Magnetic Anomaly Particle Spectrometer (MAPS) for the Lunar Vertex Mission.

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Introduction: In 2024, the first Payloads and Research Investigations on the Surface of the Moon (PRISM-1a) mission targets a combined lander/rover investigation of the Reiner Gamma (RG) swirl and magnetic anomaly [1]. The Lunar Vertex investigation will investigate the topology of the magnetic anomaly at Reiner Gamma, the nature of the plasma impact onto the lunar surface within the anomaly, and the characteristics of the surface material that has undergone space weathering. To characterize the nature of the plasma impact and to help map the 3D structure of the "mini-magnetosphere" created by the plasma interaction with the magnetic anomaly, the Lunar Vertex (LVx) investigation will carry a combined ion and electron plasma spectrometer (MAPS) on the lander that quantifies the plasma environment at the landing site. Measurements are continuously taken during the lunar day as the Sun moves across the sky and the Moon is subjected to different, time variable plasma environments in the solar wind and during the passage through Earth's magnetotail.

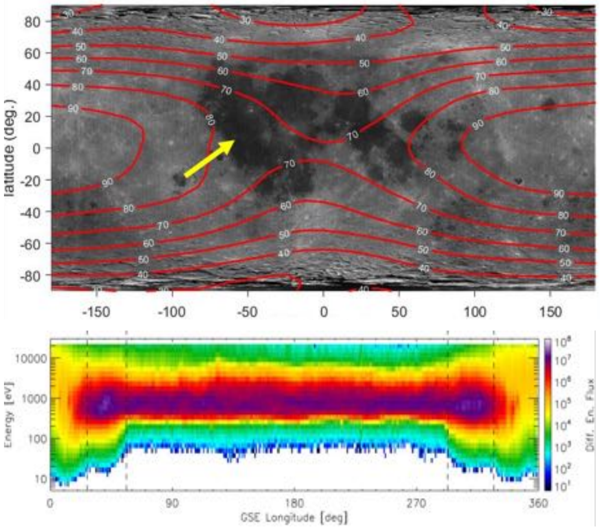

Fig. 1. The normalized cumulative particle flux of solar wind protons to the lunar surface during one lunar orbit for an idealized purely southward IMF case is location-dependent (top). The yellow arrow indicates Reiner Gamma (adapted from [2]). The mean differential ion energy flux as a function of energy and lunar GSE longitude (i.e., lunar phase) for non-SEP times has been determined by THEMIS/ARTEMIS (adapted from [3]). Vertical lines indicate the main regions traversed (from the outside): magnetosphere, sheath, and solar wind.

Plasma Particle Measurements: MAPS will encounter thermal plasma populations that are typical for the near-Earth solar wind, magnetosheath, and magnetotail environment. Therefore, the MAPS design is a direct derivative of the Rosetta/IES plasma spectrometer design that successfully took data in a nearly identical environment near Earth, and that during the prime part of the mission was subject to very similar operational constraints onboard a non-spinning spacecraft during exploration of comet 67P/Churyumov-Gerasimenko. The measurement approach is straightforward. A pair of nested toroidal deflector surfaces (the electrostatic analyzer, ESA) are charged to predetermined voltages to select a narrow energy passband of charged particles directed onto a set of Chevron micro-channel plate (MCP) detectors that count individual particles and record their arrival angle. By sweeping the voltage on the ESA surfaces, an energy spectrum is assembled. The instantaneous field of view (FOV) of MAPS over which particle spectra are assembled is 292.5°x3°, with 11.25° resolution. In the lunar orbit the predominant plasma flow directions in the solar wind and in the magnetosphere are anti-sunward, however this flow direction moves across the sky as seen from MAPS over the lunar day. MAPS addresses this by aligning the center-line of the FOV with this Sun-arc across the sky.

At the Moon we can expect deviations from the anti-sunward flow direction in the magnetosheath, where the solar wind flow is redirected around the magnetic obstacle formed by the magnetosphere, and in Earth's magnetotail, where we are shielded from the solar wind but are instead immersed in magnetospheric plasmas that at those Earth-centric distances can flow sunward or anti-sunward due to the large-scale dynamics of the magnetotail. In addition, we can expect the RG magnetic anomaly to modify and redirect charge particles before reaching the lander site. To capture all these effects, we expand the MAPS FOV with a second set of curved conducting plates located close to the entrance aperture of MAPS that electrostatically steer charged particles into the instrument. The resulting ± 45° steering capability results in a total FOV of 292.5°x90° (equivalent to the heritage Rosetta/IES design).

After landing on the Moon and deployment of the Lunar Vertex Rover, MAPS will deploy its doors and, after a brief commissioning phase, will perform continuous, automated plasma measurements.

Operating in a Dusty Environment: A secondary unique challenge for MAPS is operation in the dusty environment of the lunar surface. To mitigate dust impact during landing, MAPS is equipped with a one-time deployable barndoor style pair of doors that open downwards. While they restrict the FOV to 292.5° and thus partially obscure the view of particles backscattered/emanating from the lunar surface below, they will deploy reliable in this dusty environment. Furthermore, MAPS is mounted high on the lander at approximately 3 meters above ground, which separates MAPS from any electrostatic fields on the lander, limits other FOV obstructions by the lander, and keeps MAPS as high as possible above levitating dust present at the surface. Lastly, a grounded entrance aperture grid that is primarily designed to prevent electrostatic fields from the MAPS deflectors to penetrate into space and to suppress secondary photo electrons created by the instrument itself will also function as an additional dust mitigation device. Floating charged dust particles will likely adhere to the metallic surface and will thus be prevented from entering the open aperture of the instrument.

Interpretation of Plasma Observations: MAPS will measure the ion (no mass separation) and electron velocity distribution over a 292.5°x90° FOV from 8 eV to 17.5 keV energy per charge, taking a full energy/angle range measurement set every 120 seconds. While this does not provide a full 4π steradian coverage of particle distribution space (this cannot be achieved with a single, non-spinning instrument), the anti-sunward flow direction of the plasma is always centered in the ± 45° steering range of MAPS as the Sun moves across the sky, providing a good coverage of the "input signal" and expected modifications and deflections caused by RG.

The main challenge for MAPS data analysis will be that the undisturbed plasma flows approaching the lunar surface are actually not known. Lunar Vertex only measures plasmas inside the magnetic anomaly. The standard mitigation approach is to use solar wind measurements from the L1 point (by the Advanced Composition Explorer – ACE, and the Deep Space Climate Observatory – DSCOVR), providing a 30–40 minute time delayed solar wind observation upstream of Earth. However, when the Moon is in the magnetosheath (where plasma has passed through Earth's bow shock and has been slowed, heated, and diverted) or in the magnetotail (where no solar wind is present and instead we are subjected to both sunward and anti-sunward streaming magnetospheric populations) these measurements do not accurately describe the plasma input outside of Reiner Gamma. Instead, we will use the two-spacecraft THEMIS/ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun) constellation that orbits around the Earth-Moon L1 and L2 Lagrangian points, providing plasma measurements in direct vicinity of the Moon.

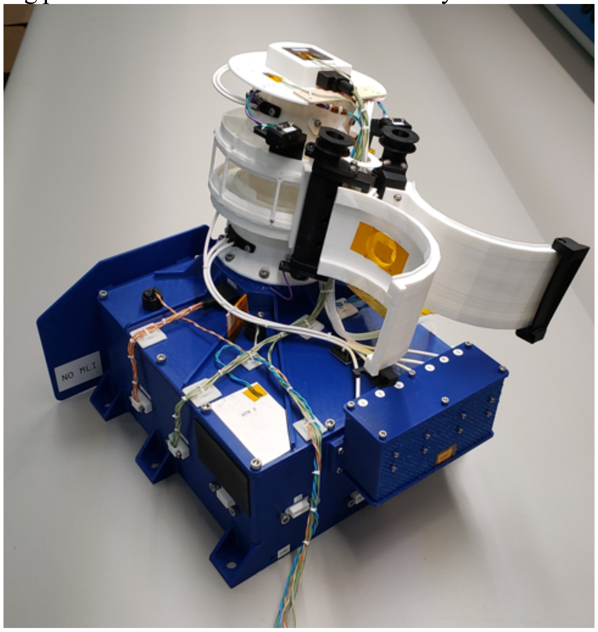

Fig. 2. 3D printed prototype of MAPS created for checking cable routing and MLI mounting points. MAPS is shown in the door-deployed configuration. On the Moon the axis of the (white) cylindrical sensor section would be north-south aligned and horizontal. The opened doors would point downwards to the surface.

Ongoing Efforts: MAPS is presently (Winter 2023) in the hardware build phase and, after testing and calibration, is slated for delivery to NASA late May 2023. MAPS follows a standard operational scheme for this type of instrument, so MAPS data acquisition, data flow, ground processing and archival of data at the PDS leverages existing resources developed and tested for other missions operating similar instruments. MAPS data therefore will be familiar to end users. The operation scheme is automated and straightforward. Since MAPS is fixed on the lunar surface and the main plasma flow direction will be apparent at all times during the mission, analysis of MAPS data will be much simpler than during typical planetary missions using three-axis stabilized yet frequently actuated spacecraft.

References: [1] Blewett, D.T. et al. (2021), *Bull. Am. Astron. Soc. 53*(4), doi: 10.3847/25c2cfeb.9295af86. [2] Kallio, E., et al. (2019), *Planet. Space Sci. 166,* doi: 10.1016/j.pss.2018.07.013. [3] Poppe, R.A. et al (2017), *J. Geophys. Res. Planets 123,* doi: 10.1002/2017JE005426.