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

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Exploring Magnetosphere-Exosphere Coupling At Mercury:
A Joint MESSENGER – BepiColombo Workshop.

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Motivations and Objectives

<u>COMPARATIVE PLANETOLOGY:</u> 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

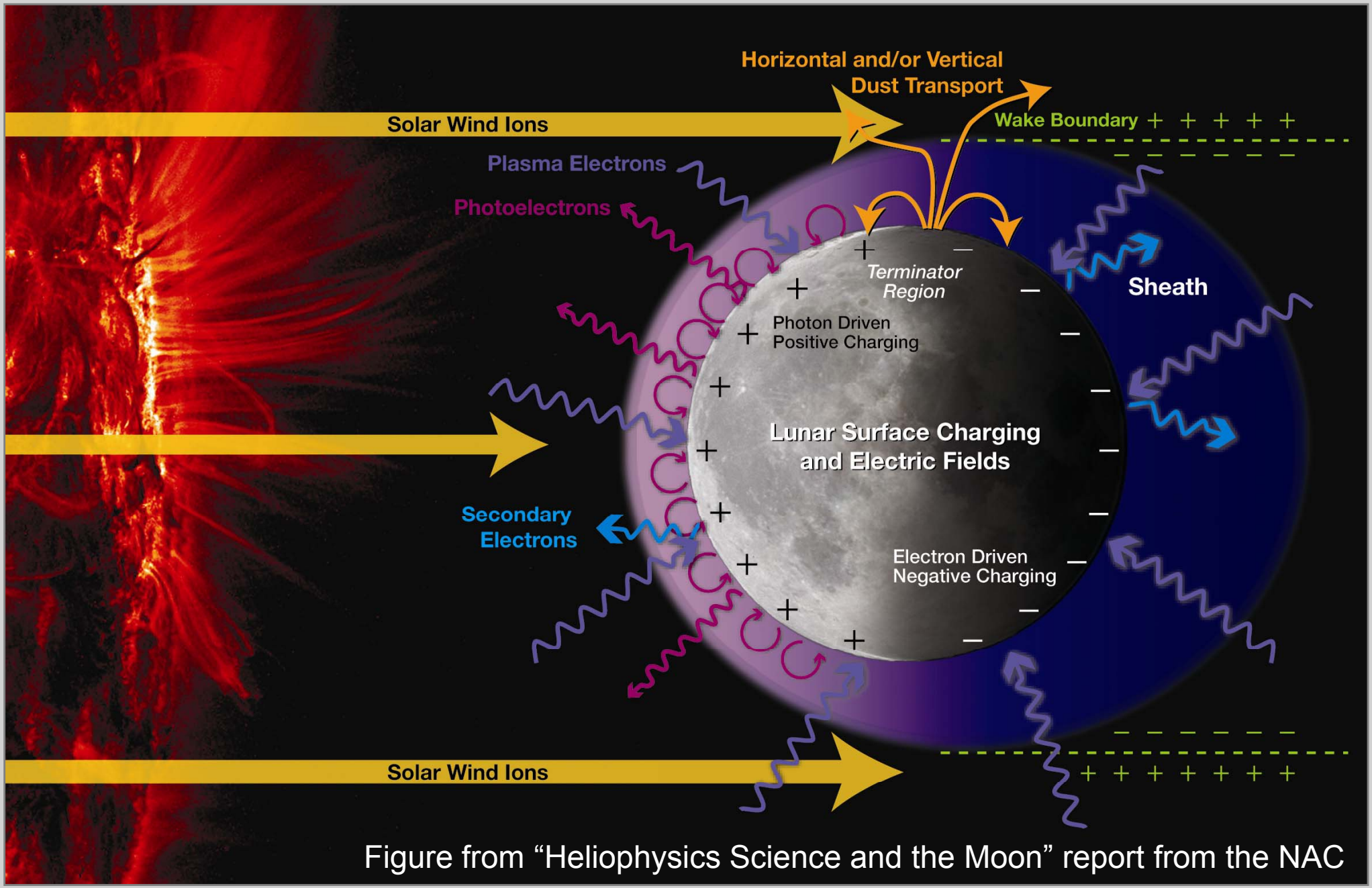
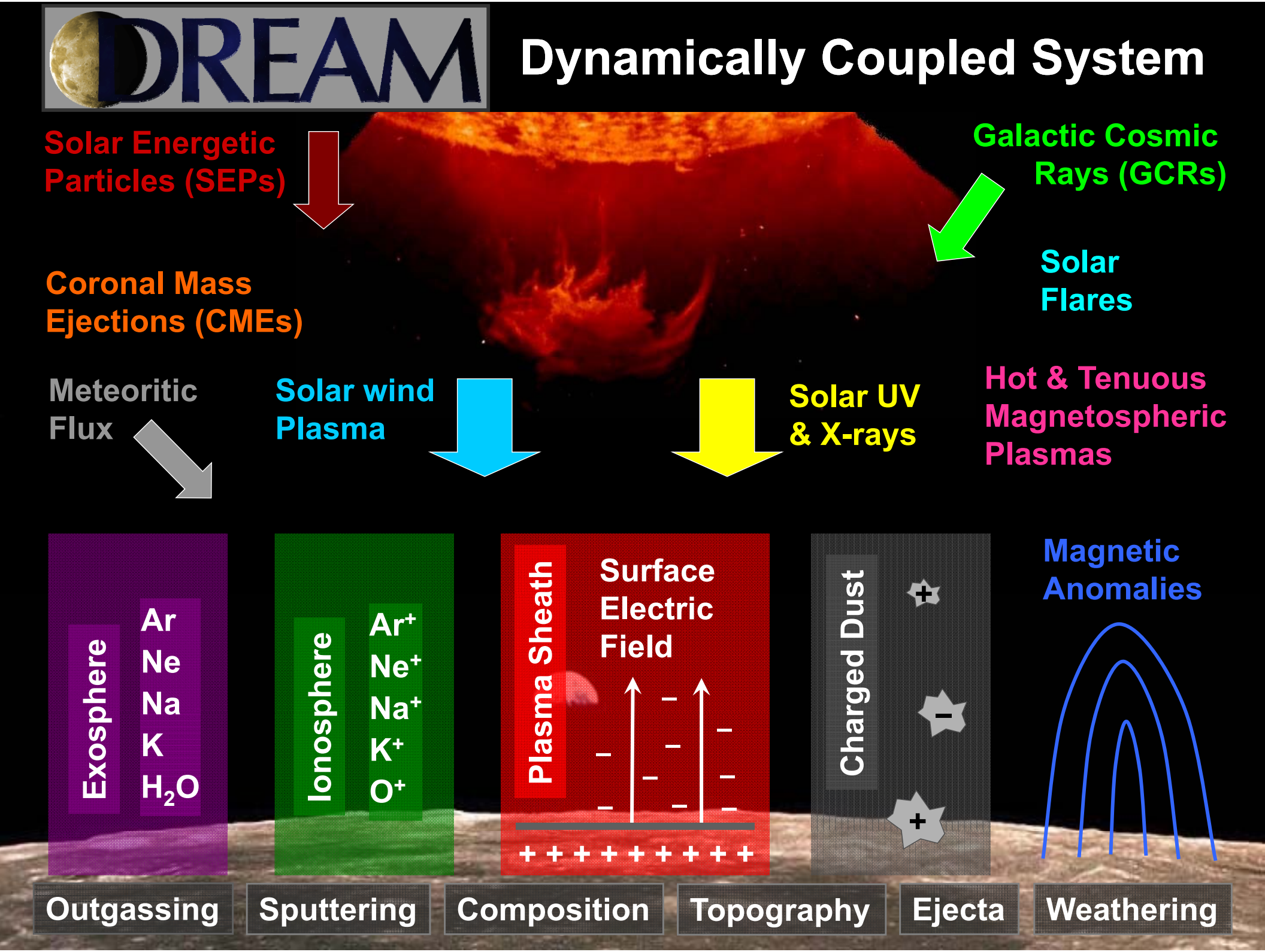


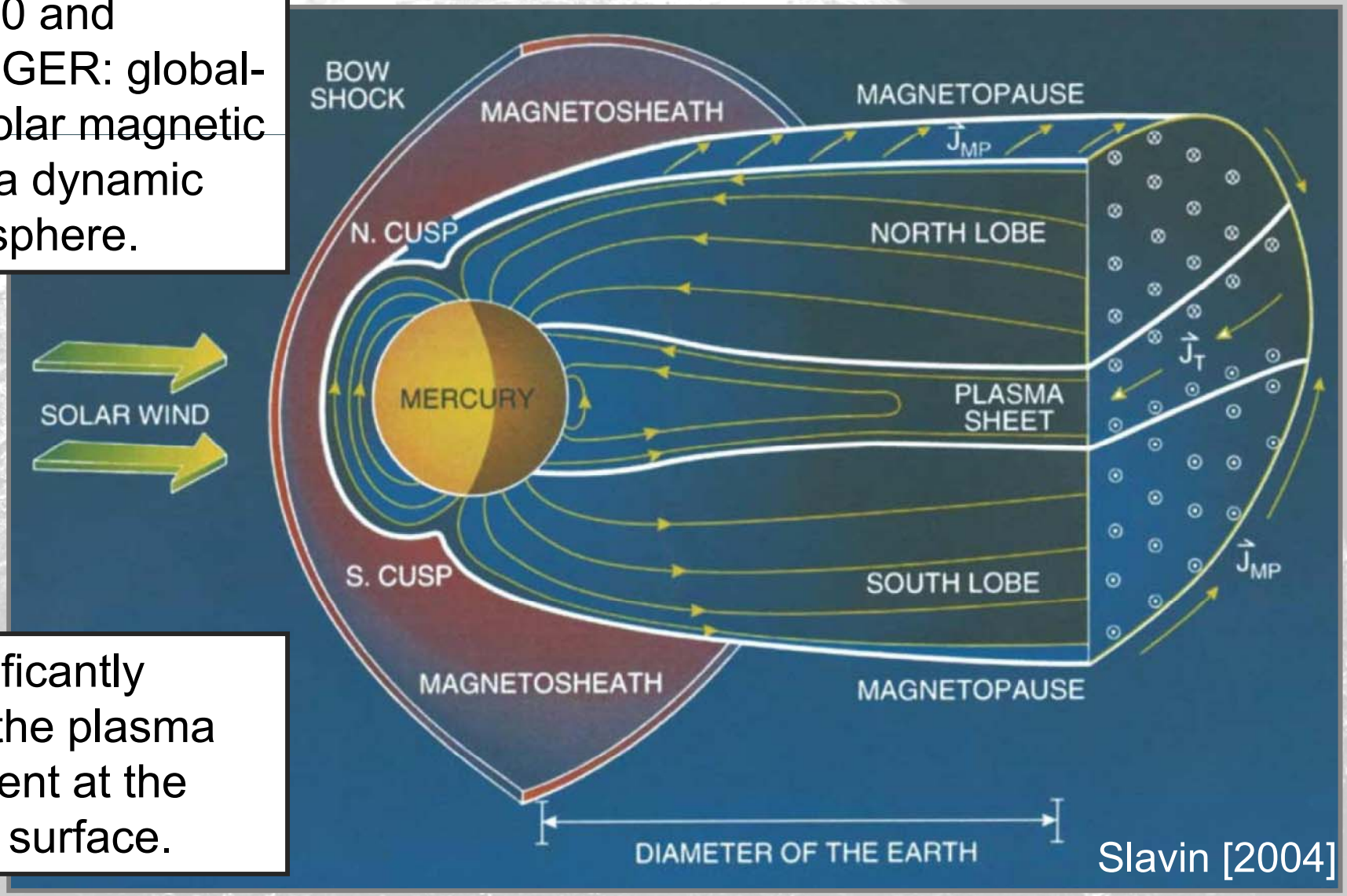
Figure from “Heliophysics Science and the Moon” report from the NAC

Dynamically Coupled System



Mercury's Magnetosphere & Plasma Environment

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



Slavin [2004]

This significantly modifies the plasma environment at the planetary surface.

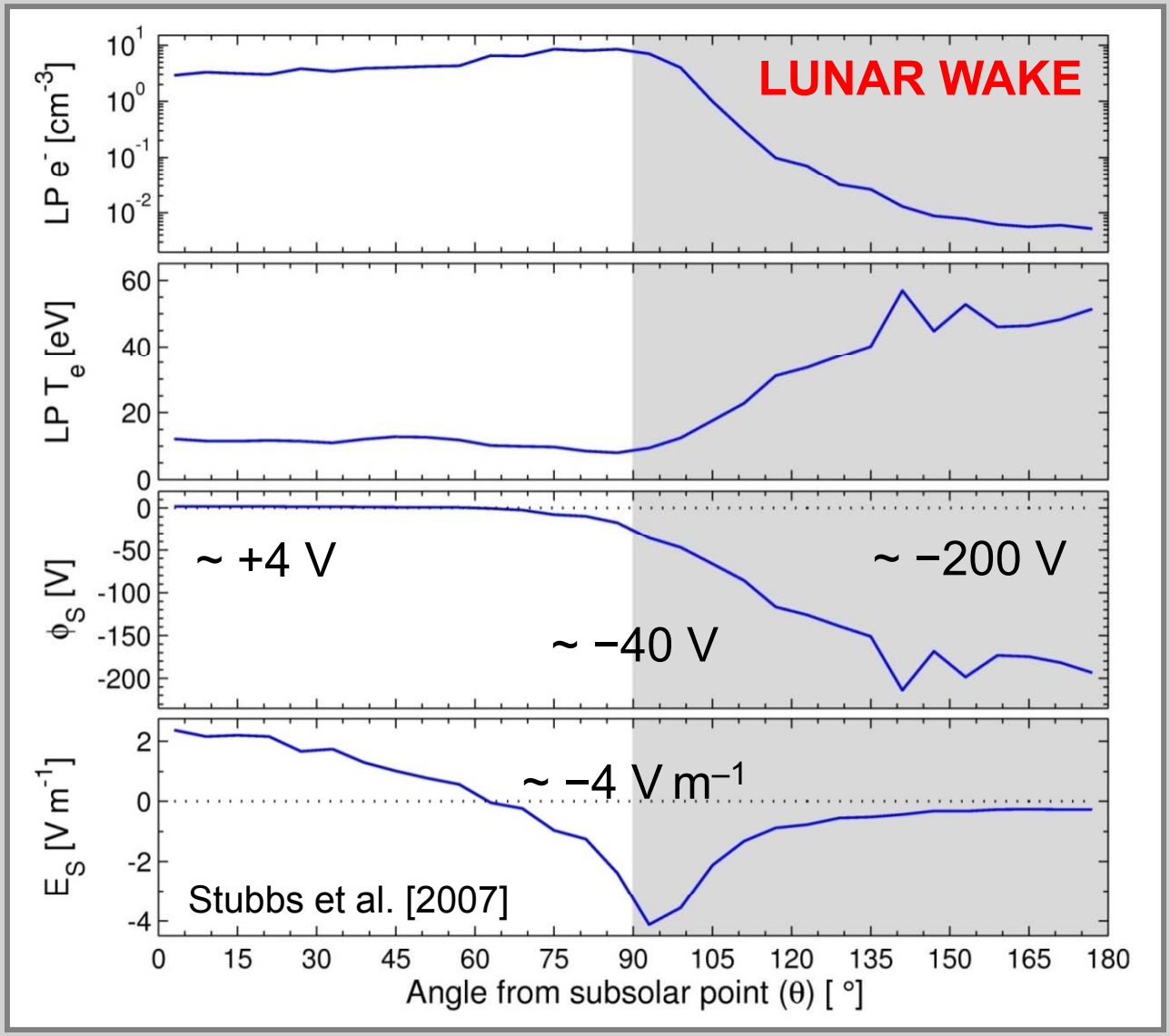
Mercury's magnetosphere is somewhat Earth-like with a plasma sheet and lobes in the tail and cusps at the dayside.

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.

Lunar Prospector Electron Observations

Surface Charging Predictions



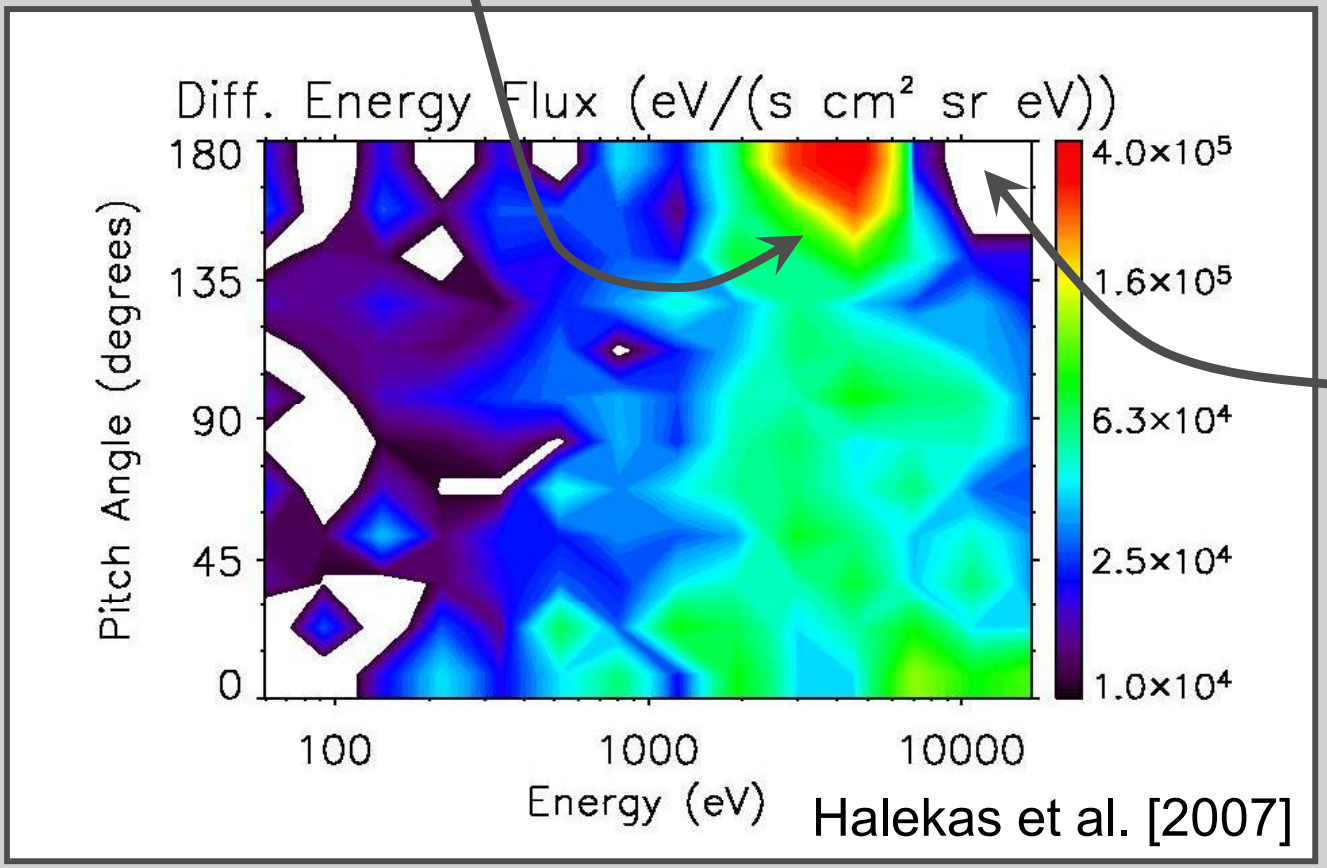
Non-Maxwellian: Electrons heated in the wake by infilling process.

Find equilibrium potential ϕ_{eq} – net current is zero.

E-field sweet spot at the terminator.

Direct Observations of Lunar Surface Charging (Extreme Case)

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.

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].

Condition	n [cm^{-3}]	T_e [eV (K)]	T_i [eV (K)]	V [km s^{-1}]
Slow solar wind	10	12.1 (1.4×10^5)	8.6 (1.0×10^5)	−400
Tail lobes	0.02	86 (1.0×10^6)	86 (1.0×10^6)*	−170
Plasma sheet	0.2	216 (2.5×10^6)	1577 (1.83×10^7)#	−100

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

Condition	**Dayside ϕ_S**	**Nightside ϕ_S**	**Electron current J_{e0}**
Slow solar wind	~ +4 V	~ −50 V	~ 1.0 μA m^{-2}
Tail lobes	~ +10 V	~ −325 V	~ 10^{-2} μA m^{-2}
Plasma sheet	~ +6 V	~ −600 V	~ 10^{-1} μA m^{-2}

Dayside – photoemission dominates plasma electron currents

Nightside – plasma electron currents (Temperature) dominate.

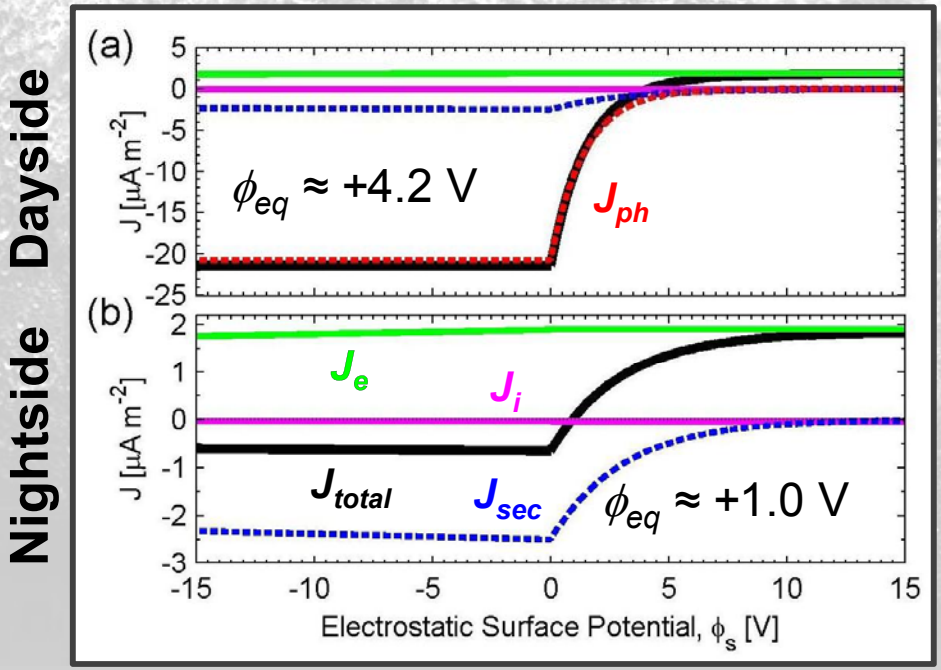
Surface Charging at Mercury

Mariner 10 observations [Ogilvie et al., 1977]

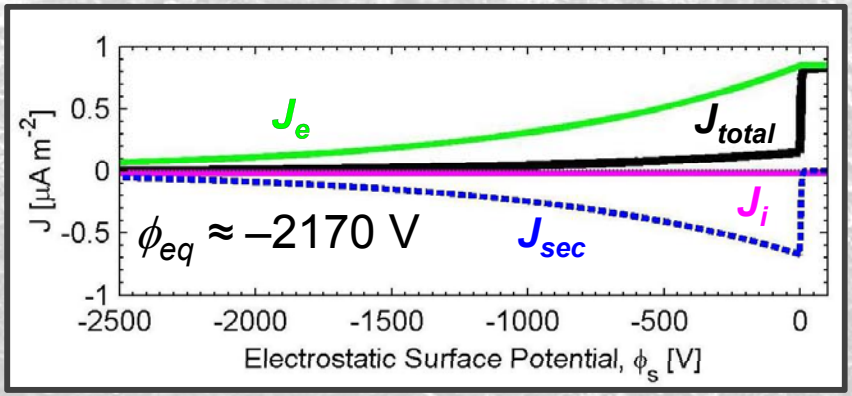
- **Cool plasma sheet:** $n_e \sim 5\ \mathrm{cm}^{-3}$ and $T_e \sim 200$ eV
- **Hot plasma sheet:** $n_e \sim 1\ \mathrm{cm}^{-3}$ and $T_e \sim 1000$ eV.

Hot electrons – secondary emission could be important.
Use the Sternglass [1954] relation with
$E_M = 400$ eV, $\delta_M = 1.5$ & $T_s = 3$ eV [Willis et al., 1973].

Cool Plasma Sheet



Hot Plasma Sheet – Nightside



Currents:

J_{ph} = photoemission of electrons;
J_e = plasma electrons; J_i = plasma ions;
J_s = secondary electrons; J_{total} = total.

Importance of Secondary Electron Currents

Dayside

Cold plasma sheet:

if J_{sec} is **included**, then $\phi_{eq} \approx$ **+4.2 V**.

if J_{sec} is **NOT included**, then $\phi_{eq} \approx$ **+3.5 V**.

Difference is relatively small, so J_{sec} is **NOT** dominant.

The value of ϕ_{eq} is typically dominated by J_{ph} and J_e.

$E_M \sim kT_e$

Nightside

Cold plasma sheet:

if J_{sec}, is **included**, then $\phi_{eq} \approx$ **+1.0 V**.

if J_{sec} is **NOT included**, then $\phi_{eq} \approx$ **–750 V**.

Difference is **HUGE**, so J_{sec} is a dominant current.

$E_M \sim kT_e$

Hot plasma sheet:

if you **include** J_{sec}, then $\phi_{eq} \approx$ **–2170 V**.

if you **do not include** J_{sec}, then $\phi_{eq} \approx$ **–3750 V**.

Again, difference is **HUGE**, so J_{sec} is a dominant current.

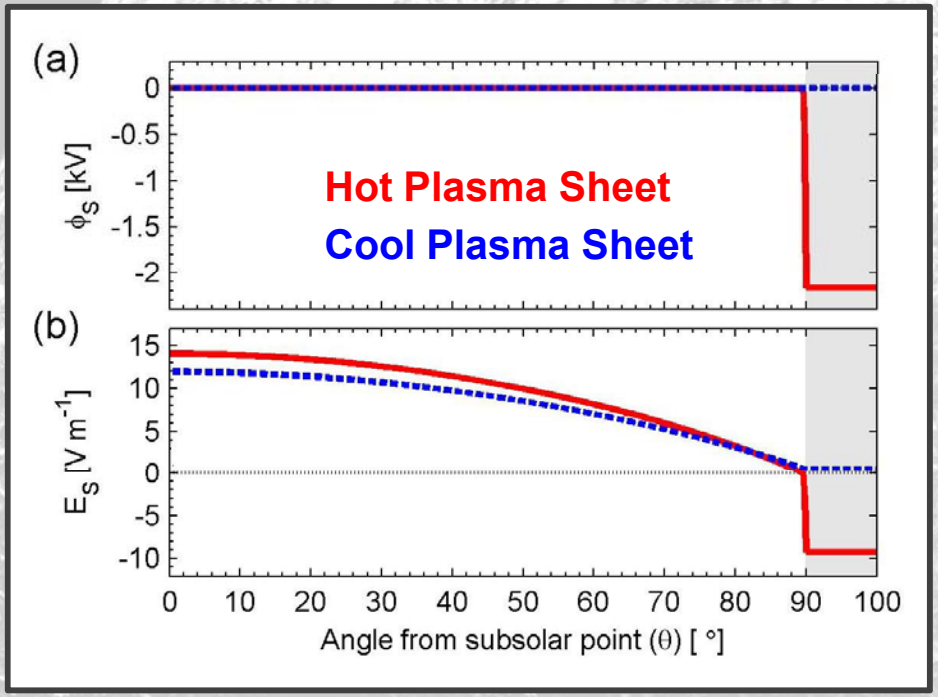
The value of ϕ_{eq} is typically dominated by J_{sec} and J_e.

$E_M < kT_e$

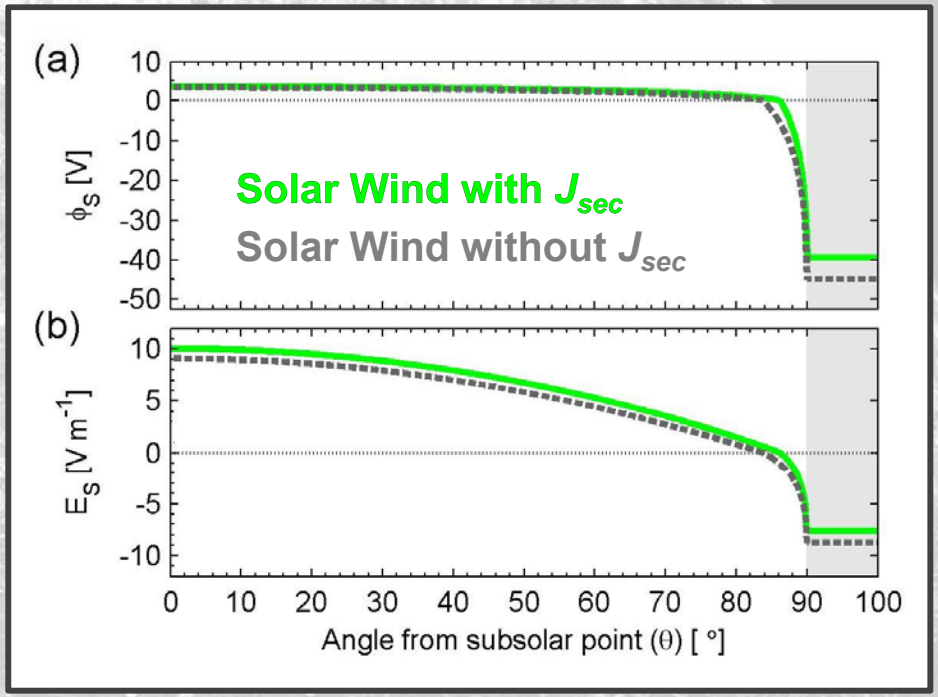
Surface Charging Variation with Location

Predictions of surface potential, ϕ_S, and surface electric field, E_S, as a function of angle from the subsolar point, θ.
(θ = 0° is equator at noon and θ = 90° is at sunset/sunrise)

Equator/Mid-Latitudes



Polar Regions (and Equator?)

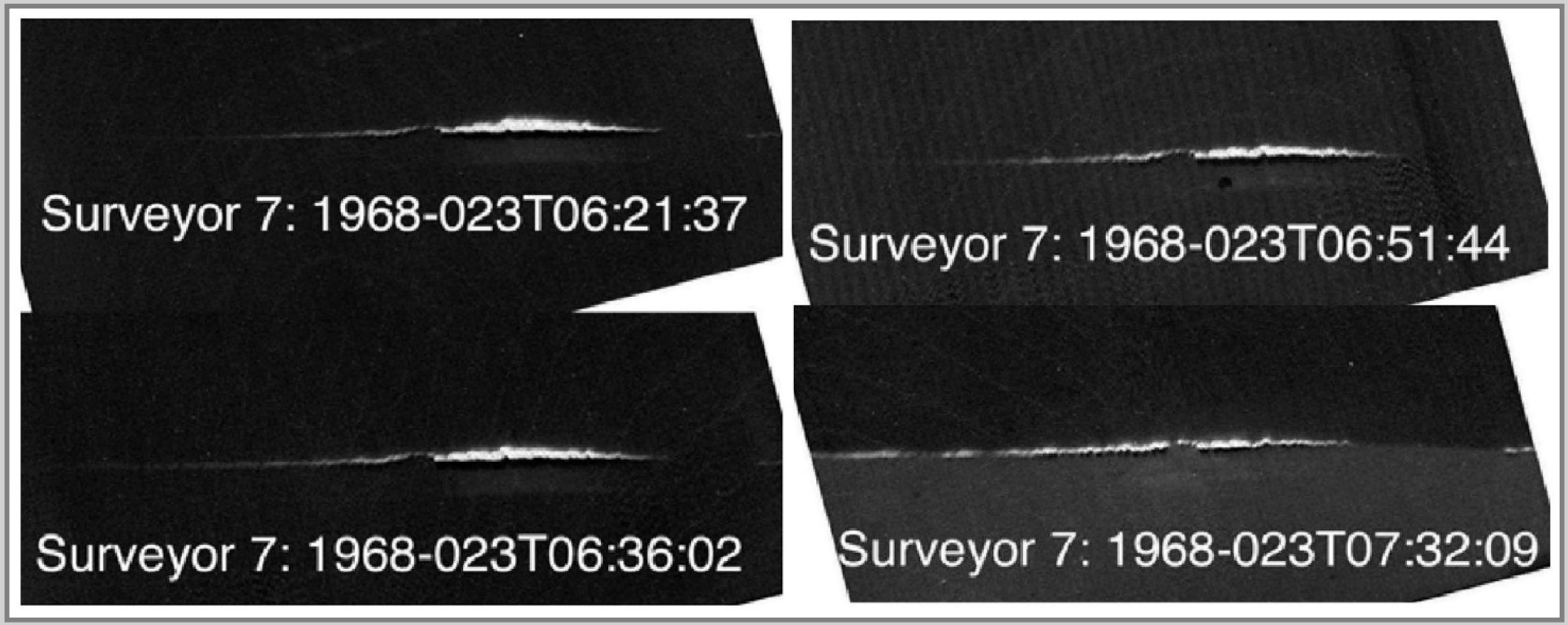


Dayside: J_{ph} appears to dominate under all conditions, so ϕ_S ~ +4 V.

Nightside: ϕ_S varies considerably (~ +1 V to –2 kV!). In the polar regions, J_{sec} does not dominate under the solar wind-like conditions.

$E_M > kT_e$

Evidence for Dust Above the Lunar Surface

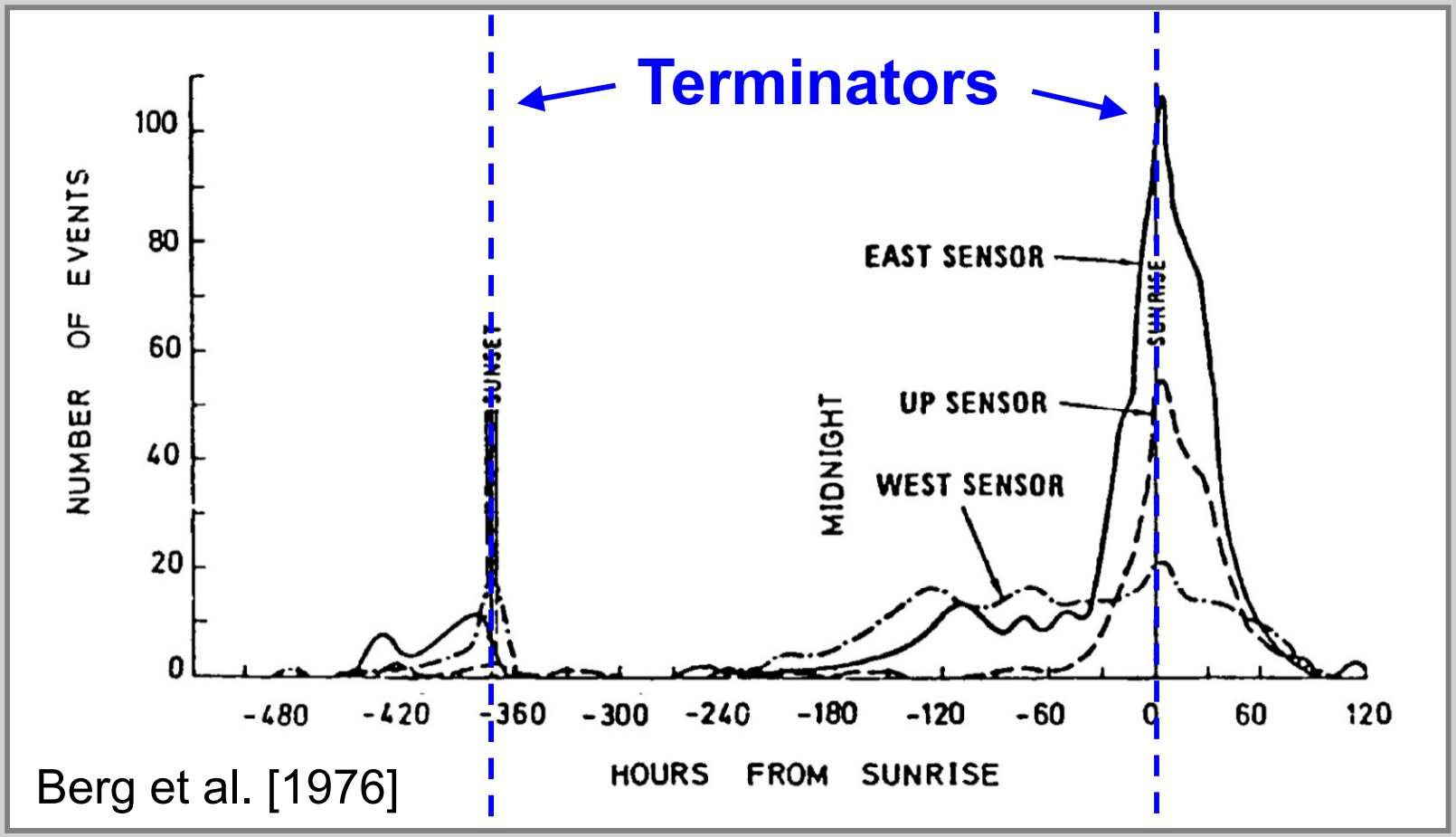


Colwell et al. [2007]

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 ~10^7 too bright to be explained by micro-meteoroid-generated ejecta [Rennilson and Criswell, 1974].

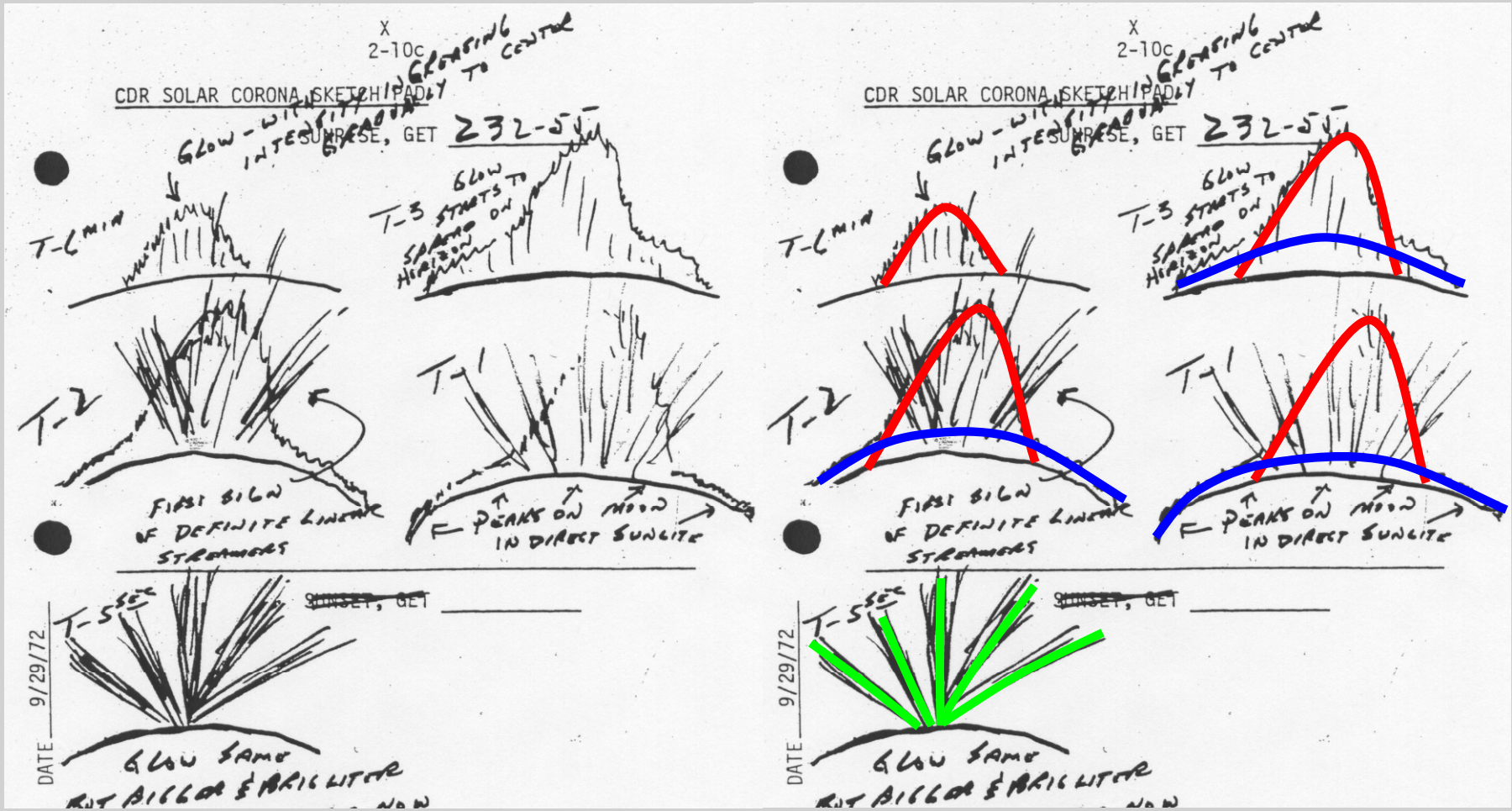
In-Situ Evidence for Dust Transport



Berg et al. [1976]

Apollo 17 Lunar Ejecta and Meteorites (LEAM) experiment.

Dust Observed at High Altitudes from Orbit



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

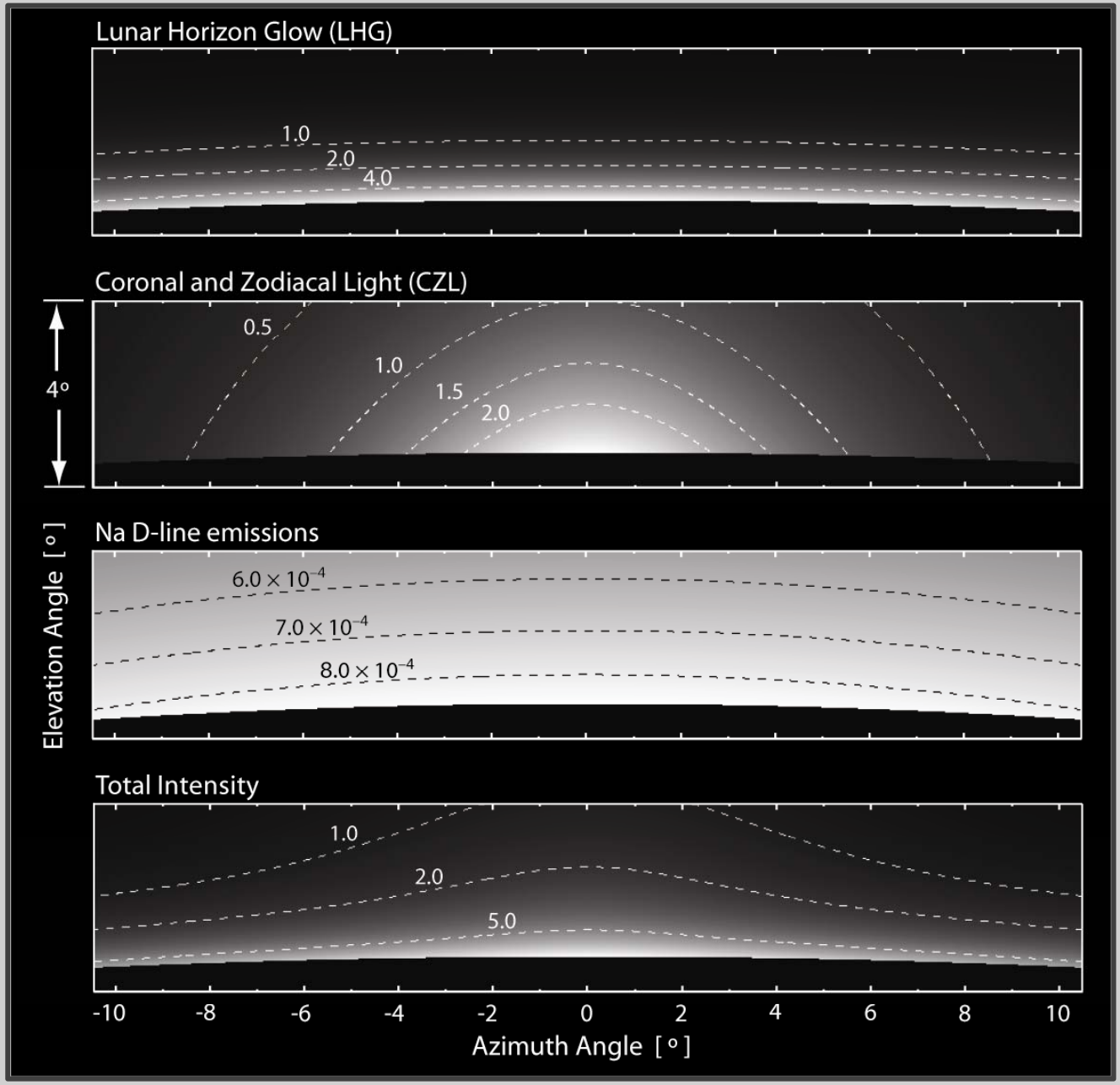
LADEE "might" be able to use Star trackers, like the Clementine mission.

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].

MDIS ???



Stubbs et al. [2010] – modeling by Dave Glenar (NMSU)

Predictions for LADEE Ultraviolet Spectrometer (UVS)

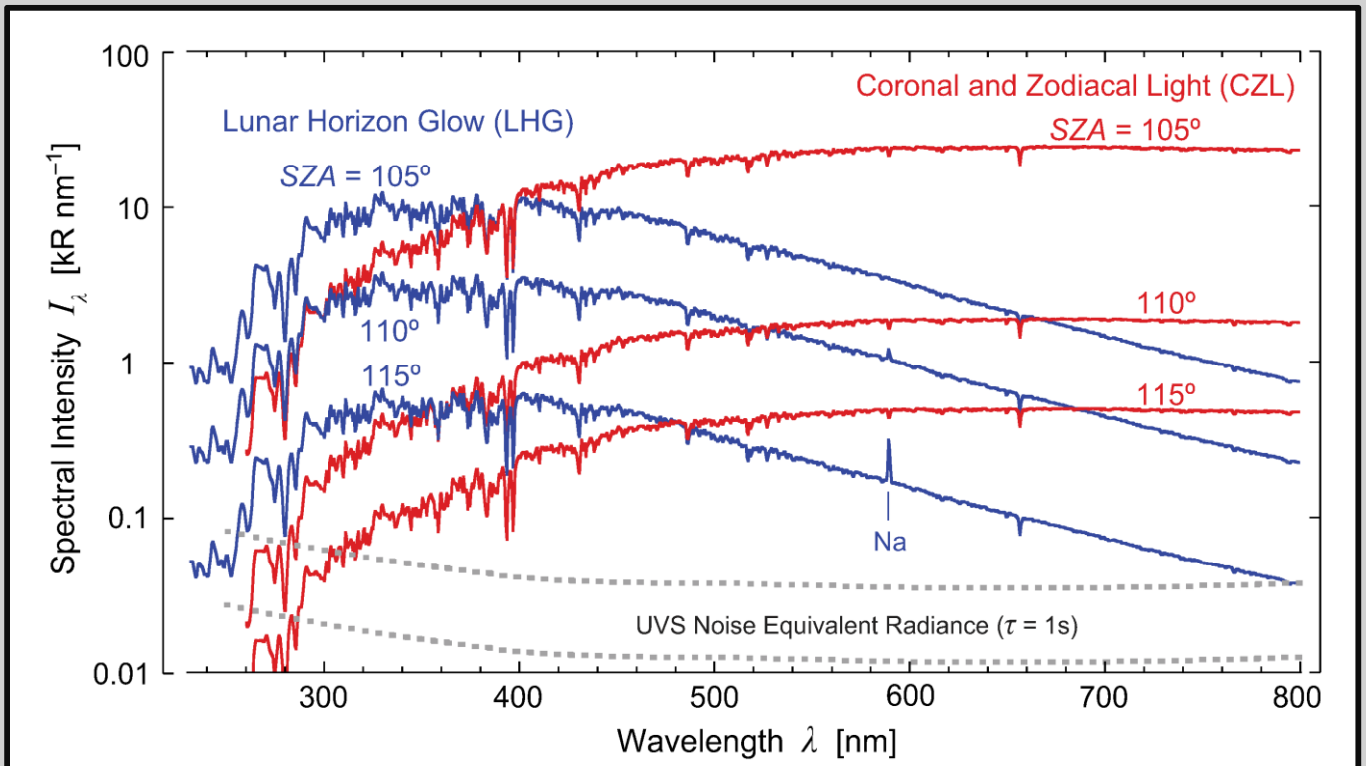
LADEE UVS has ≈ 1° FOV with $\Delta\lambda \approx 0.7$ nm.

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”.



Stubbs et al. [2010] – modeling by Dave Glenar (NMSU)

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!

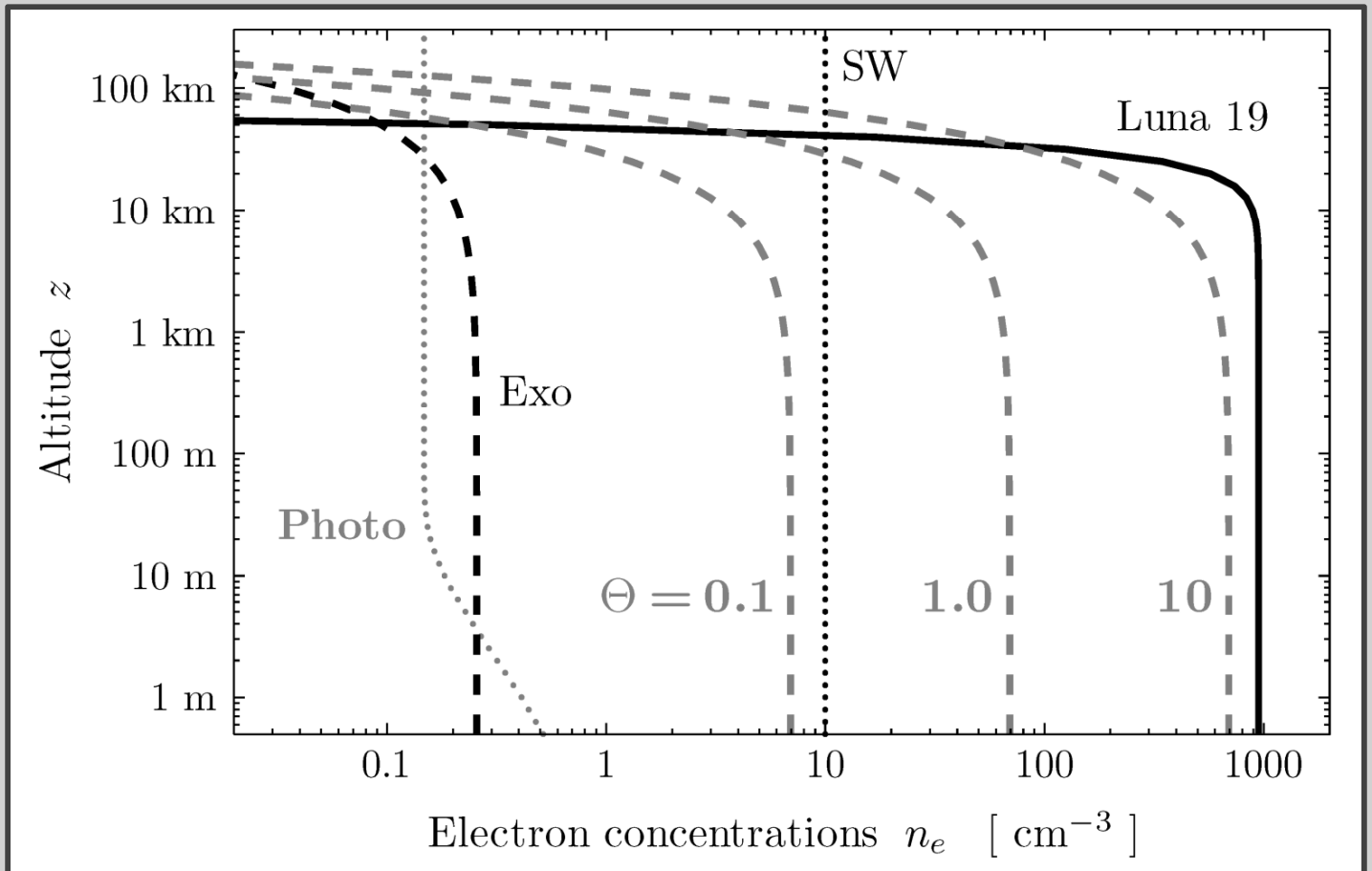
“Dust-electron” dominated lunar ionosphere?

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

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

Θ: 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.

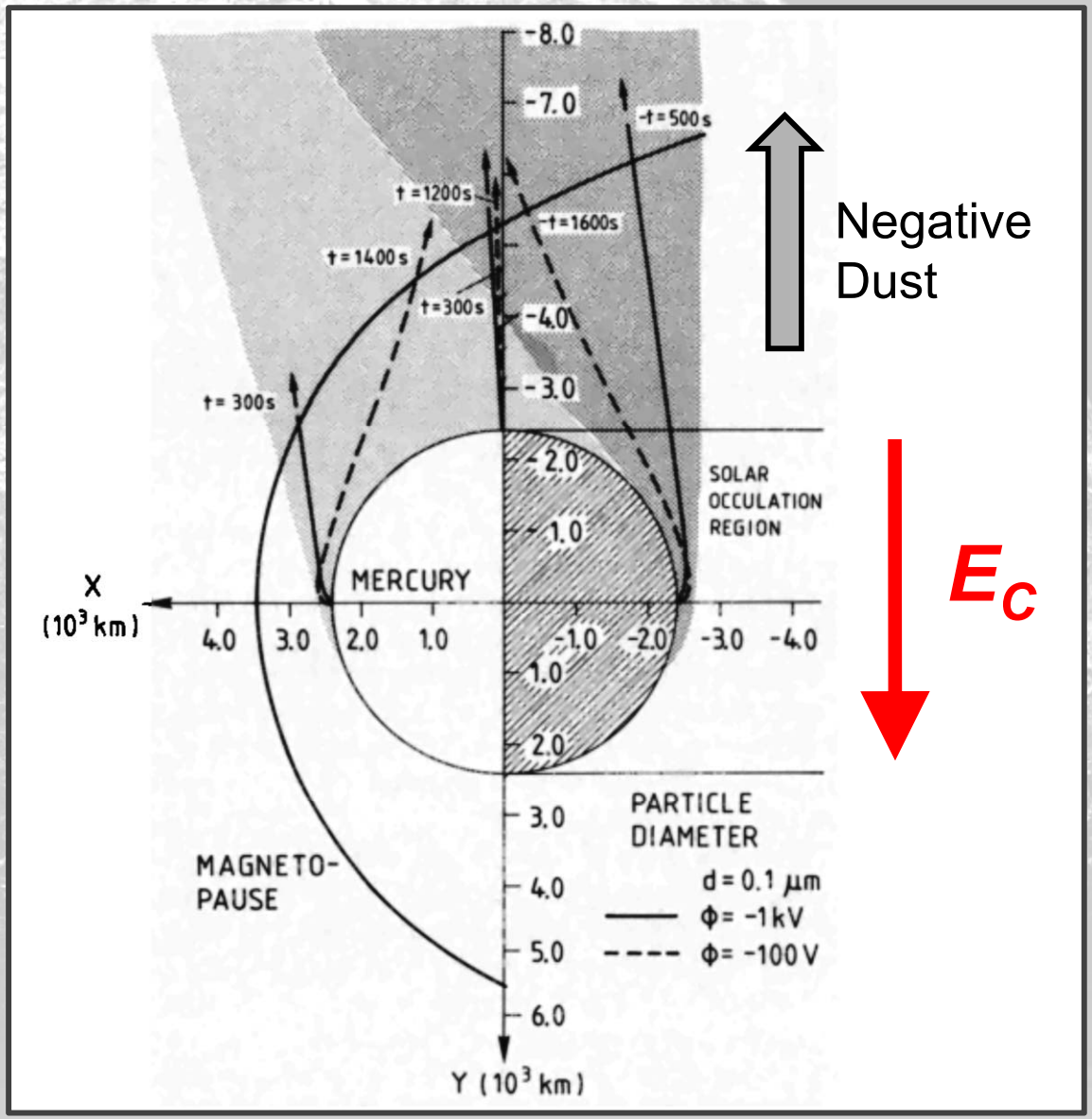
These processes at Mercury have been considered before: Ip, *GRL*, 1986.

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).