. Part of this effort included analysis of full-Earth data collected by the LCROSS spacecraft.

5. Summary and Conclusions

During our four year effort we have made significant progress on the topics described here. We will present a review of these advances at the meeting. “Luna Incognita” has truly become “Luna Cognita”