# SelenITA: A dual-spacecraft lunar CubeSat mission to characterize the near-surface electromagnetic plasma environment

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***ABSTRACT*** – SelenITA is an international interdisciplinary mission consisting of two CubeSats that will provide the first multi-point measurement in a sustained low lunar orbit. This mission will advance the understanding of spatiotemporal differentiation of the electromagnetic space environment at the Moon in support of Artemis crew and the geosciences. The candidate mission science objectives and measurement requirements are listed below. SelenITA builds on a rich history of electromagnetic plasma observations of the near lunar surface and space environment, and it answers high level science questions with state of the art instruments in a small package.

***PLAIN LANGUAGE ABSTRACT*** – SelenITA comes from the greek word for Moon, selene, with the addition of "ITA" as a reference to the Brazilian teammate, Instituto Tecnológico de Aeronáutica. In addition, in Portuguese "ita" is a prefix similar to "ite" in English, used in naming minerals, so Selenita could be seen as a lunar gemstone. In Spanish, "ita" is a diminutive suffix for "little" which is appropriate for this CubeSat mission which consists of twin 12U CubeSats in low lunar orbit. The primary science goal of the mission is to distinguish time varying features within the electromagnetic plasma environment near the surface of the Moon. The science objectives include investigating the origins of crustal magnetic fields, plasma interactions with these fields, plasma waves, surface potential, and interior properties. This mission is also interested in the radiation environment at the Moon and the amount of dust at the lunar poles. This is important because it helps us understand how future astronauts will live and work on the lunar surface and identify hazards.

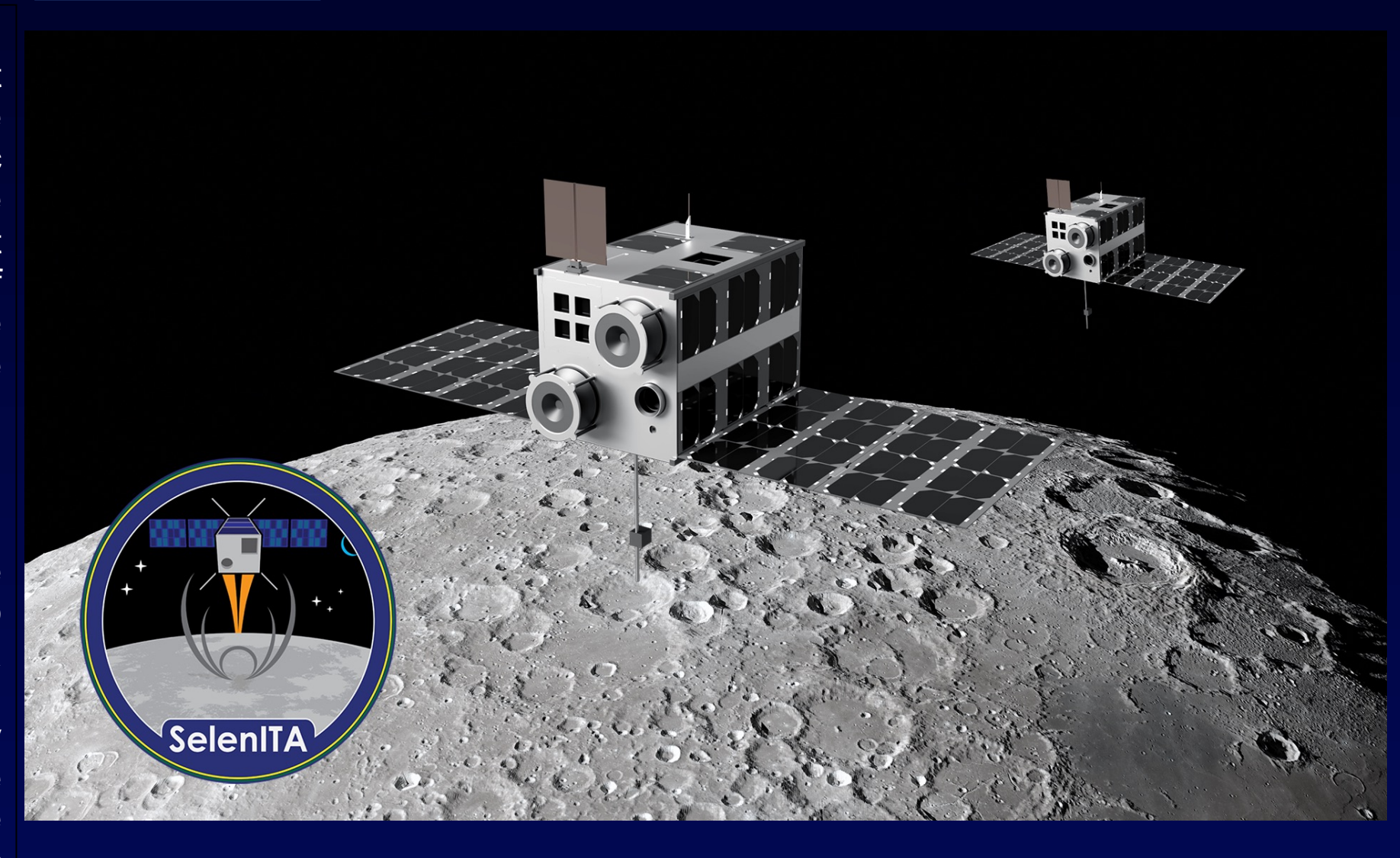

**Figure 1.** The SelenITA mission consists of twin 12U CubeSats with flying in formation in low lunar orbit. Each satellite is suited with a full complement of plasma and fields instrumentation (Matos).

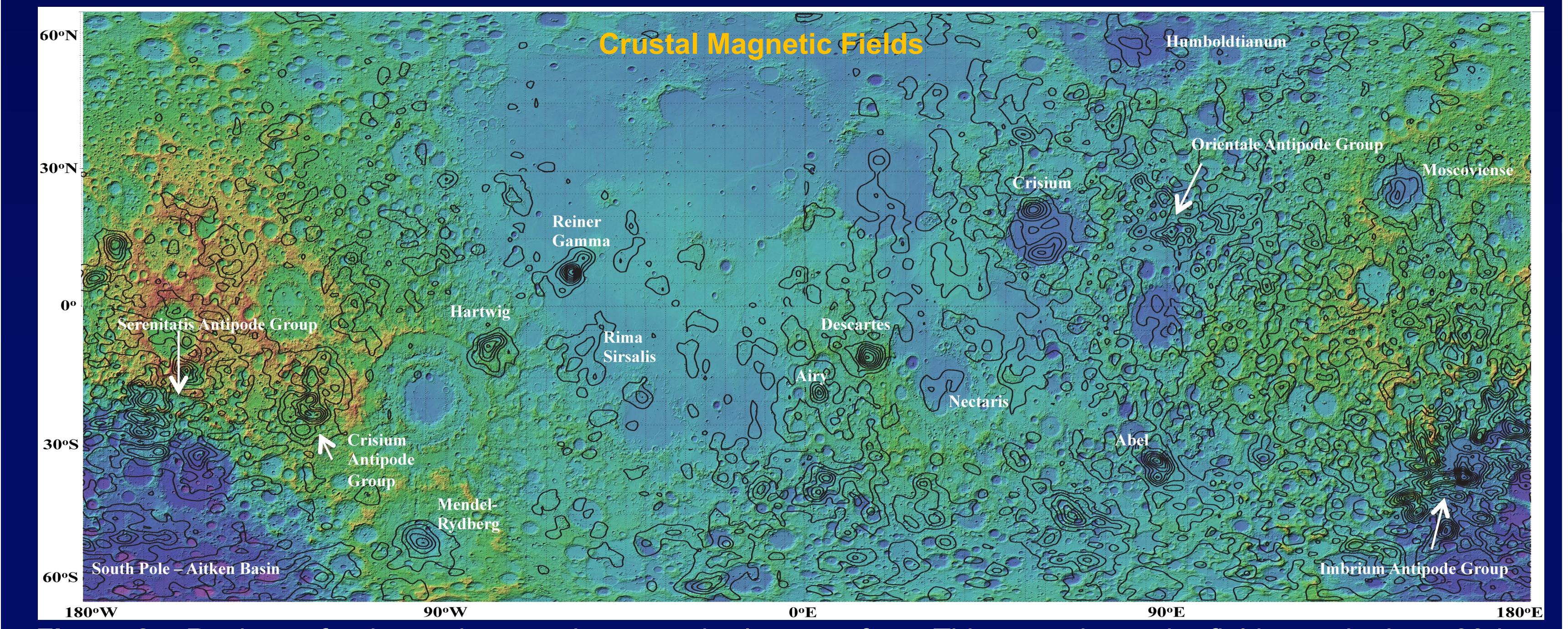

**Figure 2a.** Regions of enhanced magnetism spot the lunar surface. This map shows the field magnitude at 30 km altitude. Contou2s are at 1 nT interval, with a resolution of 32 km latitude and 100.9 km longitude. The locations of the 11 largest anomalies are notes along with four additional groups of anomalies centered approximately antipodal to young large lunar basins are indicated. Shaded relief is topography (LOLA), range -9 km to +7 km. (Hood et al 2021, JGR Planets.

## Motivation

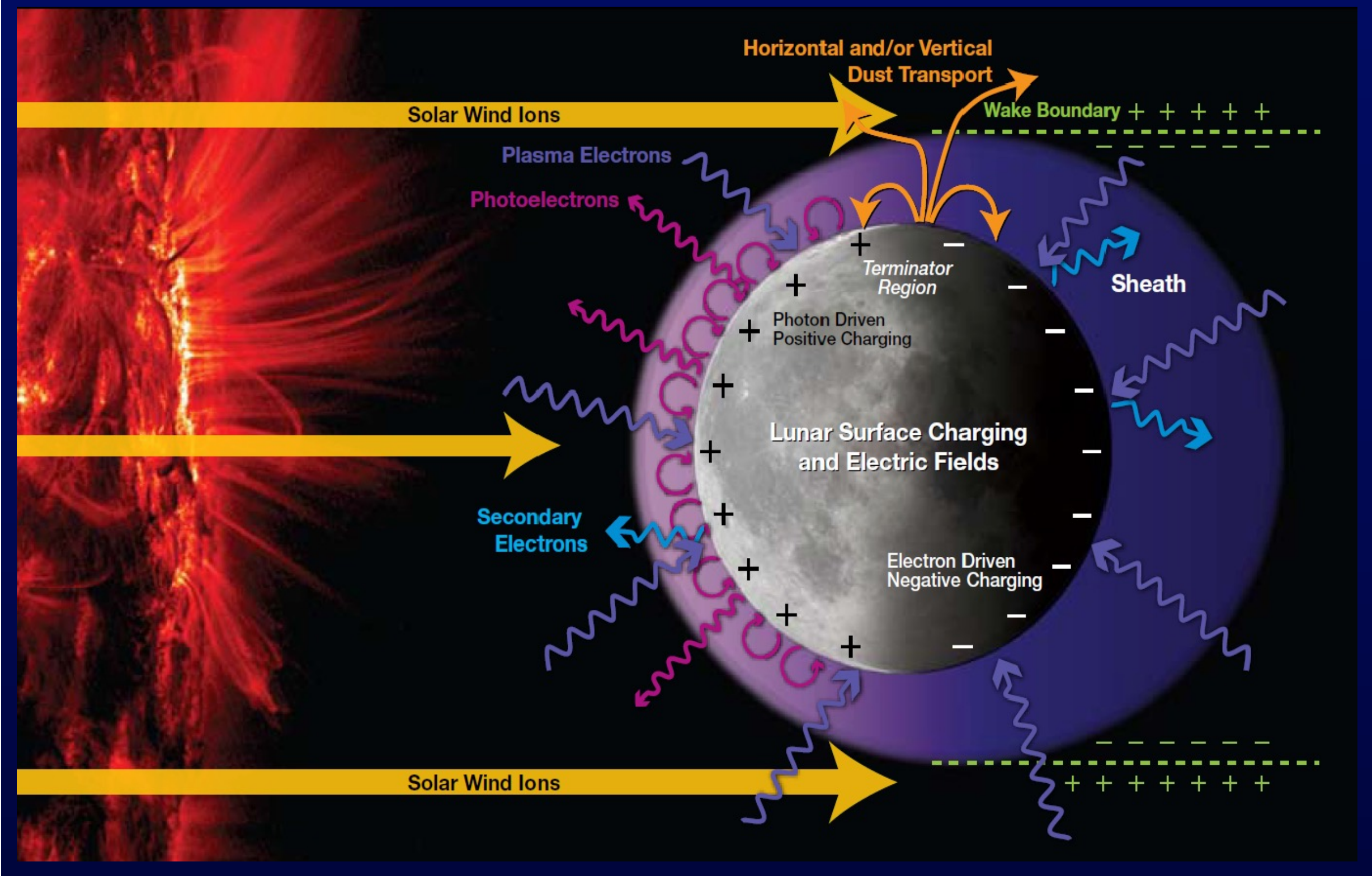

**Figure 3.** Solar wind lunar plasma environment overview (NASA/GSFC, DREAM, Farrell et al.)

The near surface lunar plasma environment is comprised of a dynamic network of plasmas, electric and magnetic fields, currents, the variable solar wind, IMF, along with particle, fluid, plasma, and electromagnetic waves. The lunar plasma environment changes over a month between transiting the magnetosphere.

## Candidate Science Objectives

- Origins of crustal magnetic fields
- Plasma interactions with crustal magnetic fields
- Plasma waves and turbulence at the Moon
- Lunar surface charging in all plasma environments
- Polar dust exosphere populations
- Interior composition, state, and structure of upper mantle & crust with EM Sounding
- Characterize the ionizing radiation environment hazardous to human and robotic systems

## Required Measurements

- 3-component vector Magnetic Field
- Plasma distribution (flux, energy, density, temperature)
- Dust
- Energetic particles (protons, electrons, gamma rays)

# MAGNETIC FIELDS

## Crustal Magnetic Fields

- ➢ **Crustal magnetic fields origins are not well constrained.**
- ➢ **Magnetic field observations from orbit contain a large amount of contamination from solar sources.**
- ➢ **Previous datasets contain gaps and are limited at some latitudes, especially for the poles.**
- ➢ **Small scale features and fields are obscured above 20 km altitude.**
- ➢ **Polar magnetic fields contribute to volatile processes.**
- ➢ ***Additional low altitude FGM observations are needed to improve the accuracy of and resolution of small-scale features within crustal field maps.***
- ➢ **This will improve the global understanding of surface fields, origins, and geophysical processes.**

## Poles

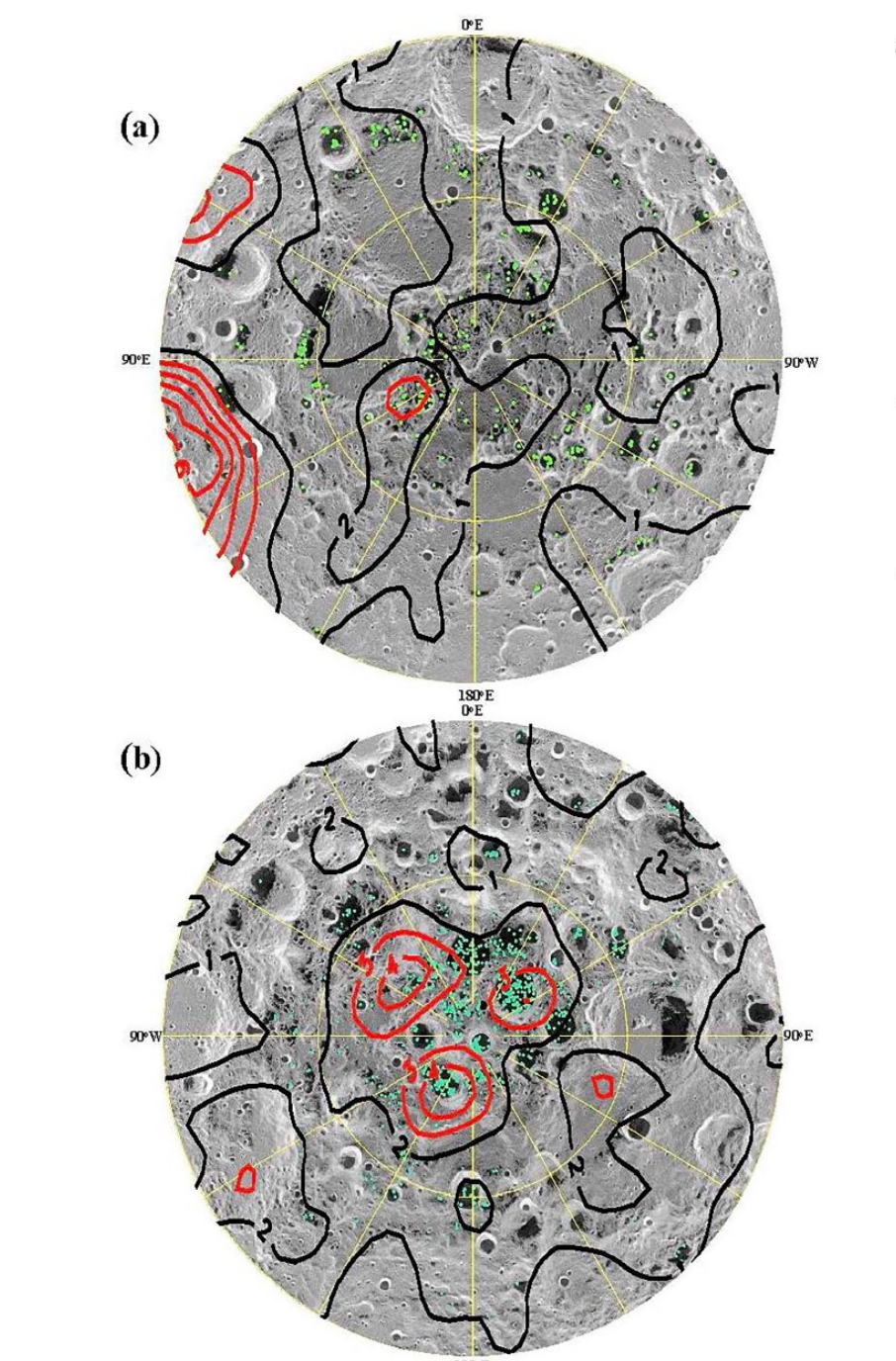

**Figure 4a. (a) North pole, (b) South pole crustal magnetic fields (red contours above 3 nT, black start at 1 nT) at 30 km, plotted over hydrogen abundances and topography shaded relief (Hood et al 2022, GRL, DOI: 10.1029/2022GL100557).**

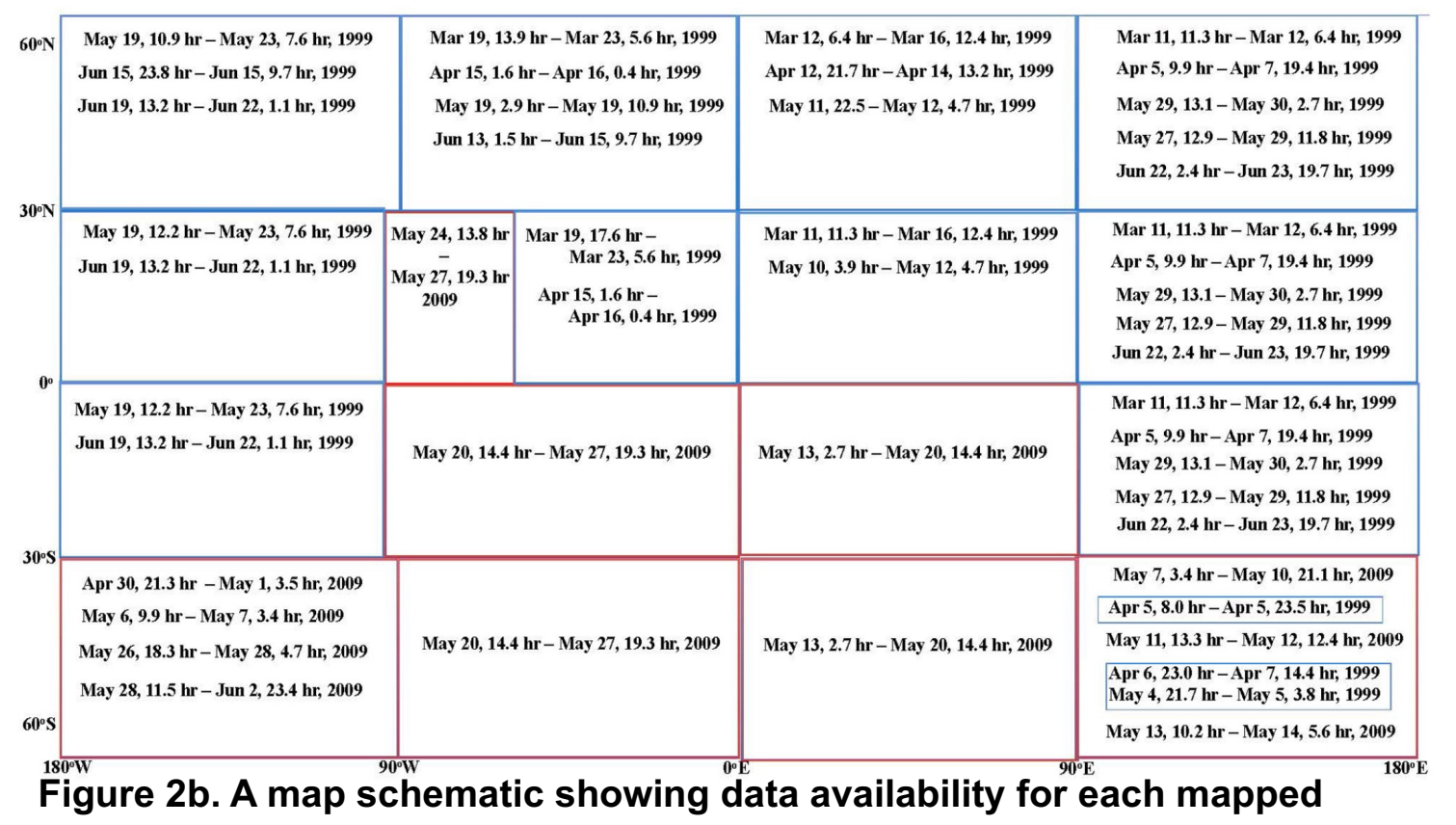

**Figure 2b. A map schematic showing data availability for each mapped region (Hood et al., 2021, JGR Planets, DOI: 10.1029/2020JE006667).**

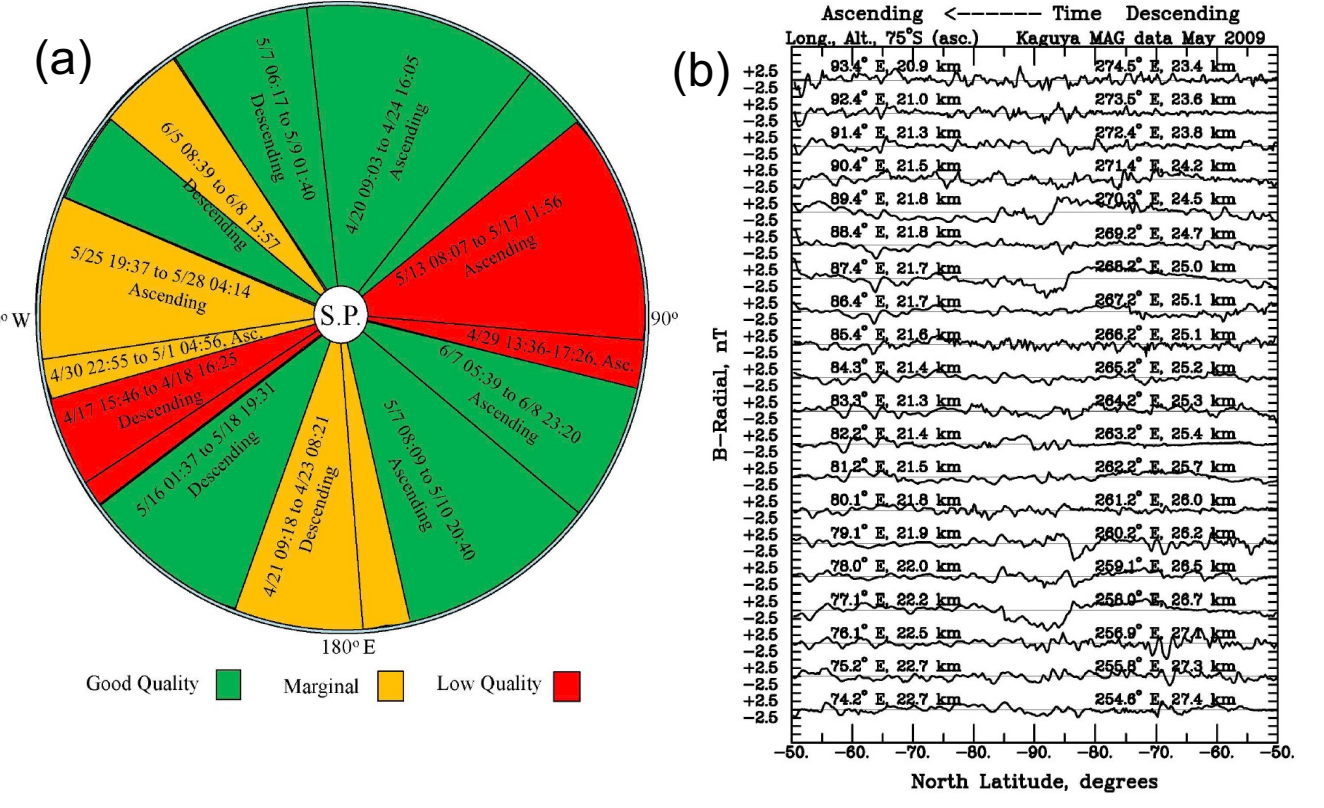

**Figure 4b. (a) South Pole showing locations of good, marginal and low-quality data (Hood). (b) low quality data is shown as an example of noise interfering with detections of crustal field signal. (Hood)**

## EM Sounding

- ➢ **Induced magnetic fields measured from orbit can constrain the electrical conductivity of the crust and mantle.**
- ➢ **FGM observations made within the nightside wake cavity and when not flying over a crustal magnetic field, can be used to isolate induction.**
- ➢ **The transfer function is a robust method uses two observers (e.g., HERMES, THEMIS-ARTEMIS) with a direct input of the driving field. No assumptions of the source is required.**
- ➢ ***Additional low altitude FGM observations are needed to improve the accuracy of the crust and upper mantle electrical conductivity at depth.***
- ➢ **Lateral variations in electrical conductivity can help with regional scale resource planning and provide constraints on the depth of the PKT.**

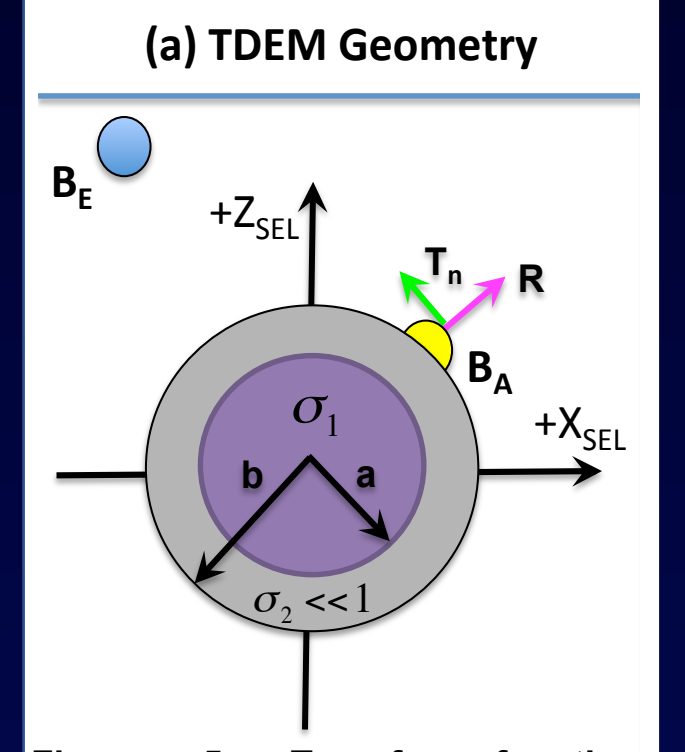

**Figure 5. Transfer function method (Haviland et al 2019, ASR).**

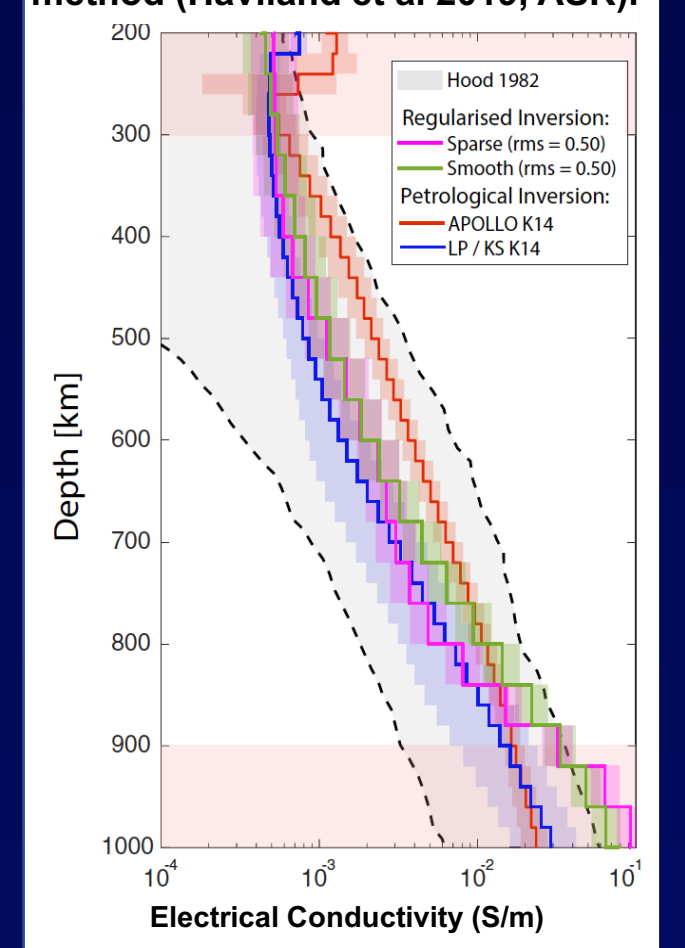

**Figure 6. Conductivity profiles constrain composition (Mittelholz et al 2022, JGR Planets).**

# PLASMA INTERACTIONS

## Mini-magnetospheres

**Open Science Questions:**

- ➢ **Determine the 3D structure of plasma interaction with crustal magnetic fields.**
- ➢ **Do they shield the lunar surface from solar wind plasma?**
- ➢ **How is incident plasma reflected/deflected from lunar crustal magnetic fields?**
- ➢ **What fundamental plasma physics processes occur in lunar crustal magnetic field interaction regions? Do collisionless shocks form above crustal magnetic fields?**

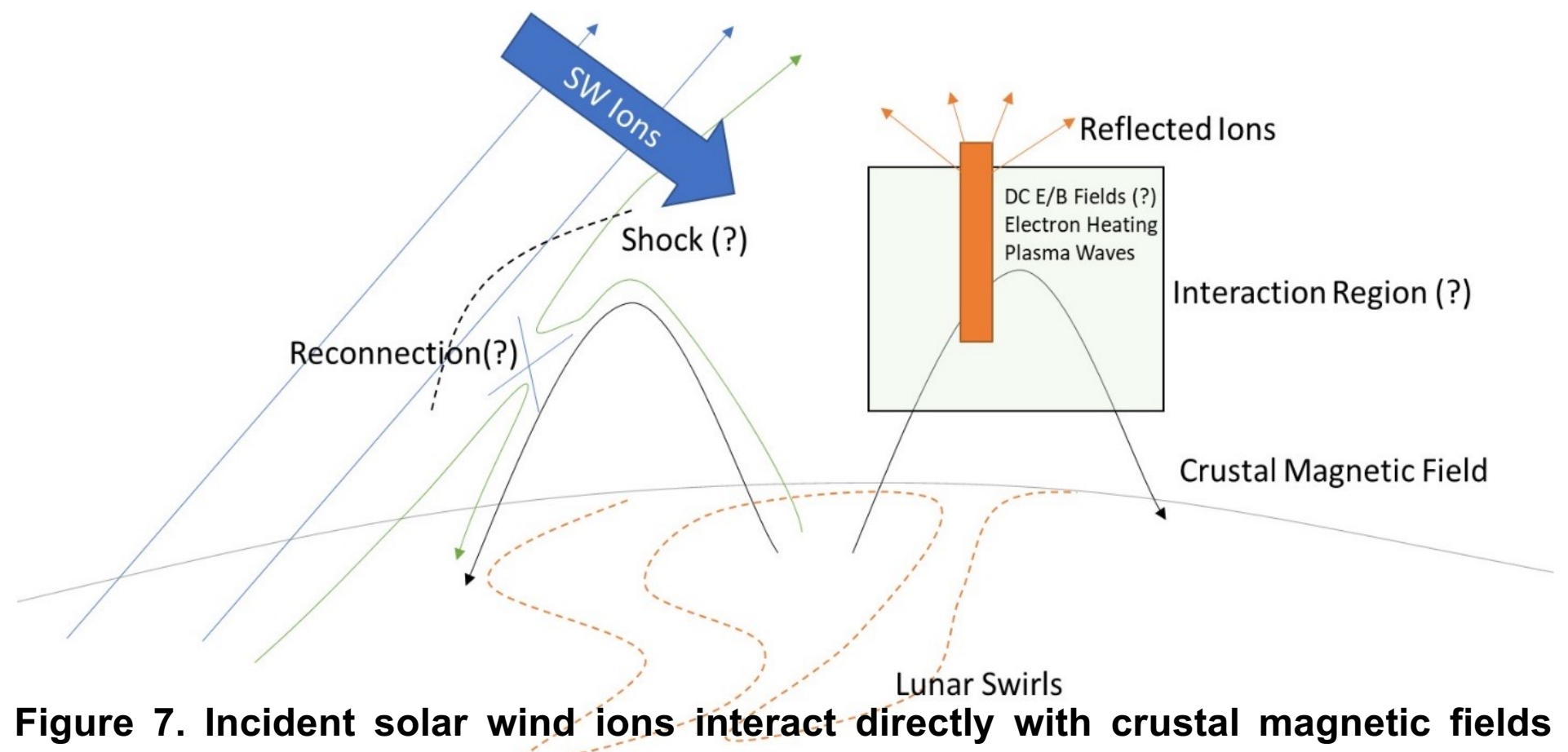

**Figure 7. Incident solar wind ions interact directly with crustal magnetic fields weathering swirls, reflecting ions, heating electrons, and producing waves. The extent of the interaction region, DC E/B fields, and the existence of fundamental physics processes, like shocks and reconnection, is unknown (Sawyer).**

- **We lack a complete understanding of how incident ion and electron fluxes vary as a function of altitude and magnetic field strength, as well as at what altitude(s) incident ions are reflected and/or deflected within lunar magnetic field interaction regions.**
- ***We wish to understand the average morphology and temporal variability of the plasma interaction region and its response to changing solar wind conditions.***
- **Fully characterizing the 3D structure of the interaction would allow us to understand the relationship between lunar magnetic anomalies and lunar swirls, and to determine whether the albedo features represent regions of the regolith shielded from solar wind bombardment.**

## Particle Reflections, Heating, Turbulence

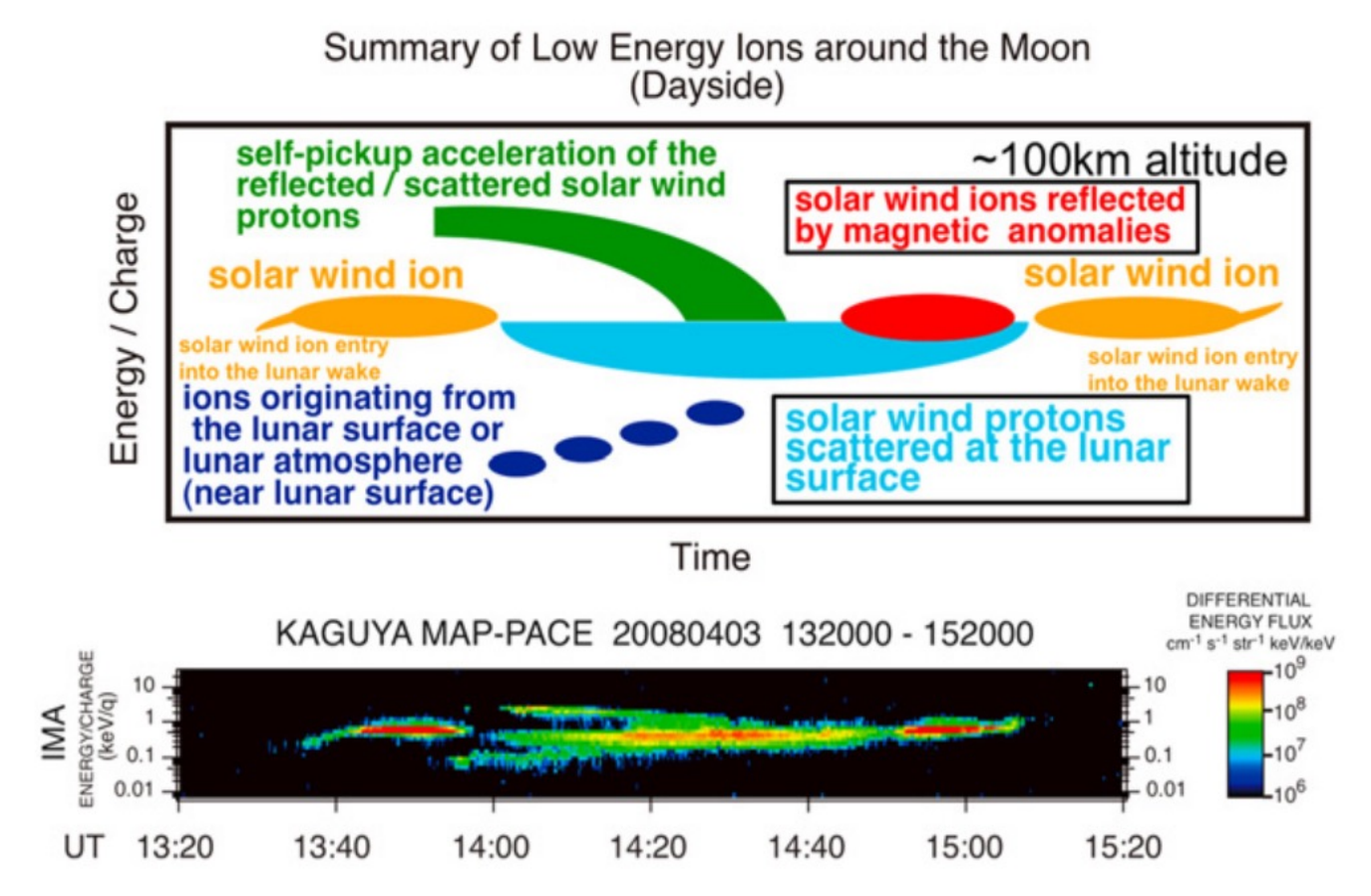

**Figure 8. Pickup ion processes (top) and data from the Kaguya mission (Halekas et al., 2011, PSS).**

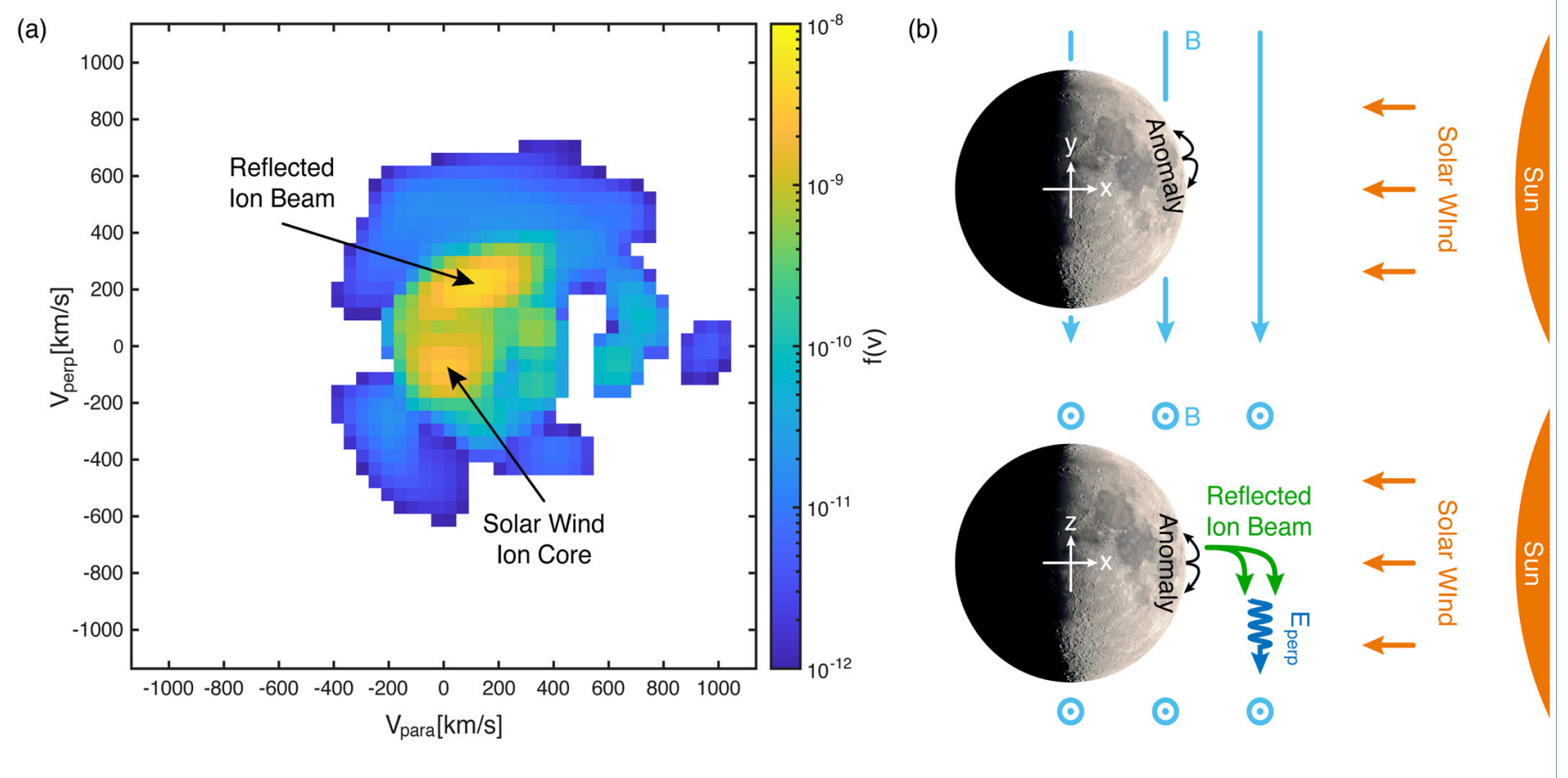

**Figure 9. Example observed reflected ion beam (Chu et al. 2021, JGR Space Physics).**

- **In situ measurements indicate that both ions and electrons can be heated in and above the interaction region [Saito et al., 2012; Halekas et al., 2012, 2014; Chu et al., 2021; Harada et al., 2021], but we lack a complete accounting of how the energy of bulk plasma motion is converted to other forms in the magnetic field interaction regions.**
- ***We wish to quantify the role of reflection/deflection by DC magnetic fields, reflection/deflection by DC electric fields, and thermalization of the distribution by non-adiabatic interactions and plasma waves.***
- **Additionally, observations are needed to confirm the presence and generation of selenogenic ion cyclotron waves [Chi et al 2013] and whistlers [e.g., Harada et al 2015].**

# DUST & SAFETY

## Dust

**Open Science Questions:**

- ➢ **What are the temporal and latitudinal variations of impact ejecta in the lunar polar region?**
- ➢ **What is the meteoroid impactor environment of the poles?**
- ➢ **What role do meteoroids play in volatile processes at the poles? (e.g., Szalay et al., 2016)**

**Objective: Measure the amount of impact ejecta as a function of time, latitude, local time, and altitude of the polar lunar space environment.**

**Summary:**

- **The lunar ejecta cloud is sustained by numerous interplanetary meteoroid impactor sources.**
- **Airless bodies are efficient amplifiers of their local meteoroid environments.**
- **The impact environment of the lunar polar regions has not yet been explored/characterized.**
- **Meteoroid bombardment may play a critical role in lunar volatile evolution.**

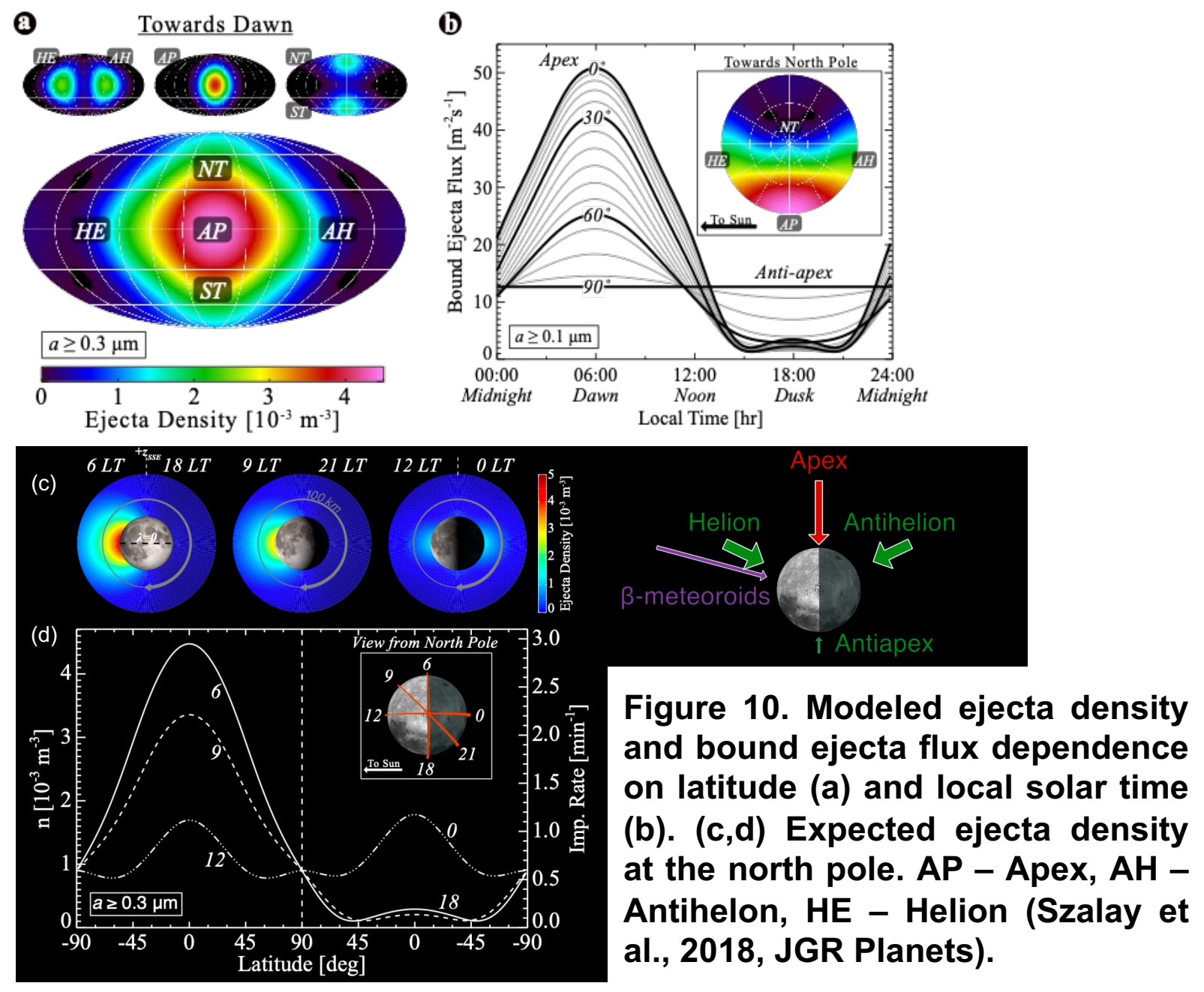

**Figure 10. Modeled ejecta density and bound ejecta flux dependence on latitude (a) and local solar time (b). (c,d) Expected ejecta density at the north pole. AP – Apex, AH – Antihelon, HE – Helion (Szalay et al., 2018, JGR Planets).**

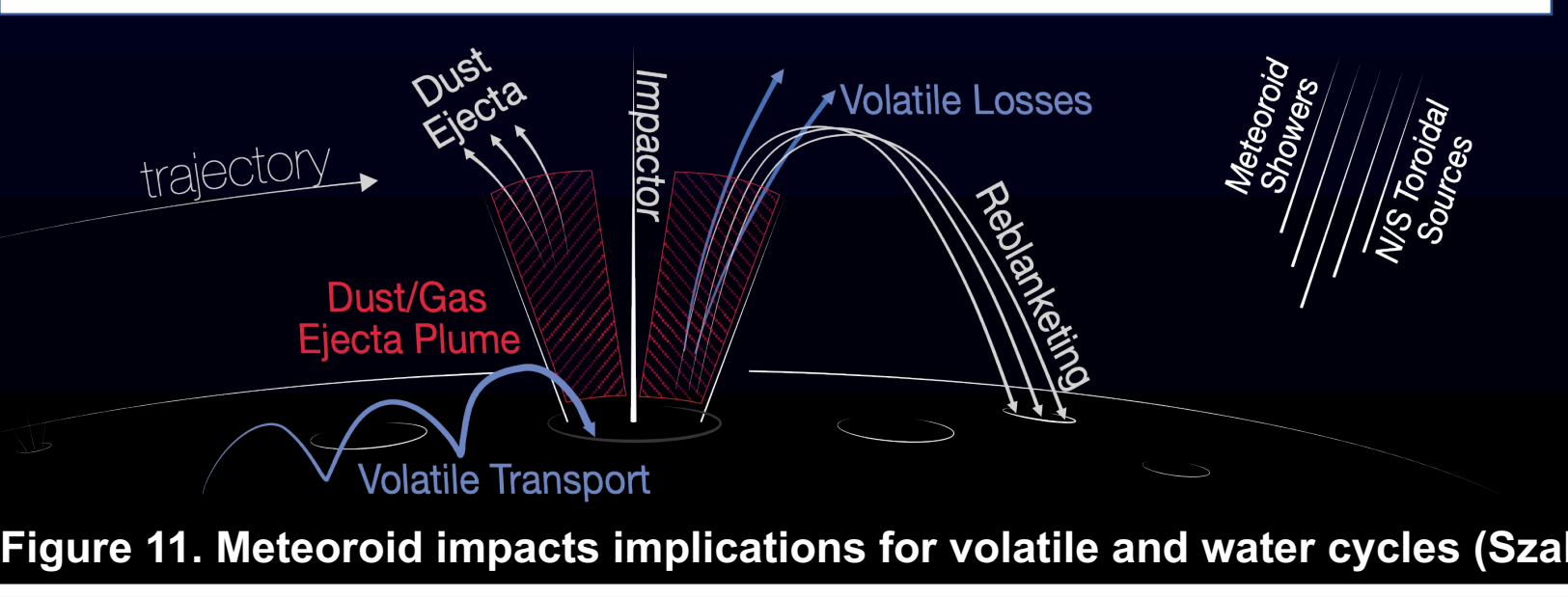

**Figure 11. Meteoroid impacts implications for volatile and water cycles (Szalay).**

## Hazards Characterization

- ➢ **Radiation, surface charging, and dust measured at low lunar altitudes can be used to characterize surface hazards for robots and crew living and working at the lunar surface.**

**Open science questions include:**

- ➢ **How does the lunar surface charge in all plasma environments?**
  - ➢ **What is the magnitude of the lunar surface potential as a function of surface location and solar zenith angle?**
  - ➢ **How does the lunar surface potential depend on the ambient plasma environment?**
  - ➢ **What is the structure of the near-surface plasma sheath? Under what conditions do non-monotonic potentials occur, and what are the implications for surface exploration?**
- ➢ **Determine the ionizing radiation in lunar orbit. What are the energies of solar energetic particles that can penetrate Earth's magnetosphere? What is the influence of lunar proton albedo on the total radiation dose? What is the total radiation dose due to energetic particles? How do high energy electrons vary spatially and temporally within the lunar orbit? How do these particles interact with the lunar surface, in terms of electrostatic charging? How does total radiation dose propagate from LEO to the Moon during a high energy particle event?**