Considerations for Investigating the Moon's Plasma and Dust Environment with the Russian LUNA Landers

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Landing Site Selection for LUNA-GLOB Mission
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Motivation and Objectives

<u>LUNA science goal</u>: Investigate interaction between cosmic plasmas and the Moon's surface, and exospheric processes at the lunar poles.

<u>LUNA measurements</u>: Ions and dust.

Recommendations for landing site selections, instrument placement, and data analysis.

Opportunities to learn from other missions, and leverage on-going research in order to maximize science return; e.g., collaboration with NLSI/DREAM.

Observational and Theoretical Work Relevant to the LUNA Missions

We draw attention to some of the research relevant to the LUNA ion and dust measurements. **NOT exhaustive!**

We point out where this can inform some of the important decisions that need to be made.

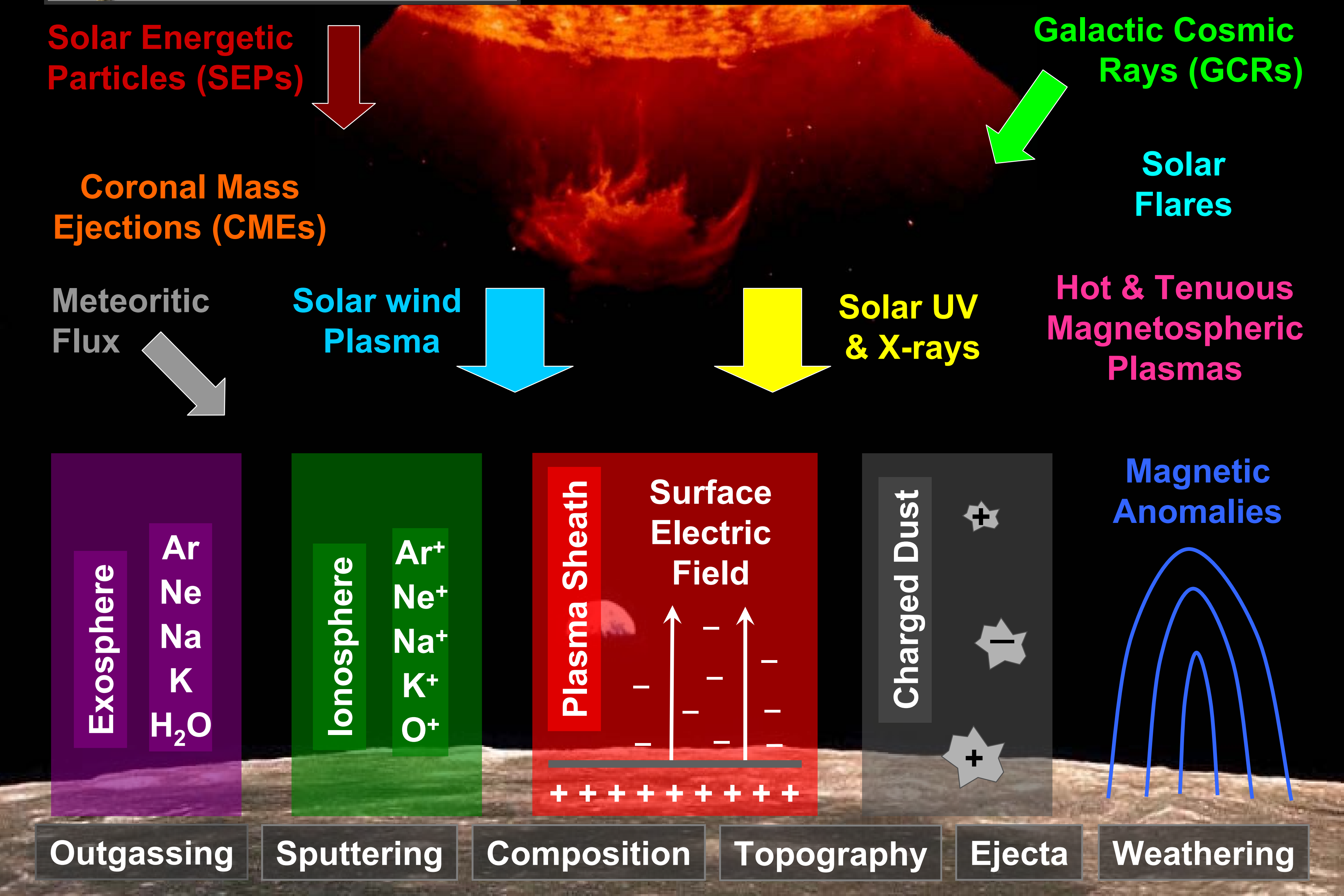
We highlight recent work done by the **D**ynamic **R**esponse of the **E**nvironment **A**t the **M**oon (**DREAM**) team, which is part of the NASA Lunar Science Institute (**NLSI**).

The DREAM Team aim to understand how the many dynamic elements of the lunar environment couple with each other.

This is primarily being accomplished by data analysis and theoretical investigations, including numerical simulations.

Therefore, the DREAM Team investigations are highly relevant to the LUNA missions.

Dynamically Coupled System



The Lunar Plasma Environment

Lunar surface electrically charged by:

- Solar Ultraviolet
- Plasma electrons & ions
- Secondary emission.

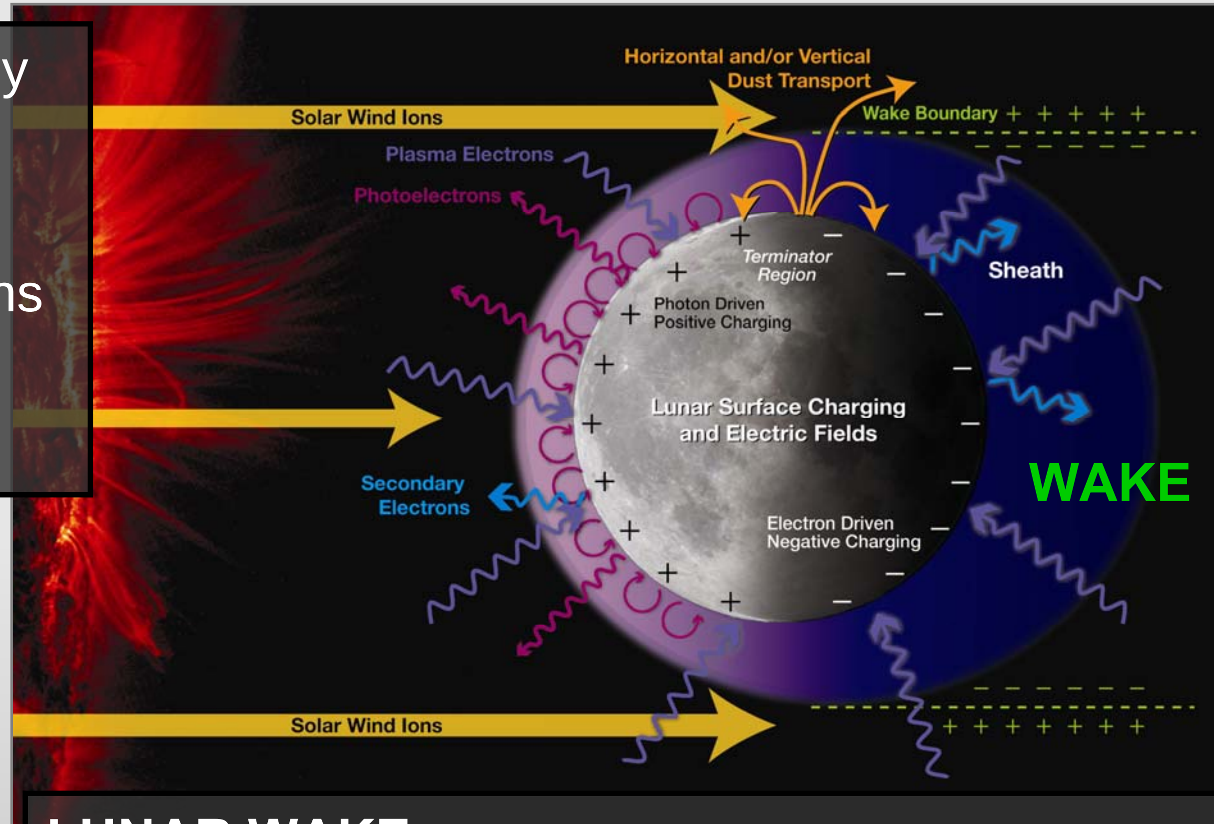
<u>Electron dominated</u>.

DAYSIDE:

Positively charged by photo-emission of electrons by solar UV.

NIGHTSIDE:

Negatively charged by collection of plasma electrons.



LUNAR WAKE:

In the solar wind a void, or “wake”, is formed downstream of the Moon.

The infilling of this wake is led by the more mobile electrons, thus forming an ambipolar electric field that draws in the ions.

Detecting Ions and Neutrals with LUNA

The LINA and ARIES instruments will detect ions and neutrals from the solar wind and lunar exosphere/ionosphere.

Best placement: topside of the landers with an unobstructed field-of-view.

Invaluable for determining ion and neutral sources, dynamics and their interaction with the surface at the lunar poles.

LINA: Detects ions and neutrals

Ion mass < 40 amu, & energies: 10 eV–15 keV.

Neutral mass 1–56 amu, & energies: 10 eV–3.2 keV.

ARIES: Panoramic energy-mass spectrometer of ions

Ion mass 1–100 amu, & energies: 3 eV–5 keV.

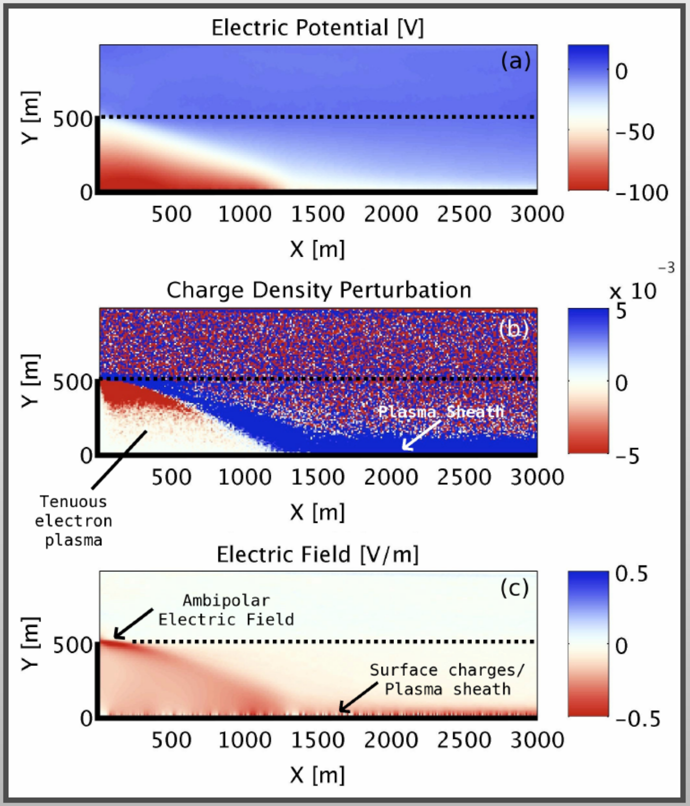
Wake and Surface Charging Processes

Wake and surface charging processes tend to be **dominated by electrons** – since they are more mobile than the heavier ions – so LINA and ARIES ion observations will need to be combined with simulations in order to understand these phenomena. For example, looking for signatures of ion deflection into the wake.

Topographic effects: "Mini-wakes" are expected to form downstream of large obstacles such as craters, basins and mountains [Farrell et al., 2007; 2010].

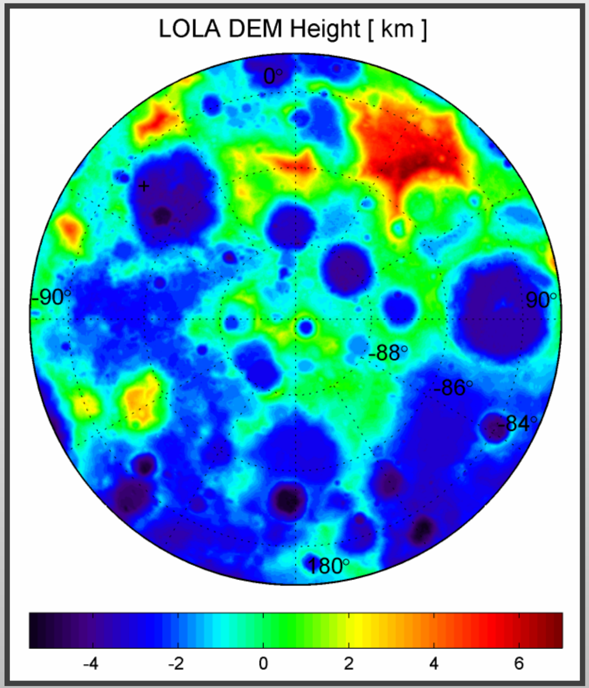
Right: 2D kinetic **particle-in-cell** (PIC) simulation of the plasma expansion in a mini-wake [Zimmerman et al., 2011].

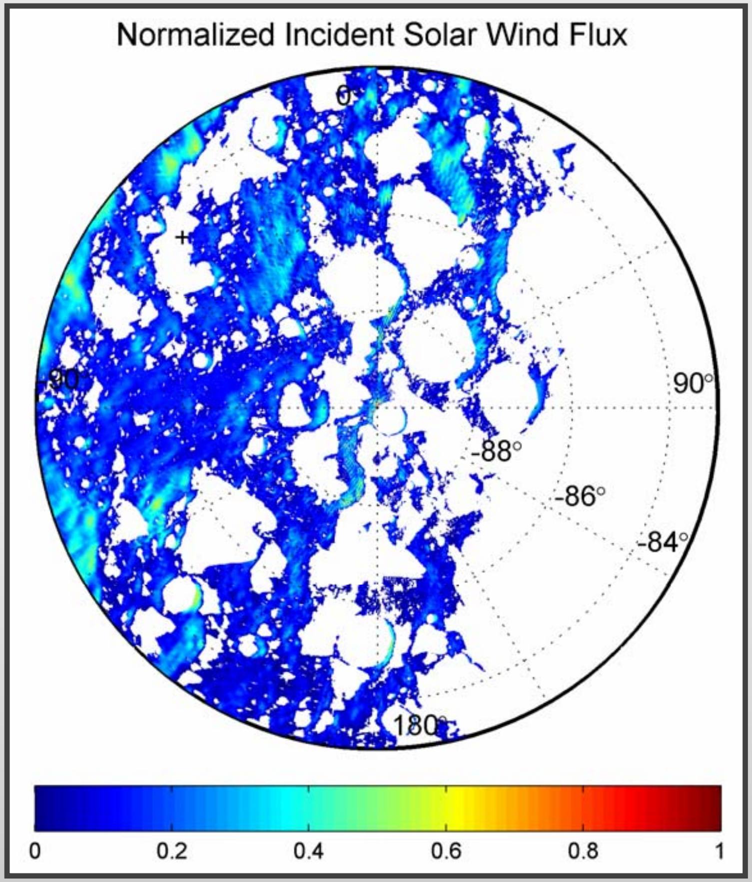
LRO Lunar Orbiter Laser Altimeter (LOLA) data can be used to make predictions for specific locations on the Moon, especially in the polar regions [Stubbs et al., 2010].



Lunar Surface Exposure to Solar Wind Ions

Use LRO/LOLA digital elevation models (DEM) to predict plasma access to the lunar surface. South pole DEM shown below.

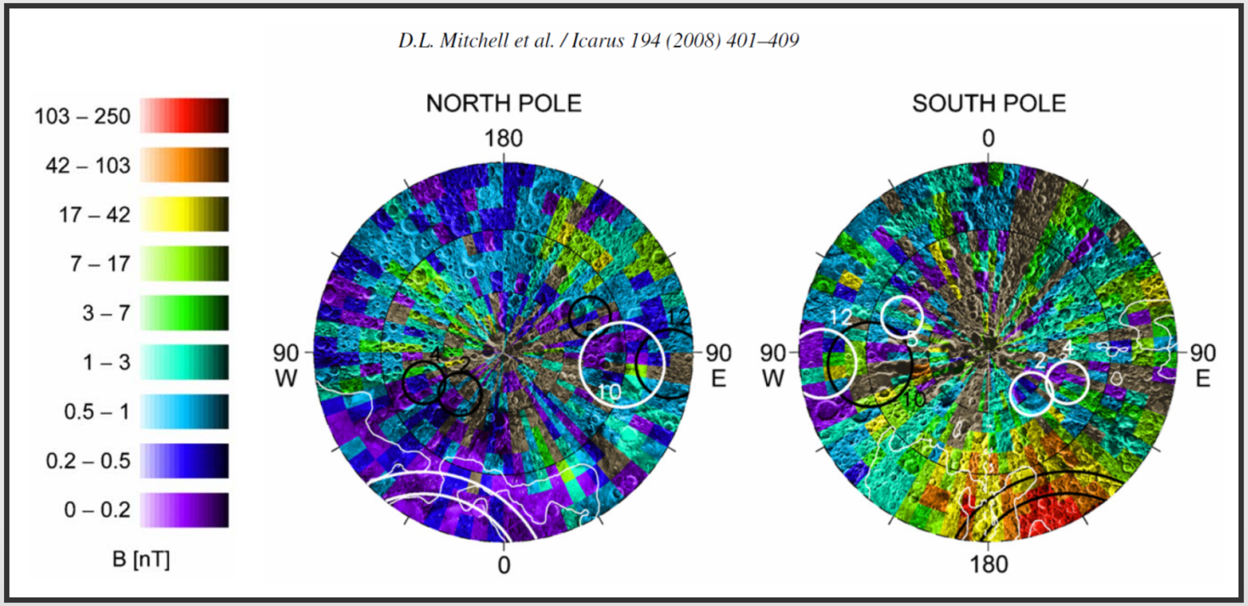




Example: Flux of solar wind ions with “direct access” – i.e., not processed by the wake – to the surface during LCROSS impact [Stubbs et al., 2010].

Plasma Interaction with Magnetic Anomalies

Remanent crustal magnetic fields (anomalies) on the Moon can significantly affect how plasma interacts with the surface [e.g., Wieser et al., 2010].



Lunar Prospector measurements (above) indicate that there are **no significant anomalies** (> ~40 nT) on 10 km-scales **within ≈15° of either pole** [Mitchell et al., 2008].

Although there could be significant anomalies on <10 km-scales, the LUNA missions will be limited in their ability to study the effects of magnetic anomalies.

However, this will permit a more straightforward investigation of the plasma interaction with an unmagnetized dielectric body.

Detecting Exospheric Dust with LUNA

Based on the instrument specifications presented by Mitrofanov et al. [2010], we believe that the **TV camera**, **UV-Optical Spectrometer-Imager**, and the **LIS**, as well as the **PmL dust detector**, could detect evidence for exospheric dust.

Given the right circumstances, the LUNA imagers and spectrometers could observe sunlight scattered by exospheric dust, which is commonly referred to as **"lunar horizon glow" or LHG**.

UV-Optical Spectrometer-Imager

Includes 9 narrow spectral bands from 278–1052 nm.

Lunar IR Spectrometer (LIS)

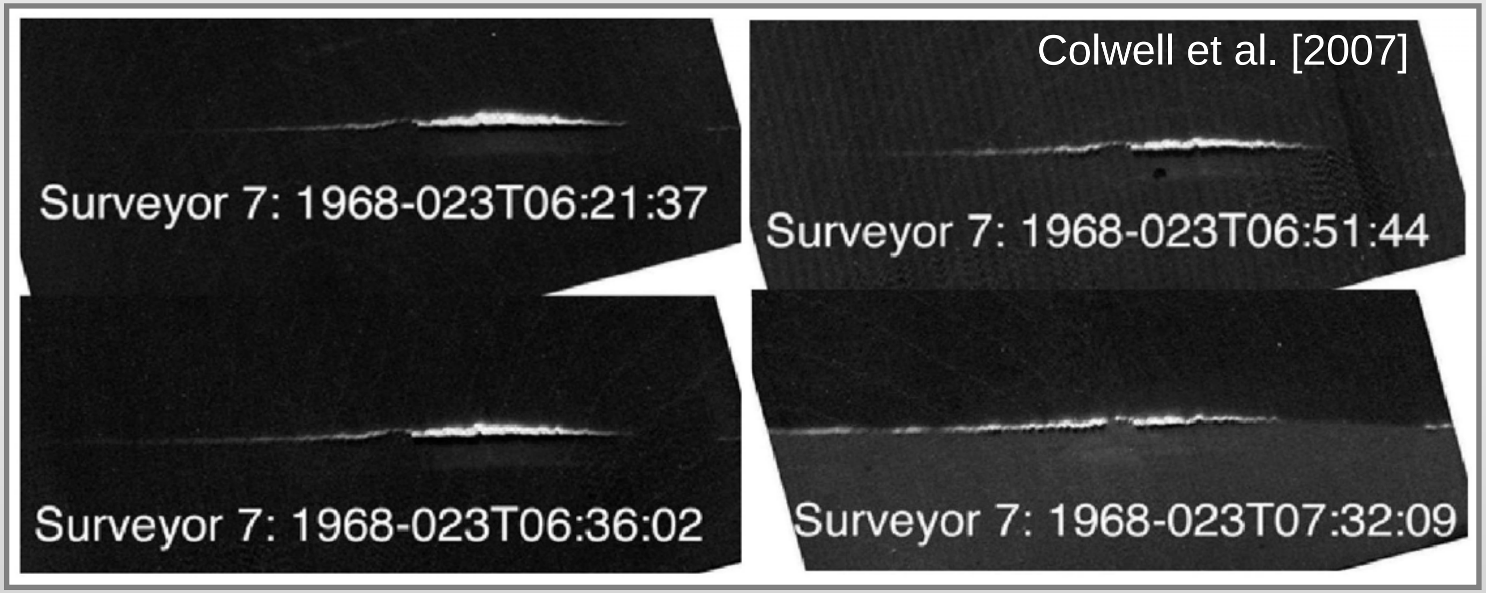
Range: 1400–3500 nm.
Resolution: 15–25 nm.

PmL Dust Detector

Measure dust impact impulse and charge.

Lunar Horizon Glow Observed Near the Surface

The TV cameras aboard Surveyor 5, 6, 7, and possibly 1, observed a persistent glow along the western horizon after sunset.



Believed to be caused by forward scattered sunlight due to dust grains with radii of **≈5 μm** at ≈ **10 to 30 cm** from the surface.

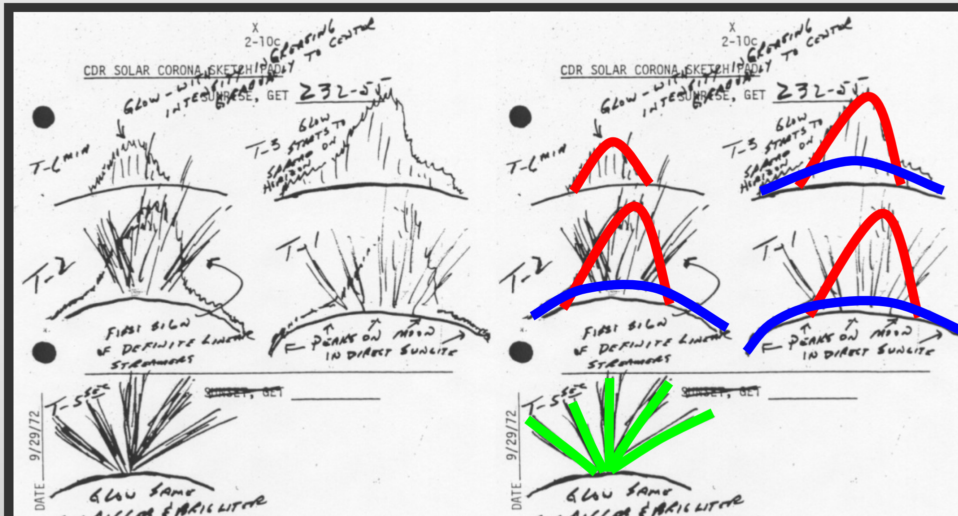
Near-surface LHG was **~10^7 too bright** to be explained by micro-meteoroid-generated ejecta, so electrostatic “levitation” was proposed to explain this phenomenon [e.g., Rennilson and Criswell, 1974].

Lunar Horizon Glow Observed at High Altitudes

LHG at altitudes in excess of 100 km was observed by Apollo astronauts (see sketch) [McCoy and Criswell, 1974; Zook & McCoy, 1991] and in coronal photographs [McCoy, 1976; Glenar et al., 2011]. Believed to be produced by **0.1 μm-scale** exospheric dust.

Also observed from the surface by the astrophotometer aboard Lunokhod-II, which discovered a brighter than expected lunar twilight sky [Severny et al., 1975].

Repeating these kinds of observations with modern instrumentation (and extra wavelength information) could significantly improve our understanding of lunar exospheric dust.



Sketches of sunrise with "horizon glow" and "streamers" viewed from lunar orbit during Apollo 17. Highlighted are: **Coronal and Zodiacal Light (CZL)**; **and possibly** **Lunar Horizon Glow (LHG) due to exospheric dust**; and **"crepuscular rays" formed by shadowing and scattered light.**

LADEE LHG Predictions

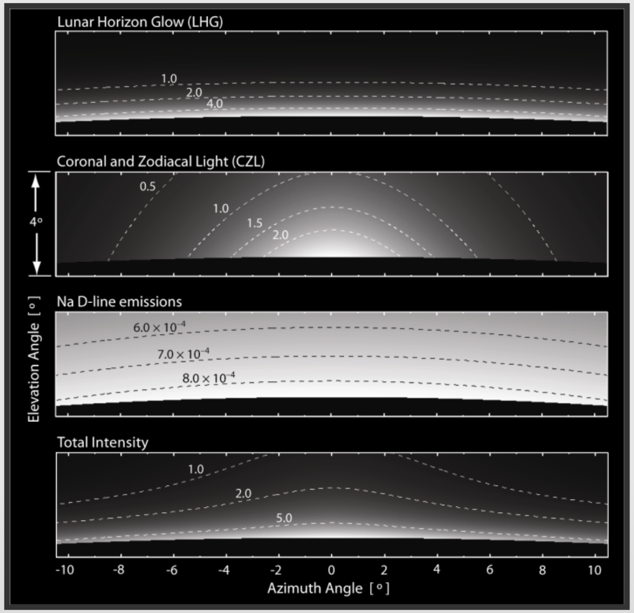
Based on previous LHG observations, Stubbs et al. [2010] used the NMSU light scattering code to make predictions for the Ultraviolet Spectrometer (UVS) and star tracker cameras on the Lunar Atmosphere and Dust Environment Explorer (LADEE).

LADEE will be looking toward sunrise from within lunar shadow in order to detect forward scattered sunlight from dust and exospheric emission lines (brightest from sodium D-lines).

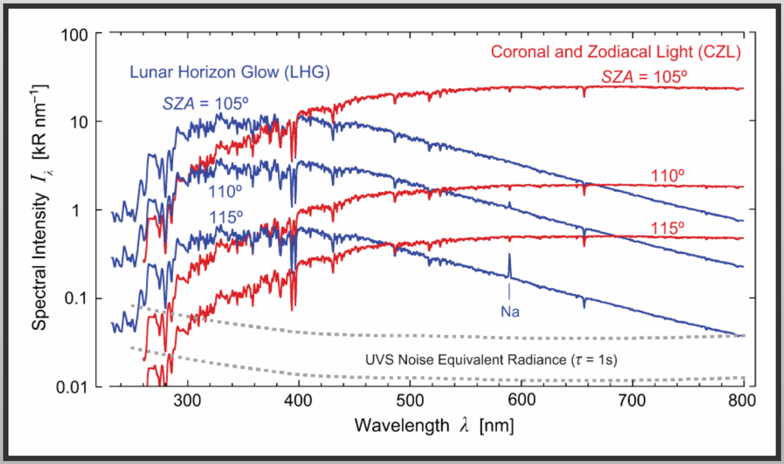
These predictions indicated that LADEE would readily distinguish LHG from the bright CZL background, and exospheric sodium.

This code could be adapted to make predictions for imagers and spectro-meters aboard the LUNA landers.

Star tracker predictions



UVS predictions



Possible Direct Detection of Exospheric Dust

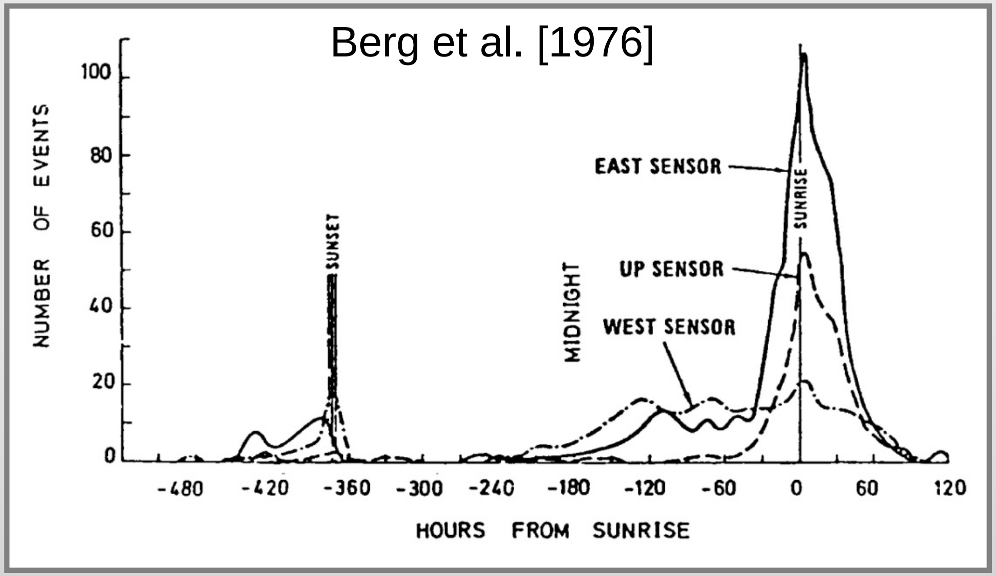
The Lunar Ejecta And Meteorite (**LEAM**) experiment was deployed on the lunar surface by Apollo 17 to detect hypervelocity (~10 km/s) meteoritic impacts at an expected rate of a few per day.

However, the LEAM measurements appeared to be **dominated by dust of lunar origin**:

- With high fluxes (up to ≈100/day)

-That was highly charged ($Q > 10^{-12}$ C)

- Relatively slow-moving (~<100–1000 m/s)



3 LEAM sensors facing UP, EAST & WEST.

LEAM data indicated a net movement of dust from day-to-night.

The highest count rates were measured by the EAST sensor around sunrise.

Preliminary Assessment of PmL Dust Detector

Anticipated instrument specifications: charge sensitivity $\approx 10^{-12}$ C ($\approx 6.25 \times 10^6\ e^-$); impulse accuracy $\approx 10^{-14}$–10^{-12} N s (also assumed to be impulse sensitivity threshold). Predicted sensitivity thresholds in the table below assume spherical grains with a density of 2500 kg m^{-3}.

Dust radius [μm]	**0.1**	**1.0**	**10.0**	**100.0**	**1000.0**
Dust mass [g]	1.1×10^{-14}	1.1×10^{-11}	1.1×10^{-8}	1.1×10^{-5}	0.011
Dust potential threshold [V]	9.0×10^4	9.0×10^3	9.0×10^2	90.0	9.0
Velocity threshold [m s^{-1}] (upper limit: 10^{-12} N s)	9.6×10^4	96.0	9.6×10^{-2}	9.6×10^{-5}	9.6×10^{-8}
Velocity threshold [m s^{-1}] (lower limit: 10^{-14} N s)	960	0.96	9.6×10^{-4}	9.6×10^{-7}	9.6×10^{-10}

Green: These potentials are unphysical (limited by field emission to ~1–100 V), so the charge on dust <100 μm would be undetectable.

Sensitive to impacts from lunar and interplanetary dust >0.1 μm.

Red: Velocity threshold exceeds lunar escape velocity (2.38 km s^{-1}), which means the detector would be limited in its ability to measure ejecta <0.1 μm, if impulse sensitivity ~10^{-12} N s.

Suggestions for Dust Detector Configuration

Since the PmL dust detector has just one sensor, great care needs to be taken to optimize its orientation and placement on the landers.

ORIENTATION: Tilted 45° from zenith and facing EAST.

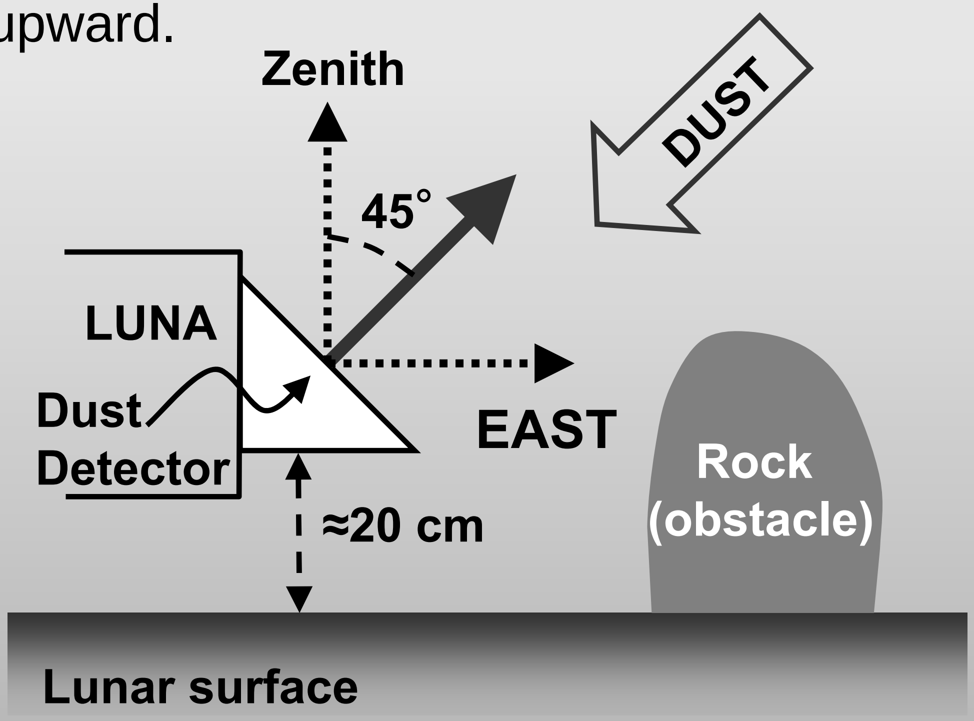
The LEAM experiment measured the highest fluxes with its EAST and UP facing sensors, so both of these directions are accommodated.

Also, the risk of the detector being blocked by a nearby boulder is mitigated by tilting upward.

HEIGHT: About 20 cm from the surface.

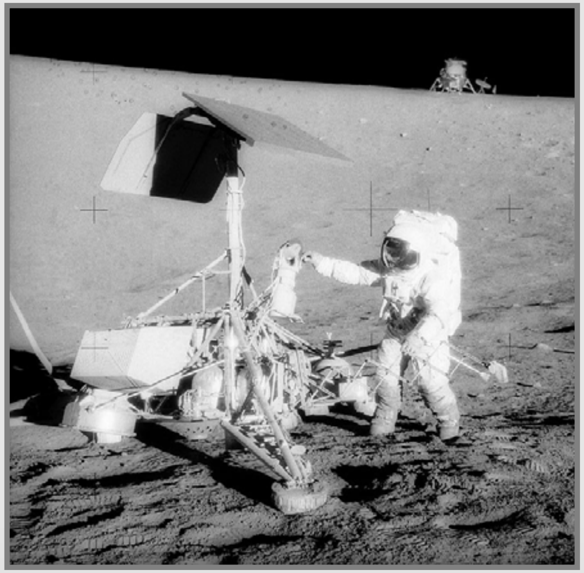
The LEAM EAST and WEST sensors were ≈20 cm above the surface.

The horizon glow observed by Surveyor is believed to be caused by dust ≈10–30 cm above the surface.



Dust Contamination: Lessons from Surveyor 3

Figures from Mandeville and Lem [1972]



Pete Conrad (Cmdr Apollo 12) collecting parts from Surveyor 3.

Areas of Surveyor 3 facing Apollo 12 as it landed nearby were effectively “sandblasted clean” by dust kicked up by its thrusters.

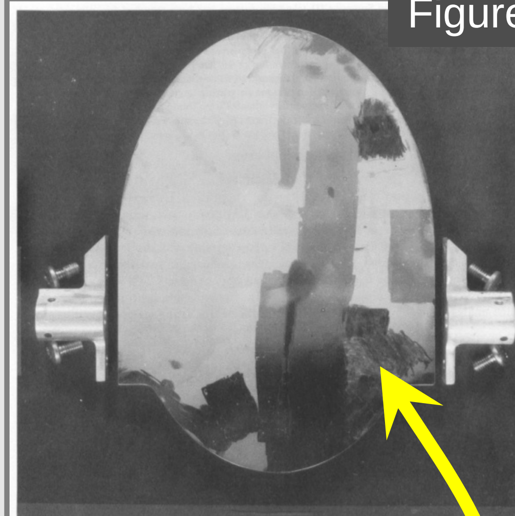


Fig. 1. Surveyor III television mirror and dismantled aluminum trunnions, showing are stripped and rubbed free of contaminating dust.

The TV mirror was protected from this sandblasting.

“areas stripped and rubbed free of contaminating dust” by the astronauts and subsequent analyses.

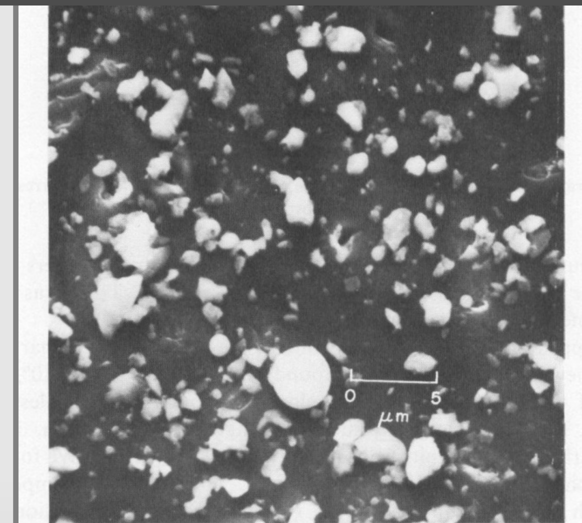


Fig. 2. Lunar dust on the television mirror in an untouched region.

Dust, a few microns and less in diameter, adhering to the TV mirror.

Much of this adhering dust was likely kicked-up by the descent engines during landing.

IMPORTANT TO BEAR IN MIND FOR LUNA …

Summary and Conclusions

CAVEAT: Previous observations of ions and dust at the lunar surface have **only been made near the equator**.

In particular, there is **no reason to believe that exospheric dust abundances will be similar around the poles**, especially if meteoritic impacts play a significant role in producing the dust that creates LHG, as suggested by Glenar et al. [2011].

The LUNA landers promise to provide an exciting set of complementary observations of the **unexplored** plasma and dust environments at the lunar poles.

The science return could be **significantly enhanced** by leveraging on-going research, e.g., by the NLSI/DREAM Team!

Comments and questions welcomed:

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