Characterizing the Near-Lunar Plasma Environment

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Motivation

Understanding the near surface plasma environment of the Moon.

Dynamic surface charging processes inferred from Apollo experiments and Lunar Prospector.

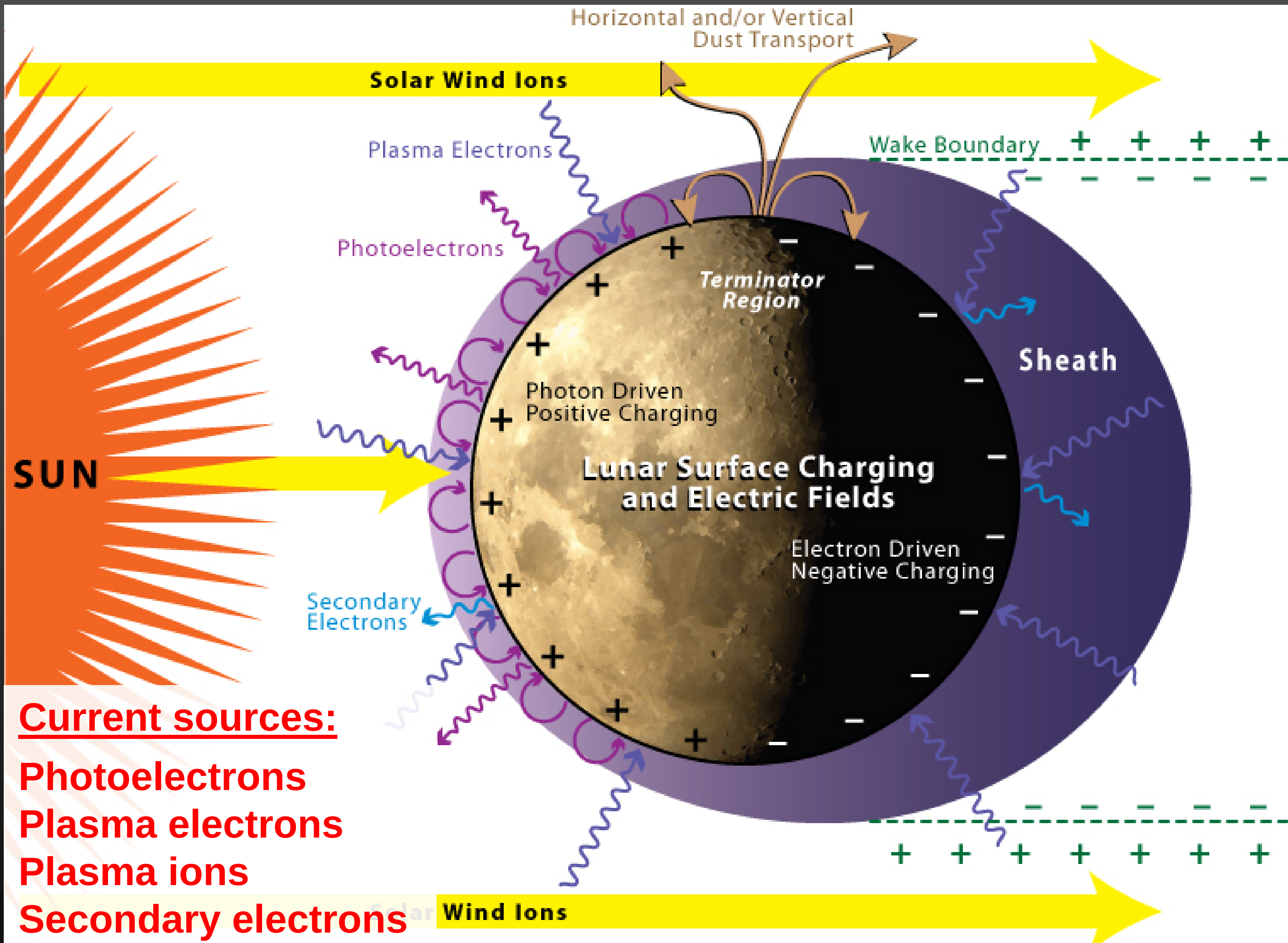
Evidence that surface charging drives the electrostatic transport of dust (< 10 μm).

Fundamental Solar System processes also seen at Saturn’s rings, asteroids (and Mercury).

Differential charging of objects could lead to harmful electrical discharges.

This environment could pose hazards to robotic and human exploration of the Moon.

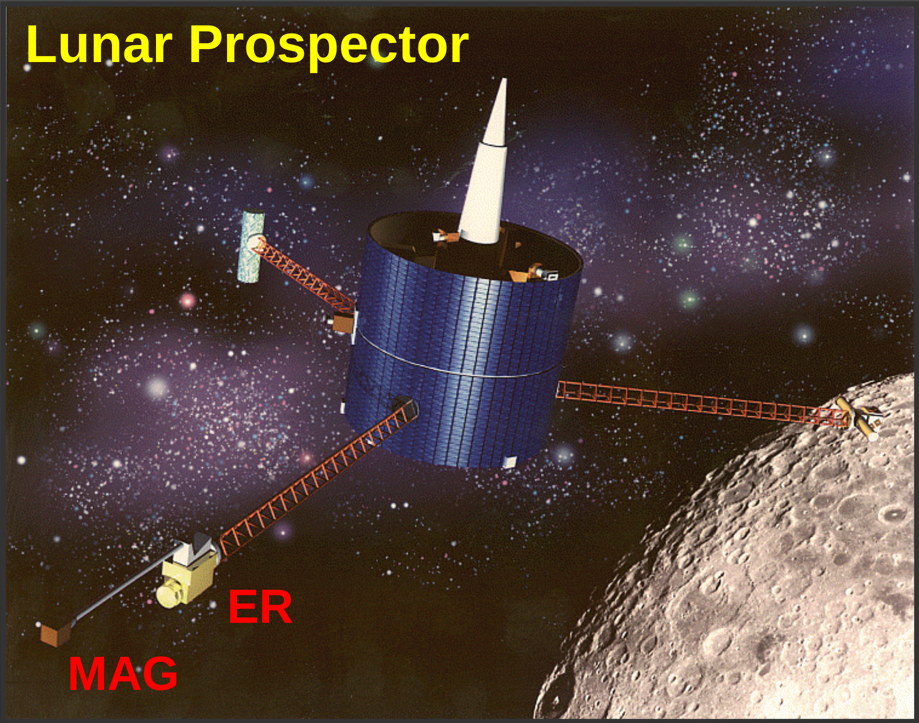
The Lunar Dust-Plasma Environment



Current sources:

- Photoelectrons
- Plasma electrons
- Plasma ions
- Secondary electrons

Recent Progress: Lunar Prospector



Electron Reflectometry

Objective of LP/ER was to map the lunar magnetic anomalies.

However, adiabatically reflected electrons give information about both **magnetic** and **electric** fields at the lunar surface.

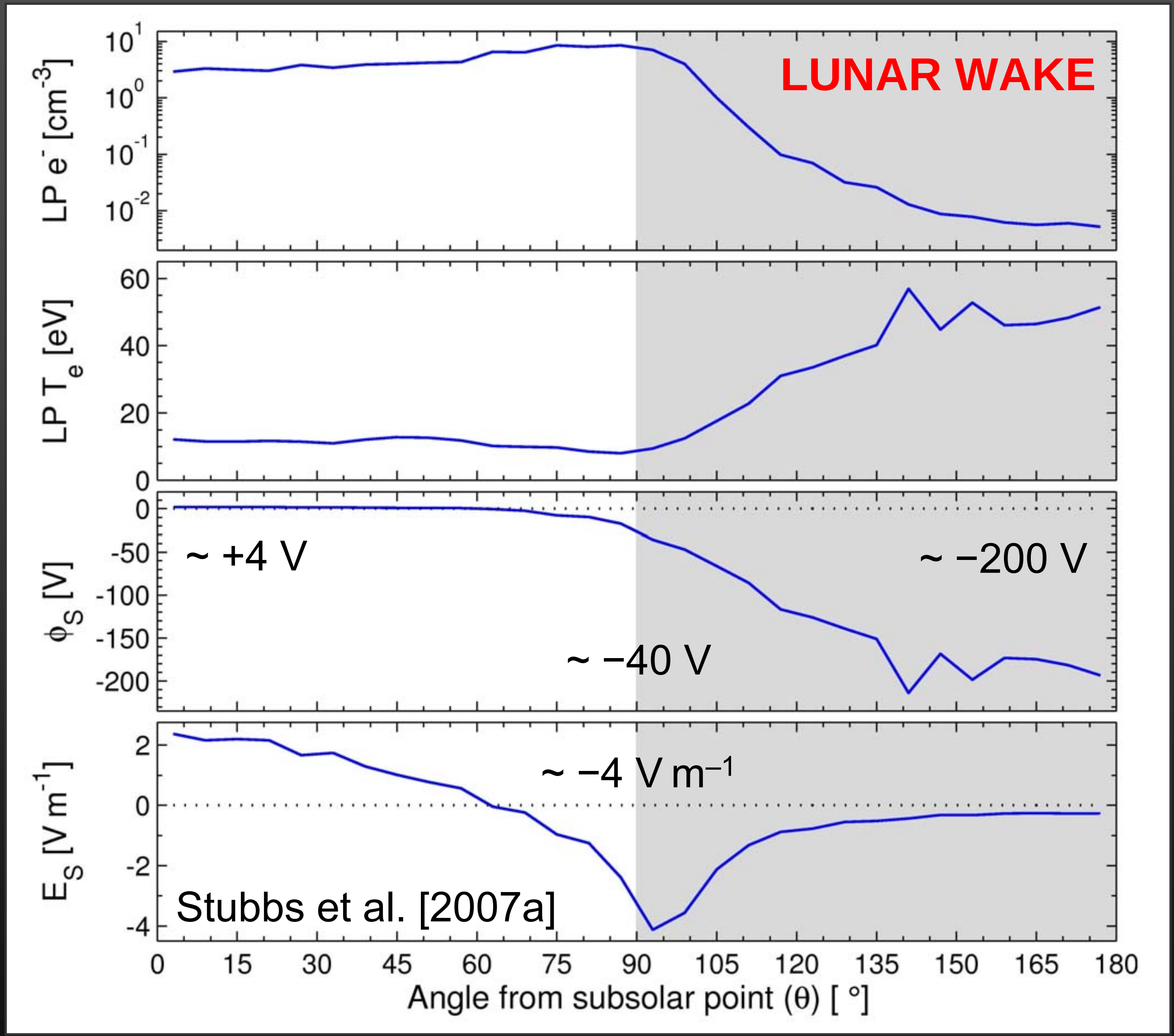
ER: Electron Reflectometer measured 3D distributions (~10 eV – 20 keV).
MAG: Magnetometer.

See Lin et al., Science, [1998] for more details about this experiment.

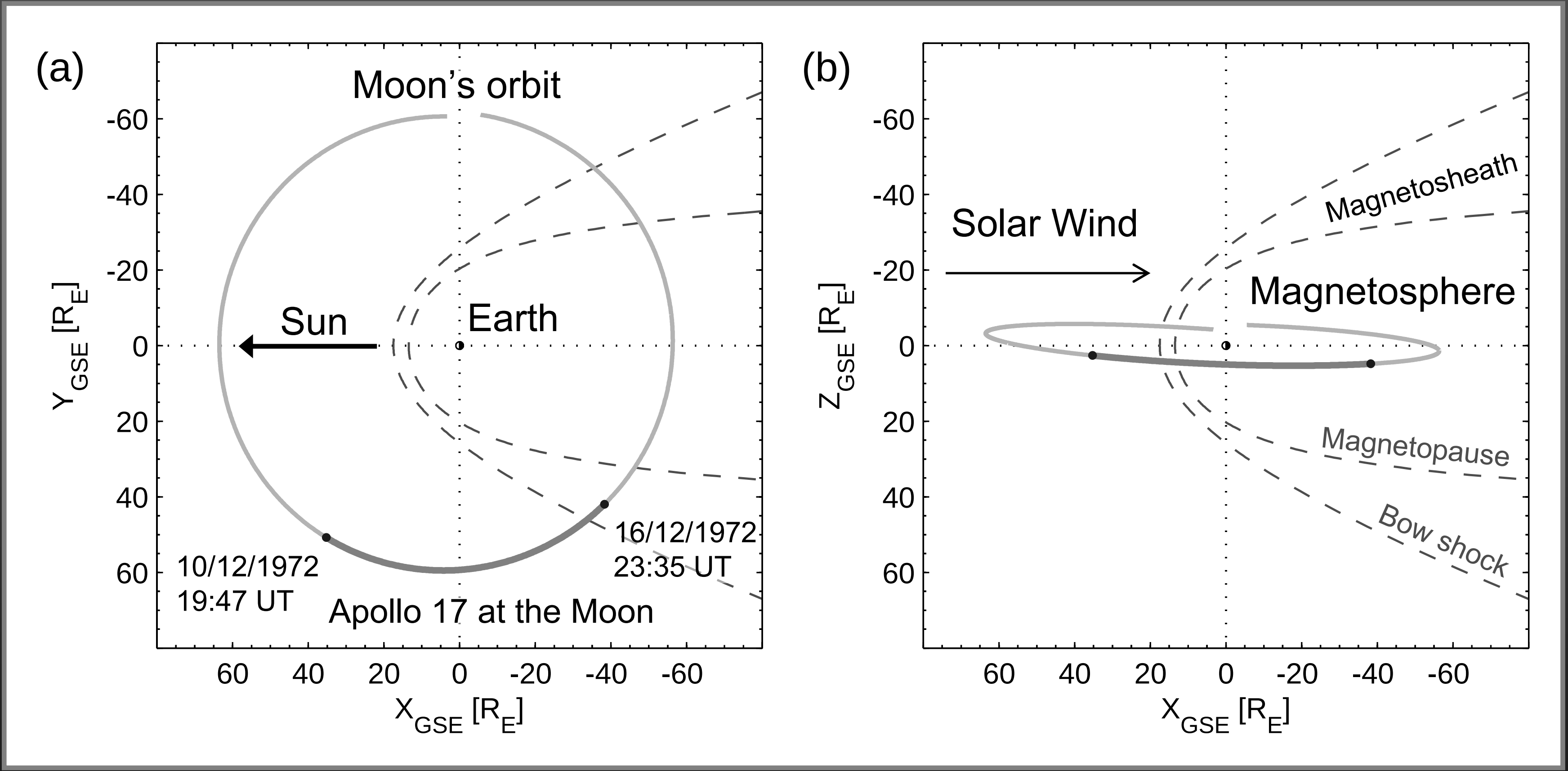
Lunar Surface Charging in the Solar Wind

Lunar Prospector Electron Observation

Surface Charging Predictions



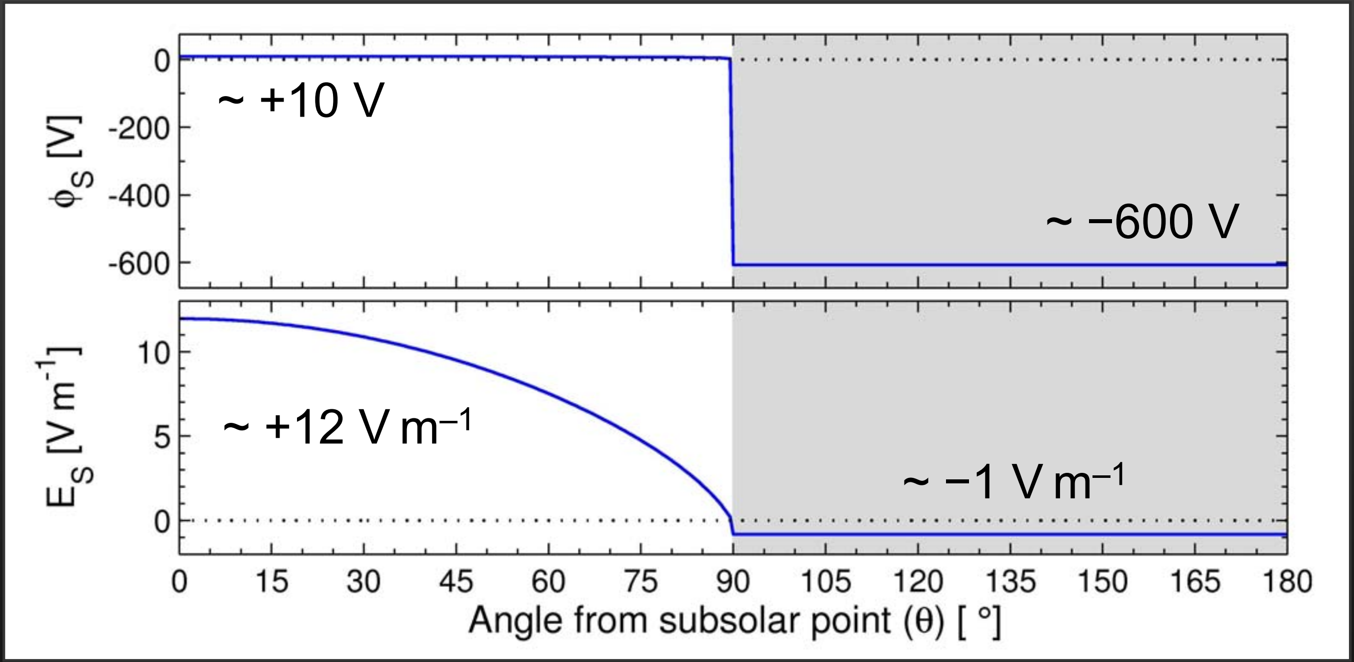
Moon in the Magnetosphere



Stubbs et al. [2007b]

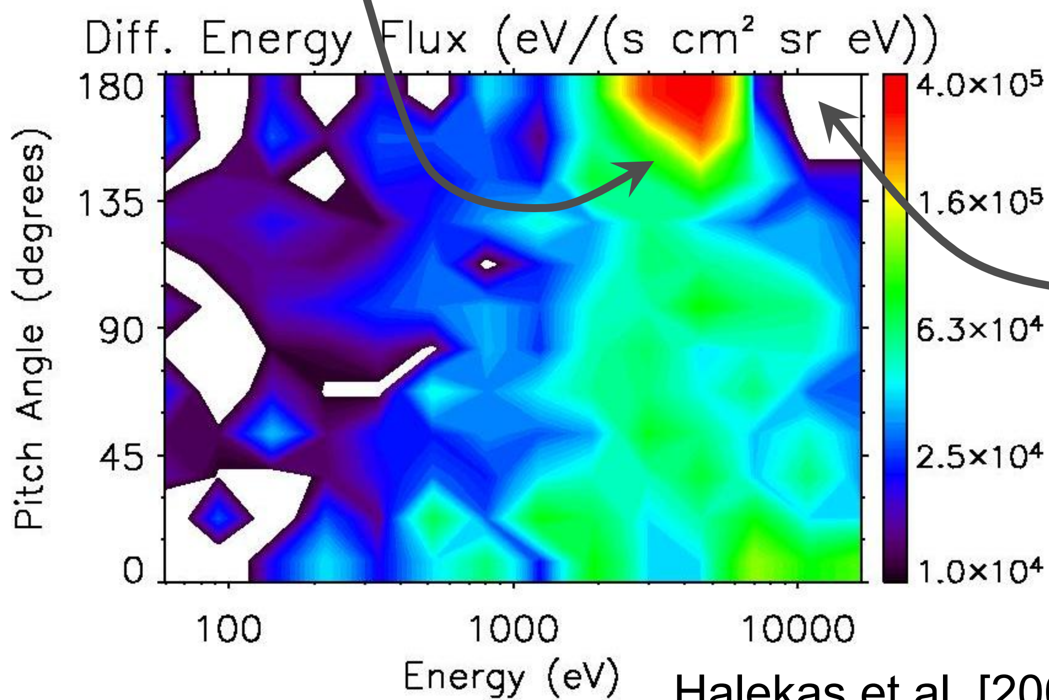
Lunar Surface Charging in the Earth's Magnetospheric Plasma Sheet

The plasma environment in the Earth's plasma sheet is hotter and more tenuous than the solar wind



Direct Observations of Extreme Surface Charging

4 keV beam of secondary electrons accelerated upward by negative surface potential.



Halekas et al. [2007]

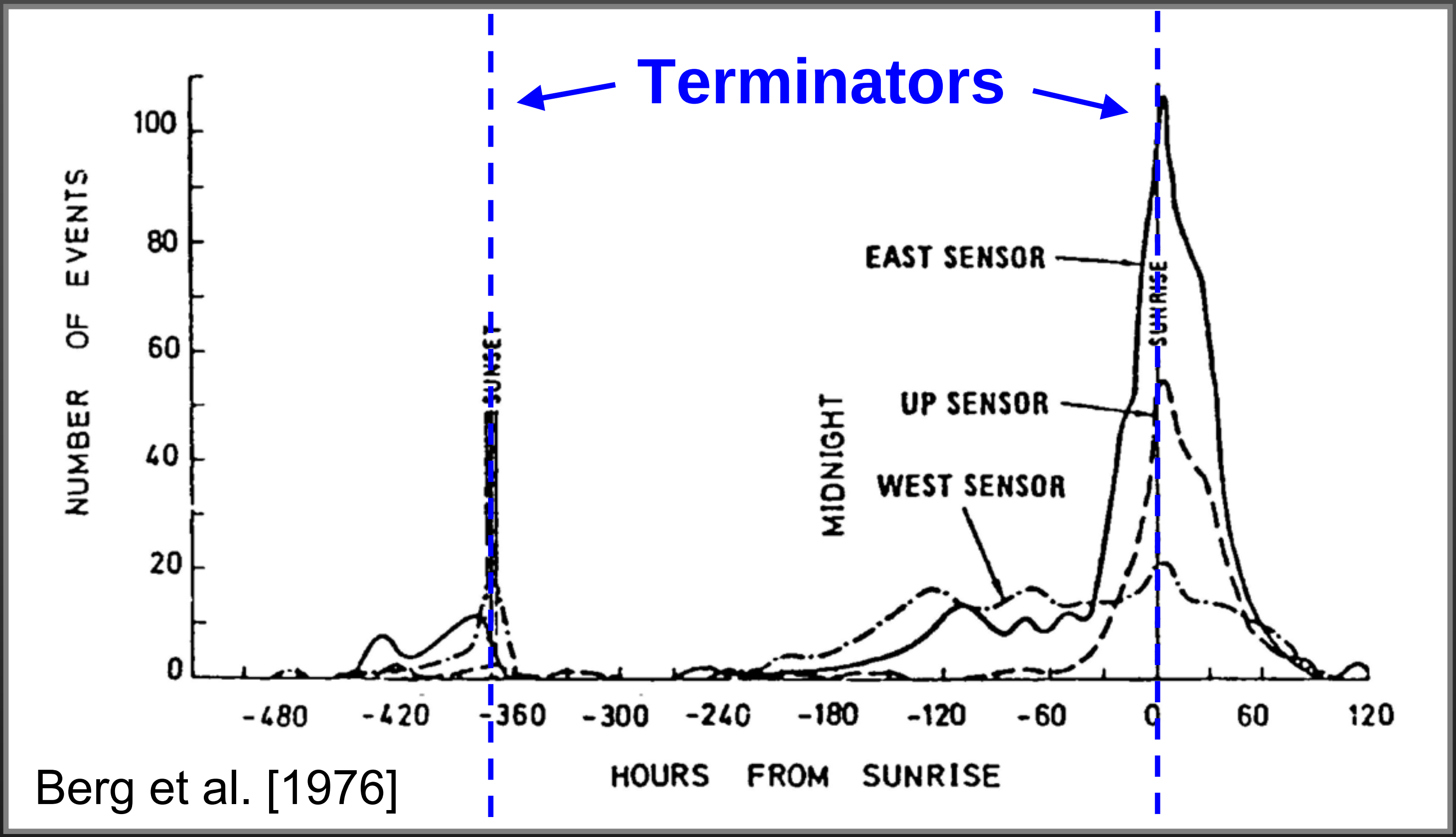
Energy-dependent loss cone indicative of repulsive surface potential.

- High energy electrons hit the surface and are lost
- Low energy electrons are reflected by the potential.

Surface potentials of up to several **kilovolts** (negative) found:

- In the terrestrial plasma sheet (high plasma temperature),
- In the solar wind during Solar Energetic Particle events.

In-Situ Evidence for E-field Driven Dust Transport



Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment.

Some Future Necessary *in-situ* Measurements

Measurement	Instrumentation
Surface electric potentials	E-fields instrument with boom (and ideally a magnetometer)
Plasma characteristics	Electron spectrometers Ion mass spectrometers
Solar Ultraviolet spectrum	Spectrometers and photometers
Dust strikes (dust mass, velocity and charge distributions)	Impact sensor (more sensitive and discriminating than LEAM).
Exospheric dust concentrations	Photometer (passive) LIDAR (active)

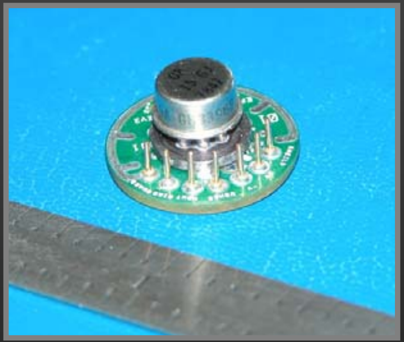
Measurements required on the surface (local) and from orbit (global), preferably at the same time.

Lunar Emissions, Electrons, and Dust (LEED) Surface Instrument

Objectives:

- Identify the processes that create the dusty exosphere.
- Discover the forces that accelerate charged dust near the terminator.
- Detect the charging of astronauts and equipment in this environment.

RF charged dust detection system, similar to techniques used at the planets [Gurnett, 1983].



DC E-field system with heritage from POLAR and Cluster.

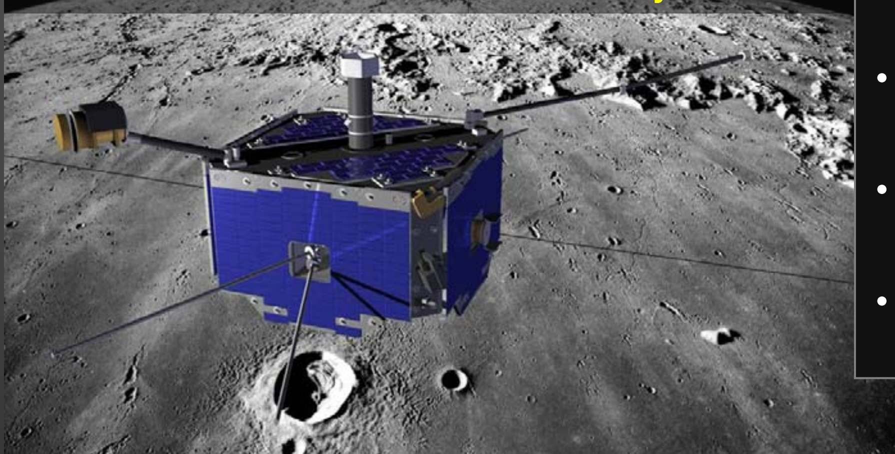
Electron and Ion plasma spectrometers, like those built for Triana.

Patch plate to measure dust adhesion on various materials.

Integrated IDPU to obtain well-correlated high rate data during the most active periods.

Lunar Explorer for Elements And Hazards (LEEAH)

- Magnetic & Electric Fields
- Electron/ion spectra & direction
- Ion composition
- In-situ and remote dust analysis



CUTTING EDGE SCIENCE with PROVEN SYSTEMS

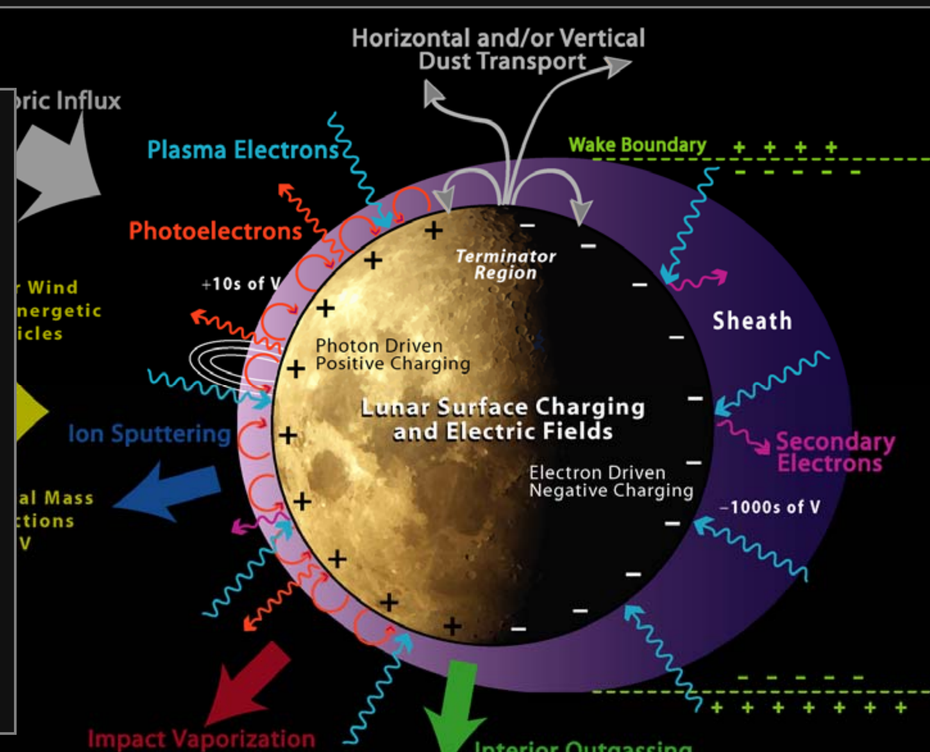
- Finalist for LRO Secondary Payload; funded Phase A development in 2006
- High-heritage instruments and spacecraft (TRL 7-9) from THEMIS & Lunar Prospector
- Science, operations, management teams in place; ~2.25 yr development schedule
- Low cost secondary (<$60M) or primary (<$100M) mission options on EELV, Minotaur, Delta-II

SCIENCE

- Lunar surface charging in response to solar and plasma environment
- Dust transport and dusty plasmas/exosphere
- Map surface composition and volatiles
- Fundamental space plasma physics and lunar-solar interactions

EXPLORATION

- Identify resources, including H_2O
- Quantify dust electrification and motion
- Correlate with environmental drivers for prediction and mitigation



Rationale of Timing with Respect to Lunar Exploration

Early Robotic Phase (<2018)

Acquire crucial measurements of the natural plasma environment from orbit and strategic locations on the surface.

Experiments like LEED and missions such as LEEAH should be a priority during this phase.

Early Human Phase (2018 – 2025)

Increase the monitoring of this environment with the greater resources able to be placed on the Moon during this phase.

In particular, study the impact of surface operations, such as ISRU, that will result in the formation of a modified plasma environment.

Beyond (>2025)

Deploy large-scale surface network and develop accurate predictive capability (analogous to weather forecasting on the Earth).

Each station in the network could carry a multi-disciplinary payload (e.g., E-field booms, dust sensors, seismometers, etc).

Summary and Conclusions

There is **much compelling evidence** for a dynamic lunar plasma environment from previous observations.

Fundamental Solar System process.

Understanding how astronauts and equipment couple to the lunar plasma environment is crucial in order to assess risks associated with **electrical discharges**.

Surface charging processes drive the transport of charged lunar dust – a recognized nuisance and potential **hazard for future explorers**.

Require **targeted observations** of this environment as soon as possible, in order to develop **effective discharge and dust mitigation strategies** for robotic and human exploration.