A Comparison between Surface Charging and Dust Transport Processes at the Moon and Mercury

Tim Stubbs


University of Maryland, Baltimore County
NASA Goddard Space Flight Center
NASA Lunar Science Institute
Motivations and Objectives

COMPARATIVE PLANETOLOGY: Like the Moon, the surface of Mercury is exposed to various plasma populations, as well as solar UV radiation, and becomes electrically charged.

Evidence from the Apollo era suggests that a greater abundance of dust can exist in the lunar exosphere than can be explained by meteoritic ejecta alone.

“Lunar horizon glow” (LHG) believed to be caused by sunlight scattering from exospheric dust was observed near the surface and at high altitudes. It has been proposed that these dust populations were electrostatically transported.

Predict surface potentials and electric fields at Mercury’s surface for various plasma environments.

Suggest how to search for exospheric dust at Mercury with MESSENGER, based on strategies being considered for the Moon with LADEE UVS.
The Lunar Plasma (and Dust) Environment

Figure from “Heliophysics Science and the Moon” report from the NAC
Mercury’s Magnetosphere & Plasma Environment

Mariner 10 and MESSENGER: global-scale dipolar magnetic field and a dynamic magnetosphere.

This significantly modifies the plasma environment at the planetary surface.

Mercury’s magnetosphere is somewhat Earth-like with a plasma sheet and lobes in the tail and cusps at the dayside.

Slavin [2004]
Lunar Surface Charging in the Solar Wind

Simple charging model: photoemission, plasma electron and ion currents. Solar wind electrons are “typically cool”, so can ignore secondaries.

Non-Maxwellian: Electrons heated in the wake by infilling process.

Find equilibrium potential $\phi_{eq}$ – net current is zero.

E-field sweet spot at the terminator.

Stubbs et al. [2007]
Direct Observations of Lunar Surface Charging

(Extreme Case)

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

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.

Halekas et al. [2007]

It’s not possible to make similar measurements with MESSENGER because of the energy range of the electrons involved ... may be possible with BepiColombo, depending on the orbit altitude.
A Comparison Between Lunar Surface Charging in the Solar Wind and Magnetotail

Typical plasma conditions – ISEE-3 electron data [Slavin et al., 1985].

<table>
<thead>
<tr>
<th>Condition</th>
<th>$n$ [cm$^{-3}$]</th>
<th>$T_e$ [eV (K)]</th>
<th>$T_i$ [eV (K)]</th>
<th>$V$ [km s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow solar wind</td>
<td>10</td>
<td>12.1 (1.4 x 10$^5$)</td>
<td>8.6 (1.0 x 10$^5$)</td>
<td>-400</td>
</tr>
<tr>
<td>Tail lobes</td>
<td>0.02</td>
<td>86 (1.0 x 10$^6$)</td>
<td>86 (1.0 x 10$^6$)$^*$</td>
<td>-170</td>
</tr>
<tr>
<td>Plasma sheet</td>
<td>0.2</td>
<td>216 (2.5 x 10$^6$)</td>
<td>1577 (1.83 x 10$^7$)$^#$</td>
<td>-100</td>
</tr>
</tbody>
</table>

Assumptions: $^*$ $T_i = T_e$ and $^#$ $T_i = 7.3T_e$.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dayside $\phi_S$</th>
<th>Nightside $\phi_S$</th>
<th>Electron current $J_{e0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow solar wind</td>
<td>~ +4 V</td>
<td>~ -50 V</td>
<td>~ 1.0 μA m$^{-2}$</td>
</tr>
<tr>
<td>Tail lobes</td>
<td>~ +10 V</td>
<td>~ -325 V</td>
<td>~ 10$^{-2}$ μA m$^{-2}$</td>
</tr>
<tr>
<td>Plasma sheet</td>
<td>~ +6 V</td>
<td>~ -600 V</td>
<td>~ 10$^{-1}$ μA m$^{-2}$</td>
</tr>
</tbody>
</table>

**Dayside** – photoemission dominates plasma electron currents

**Nightside** – plasma electron currents (Temperature) dominate.
Surface Charging at Mercury

Mariner 10 observations [Ogilvie et al., 1977]
- **Cool plasma sheet**: $n_e \sim 5 \text{ cm}^{-3}$ and $T_e \sim 200 \text{ eV}$
- **Hot plasma sheet**: $n_e \sim 1 \text{ cm}^{-3}$ and $T_e \sim 1000 \text{ eV}$.

Hot electrons – secondary emission could be important.

Use the Sternglass [1954] relation with $E_M = 400 \text{ eV}$, $\delta_M = 1.5$ & $T_s = 3 \text{ eV}$ [Willis et al., 1973].

**Cool Plasma Sheet**

Currents:
- $J_{ph} = \text{photoemission of electrons}$;
- $J_e = \text{plasma electrons}$;
- $J_i = \text{plasma ions}$;
- $J_s = \text{secondary electrons}$;
- $J_{total} = \text{total}$.
Importance of Secondary Electron Currents

Cold plasma sheet:

- If $$J_{\text{sec}}$$ is included, then $$\phi_{eq} \approx +4.2 \text{ V}$$.
- If $$J_{\text{sec}}$$ is NOT included, then $$\phi_{eq} \approx +3.5 \text{ V}$$.

Difference is relatively small, so $$J_{\text{sec}}$$ is NOT dominant.

The value of $$\phi_{eq}$$ is typically dominated by $$J_{\text{ph}}$$ and $$J_e$$.

Cold plasma sheet:

- If $$J_{\text{sec}}$$ is included, then $$\phi_{eq} \approx +1.0 \text{ V}$$.
- If $$J_{\text{sec}}$$ is NOT included, then $$\phi_{eq} \approx -750 \text{ V}$$.

Difference is HUGE, so $$J_{\text{sec}}$$ is a dominant current.

Hot plasma sheet:

- If you include $$J_{\text{sec}}$$, then $$\phi_{eq} \approx -2170 \text{ V}$$.
- If you do not include $$J_{\text{sec}}$$, then $$\phi_{eq} \approx -3750 \text{ V}$$.

Again, difference is HUGE, so $$J_{\text{sec}}$$ is a dominant current.

The value of $$\phi_{eq}$$ is typically dominated by $$J_{\text{sec}}$$ and $$J_e$$.
Surface Charging Variation with Location

Predictions of surface potential, $\phi_S$, and surface electric field, $E_S$, as a function of angle from the subsolar point, $\theta$. ($\theta = 0^\circ$ is equator at noon and $\theta = 90^\circ$ is at sunset/sunrise)

**Equator/Mid-Latitudes**

- Dayside: $J_{ph}$ appears to dominate under all conditions, so $\phi_S \sim +4$ V.
- Nightside: $\phi_S$ varies considerably ($\sim +1$ V to $-2$ kV!). In the polar regions, $J_{sec}$ does not dominate under the solar wind-like conditions.

**Polar Regions (and Equator?)**

- Solar Wind with $J_{sec}$
- Solar Wind without $J_{sec}$

\[ E_M > kT_e \]
Evidence for Dust Above the Lunar Surface

Colwell et al. [2007]

Horizon glow from forward scattered sunlight

- Dust grains with radius of 5 – 6 μm at about 10 to 30 cm from the surface, where electrostatic and gravitational forces balance.
- Horizon glow $\sim 10^7$ too bright to be explained by micro-meteoroid-generated ejecta [Rennilson and Criswell, 1974].
In-Situ Evidence for Dust Transport

Terminators

Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment.

Berg et al. [1976]
Sketches of sunrise with “horizon glow” and “streamers” viewed from lunar orbit during Apollo 17. Highlighted are the sources of the scattered light: **Coronal and Zodiacal Light (CZL) – RED;** **Lunar Horizon Glow (LHG) due to exospheric dust – BLUE;** and possibly “crepuscular rays” formed by shadowing and scattered light – **GREEN**
Predictions for LADEE Star Tracker Camera

LADEE “might” be able to use Star trackers, like the Clementine mission.

Observations from a broadband imager would be great for providing context – although wavelength info would be better.

Predictions in kR nm\(^{-1}\) for altitude = 50 km and SZA = 110° (from within lunar shadow).

Exospheric dust model based on Apollo era observations [Murphy and Vondrak, 1993].

Stubbs et al. [2010] – modeling by Dave Glenar (NMSU)
Predictions for LADEE Ultraviolet Spectrometer (UVS)

LADEE UVS has ≈ 1° FOV with Δλ ≈ 0.7 nm.

Predictions for observations from within lunar shadow just above limb.

Fraunhofer (solar) lines are important.

Lunar Horizon Glow (LHG) is “bluer”.

Coronal and Zodiacal Light (CZL) is “redder”.

Possibility of making similar observations at Mercury with MASCS?

Better to focus on the blue part of the spectrum (< 500 nm) where we would anticipate Hermean Horizon Glow (HHG) to dominate.

Scan to get intensity as a function of tangent height (altitude at the limb). Need to characterize CZL as observed from Mercury – intrinsically interesting!
“Dust-electron” dominated lunar ionosphere?

Radio occultation measurements by the Soviet Luna 19 and 22 missions indicated electron concentrations of $\sim 10^3 \text{ cm}^{-3}$! Much higher than expected $\sim 1 \text{ cm}^{-3}$.

Estimated electron concentrations produced by photo-charged exospheric dust using dust concentrations inferred from Apollo 15 coronal photographs.

$\Theta$: scaling parameter to account for uncertainties and variability (mostly in dust concentrations?).

Dust-electrons are the most plausible mechanism for producing the observed lunar ionosphere.

Stubbs et al., 2010, under review.
These processes at Mercury have been considered before: Ip, GRL, 1986.

- Qualitative discussion of the phenomena.
- Rough estimate for surface charging – up to kilovolts negative.
- Speculated that charged dust produced via meteoritic ejecta could form a dust coma or tail.

Grard [1997] also considered surface charging at Mercury and the dayside photoelectron sheath.
Summary and Conclusions

Comparative planetology: the Moon and Mercury have a lot in common, especially the space environment interaction with the surface regolith.

The surface of Mercury is electrically charged:
- negative kilovolt potentials should be fairly common.
- secondary emission of electrons is often important.

Extremely important to take into account when considering the magnetospheric interaction with Mercury.

Could be electrostatically transported dust at Mercury – worth a look!

Not sure what to expect … could be many controlling factors – plasma environment, meteoritic flux, regolith composition, shape and particle size distribution, etc …

Instrument considerations: viewing geometries, solar avoidance.

Consequences for exosphere, ionosphere and magnetosphere.
Subtle influence on the evolution of the regolith (dust component).