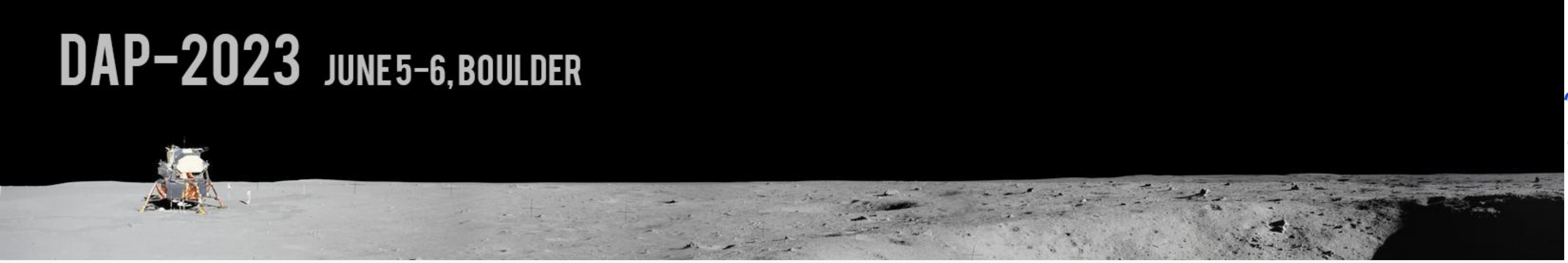


Non-Monotonic Potential Structures Within Lunar Photoelectron Sheath

Trinesh Sana*, S. K. Mishra

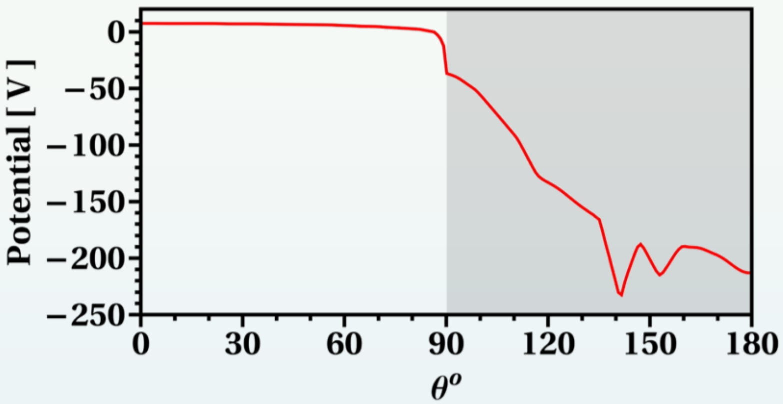
Planetary Sciences Division
Physical Research Laboratory, India

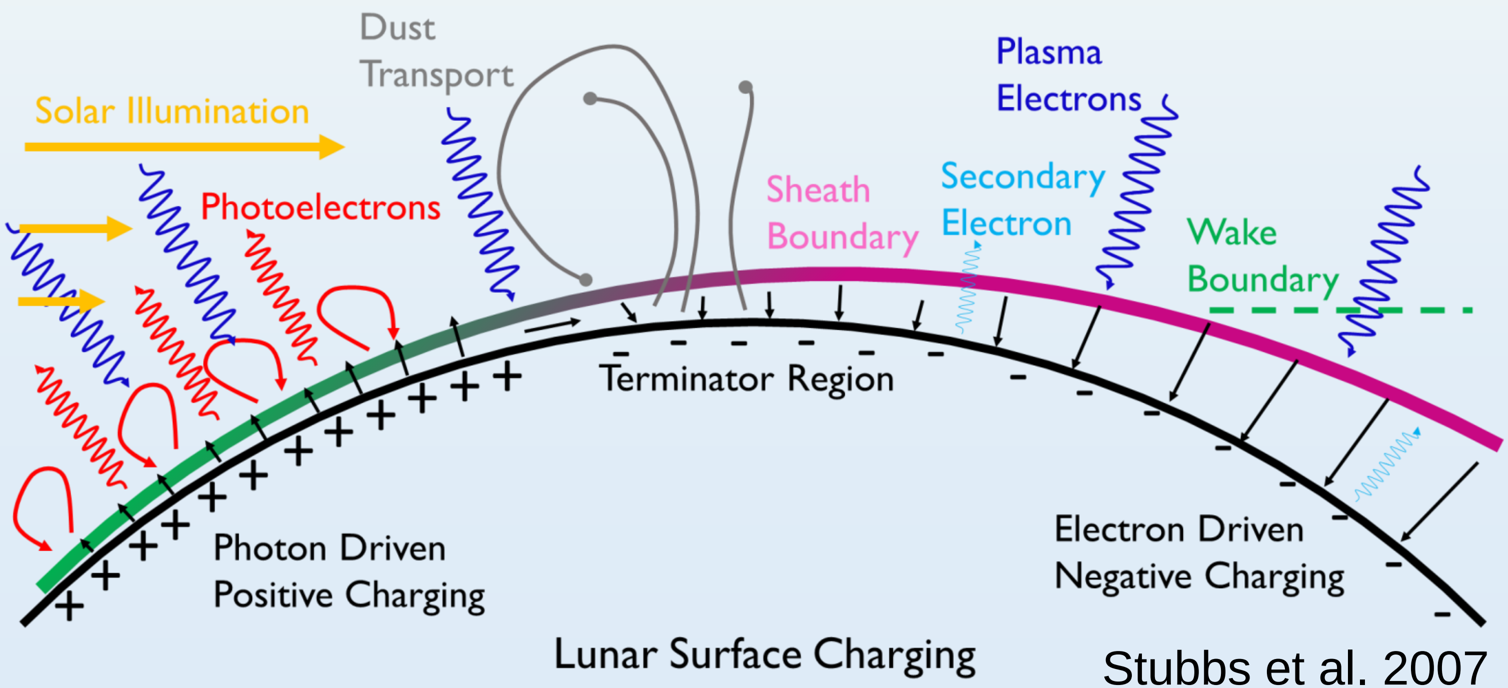
*sanatrinresh@gmail.com

The 4th Dust, Atmosphere, and Plasma Environment of the Moon and Small Bodies (DAP-2023) workshop

Lunar Plasma Environment

A Composite System of
- ✓ charged surface
- ✓ dust particles
- ✓ Photoelectrons
- ✓ solar wind/ ambient plasma





Stubbs et al. 2007

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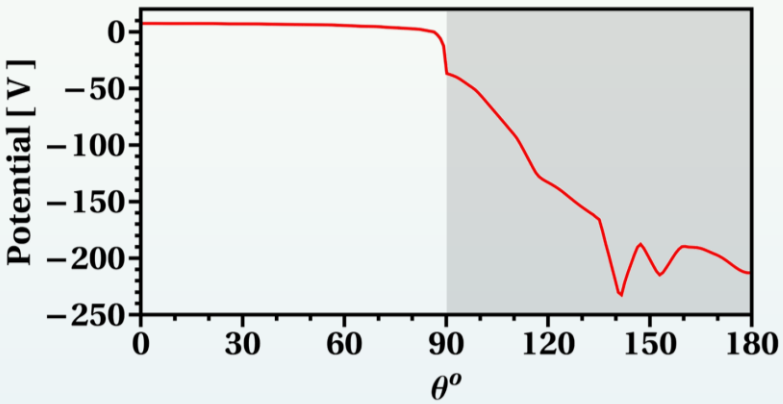
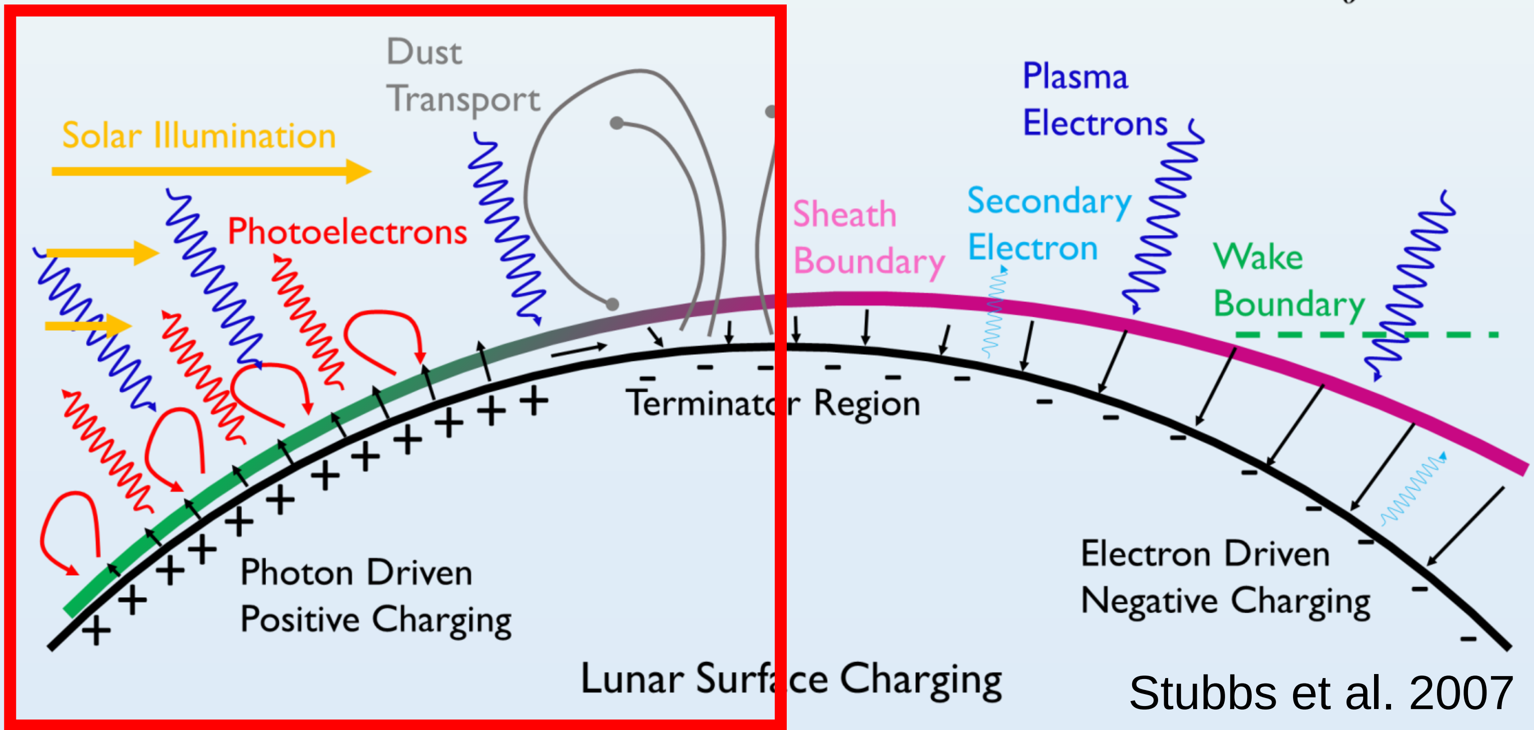


Study Area



Stubbs et al. 2007

Physics Problem

A photoemitting body exposed to plasma

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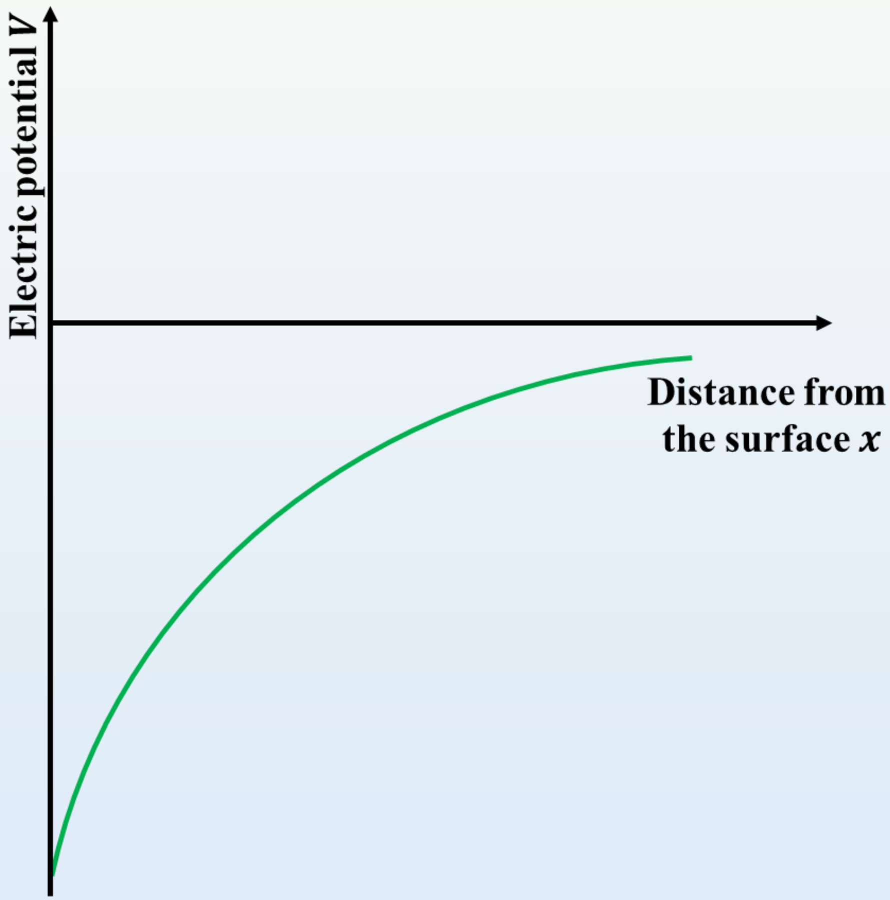

Physics Problem

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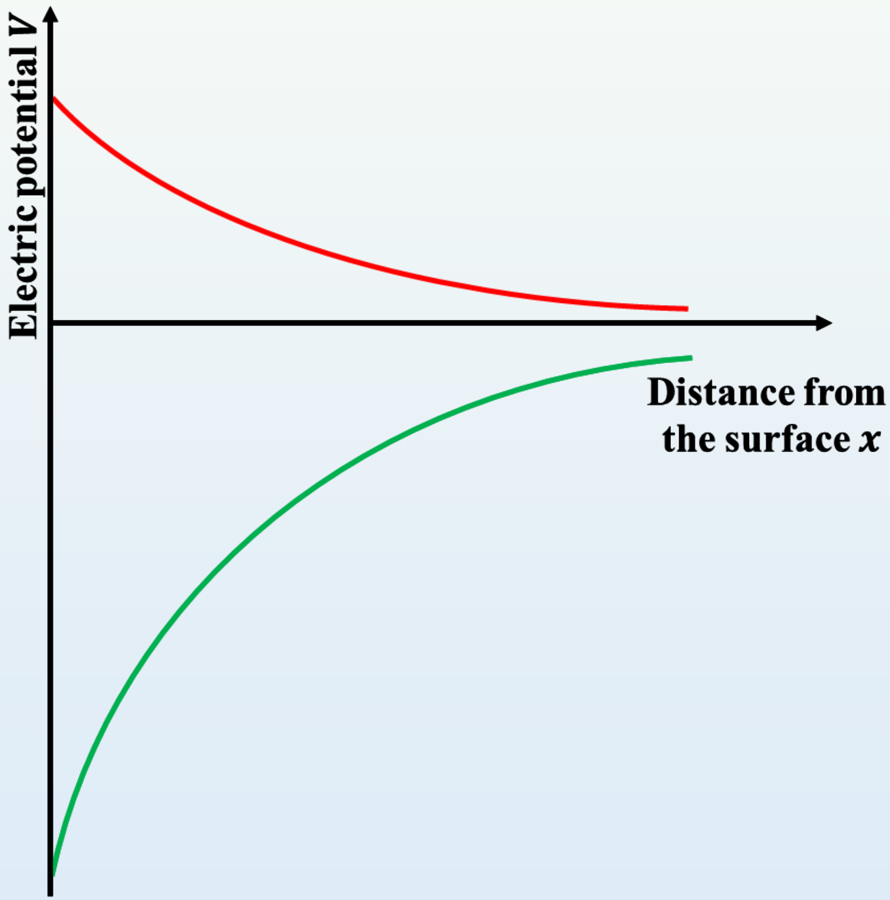
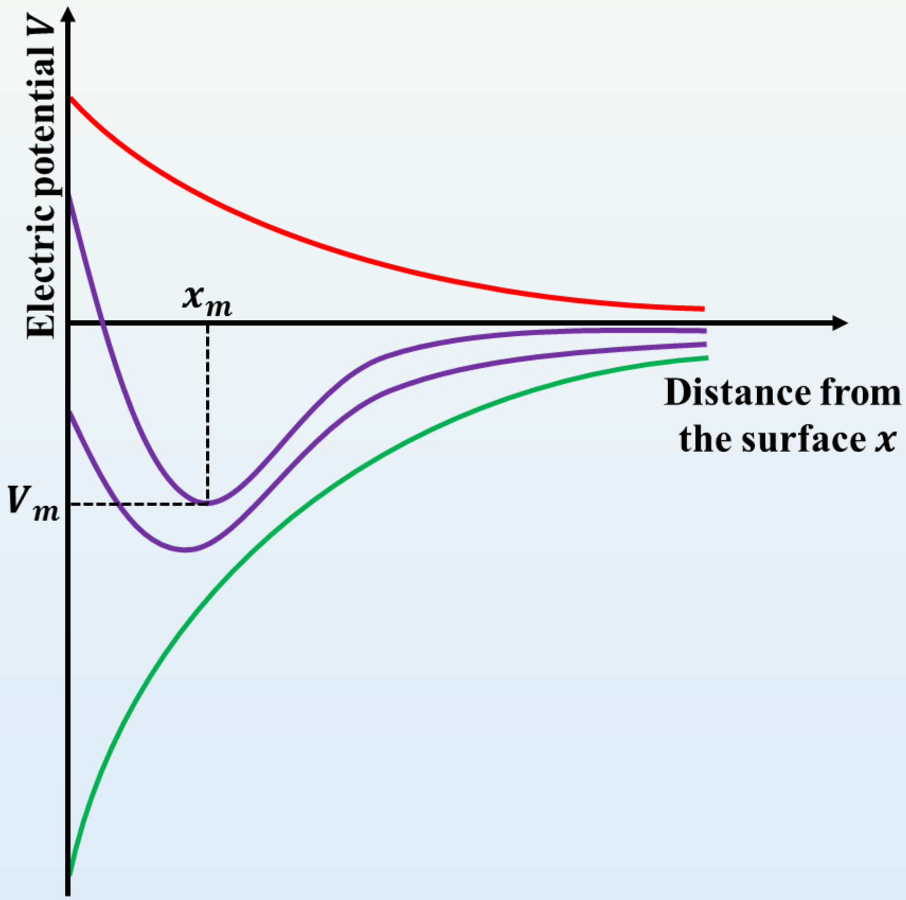


Physics Problem

A photoemitting body exposed to plasma

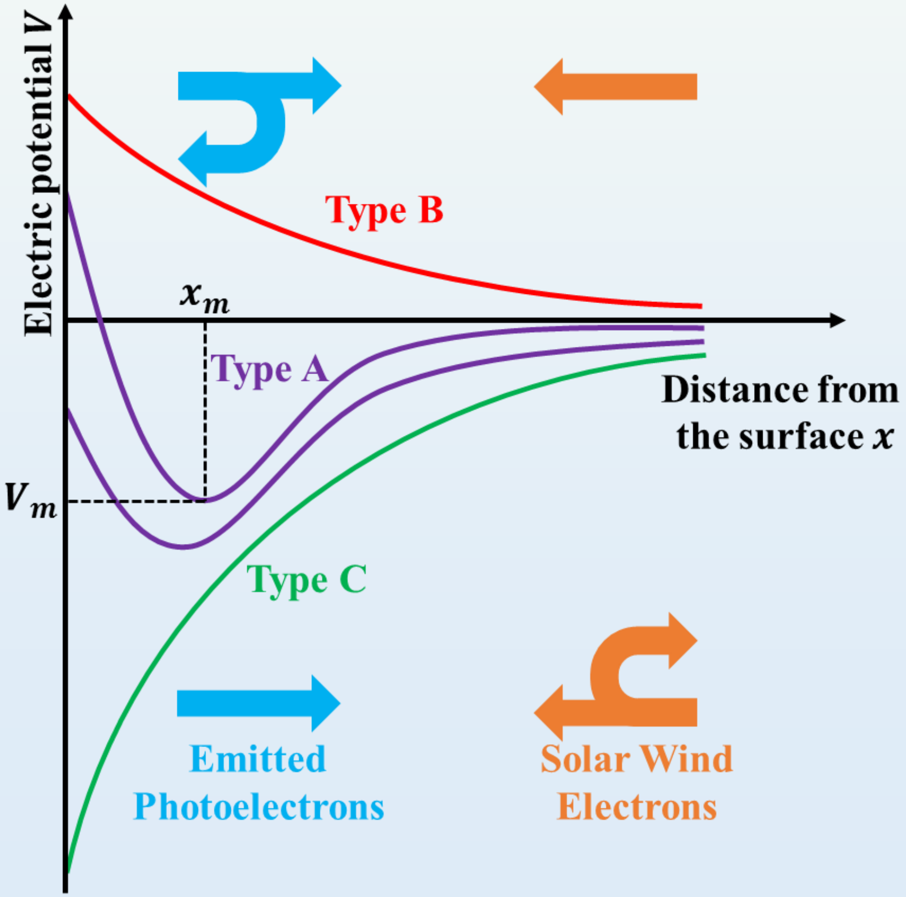


✓ Guernsey & Fu 1970; Nitter et al 1998

Poisson's equation

$$\frac{d^2V}{dx^2} = -\frac{e}{\varepsilon_0}\left[n_{\mathrm{si}} - n_{\mathrm{sef}} - n_{\mathrm{sec}} - n_{\mathrm{pef}} - n_{\mathrm{pec}}\right]$$

BCs: $V(0) = V_0, V'(\infty) = 0, V(x_m) = V_m$ and $V'(x_m) = 0.$



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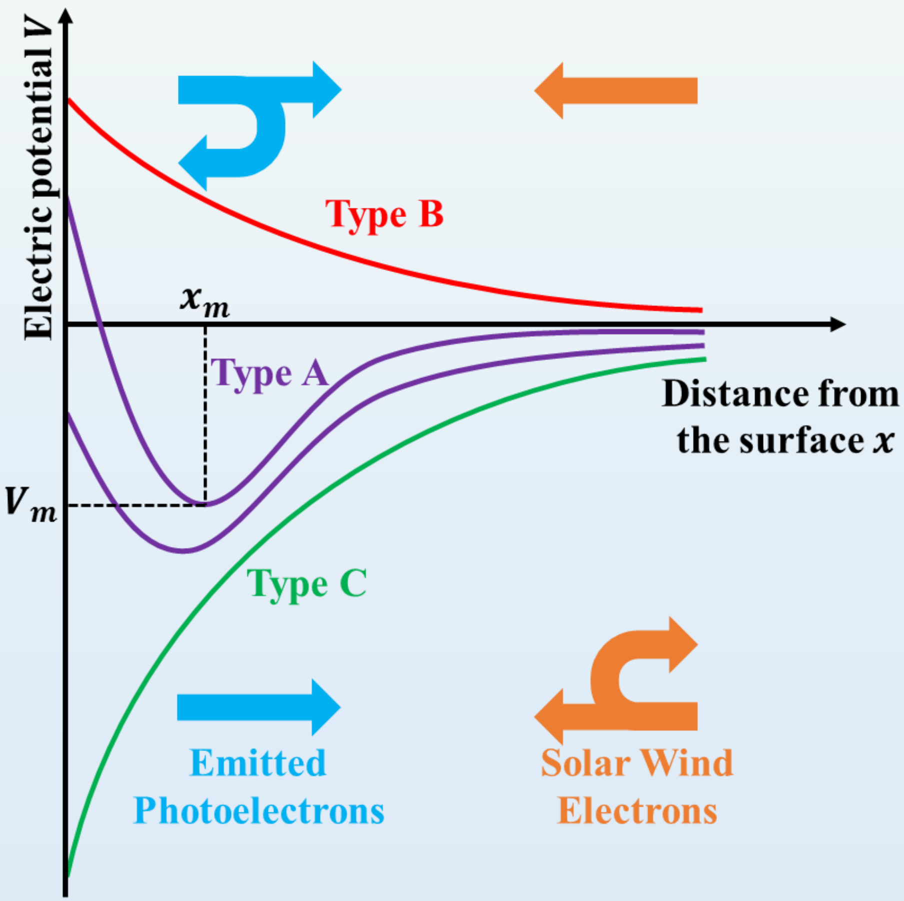

Solar wind/ambient plasma

- ✓ Bulk Density & Temperature
- ✓ Velocity Distribution Function (VDF)

Photoelectrons

- ✓ Solar photon flux
- ✓ Regolith Work function
- ✓ Quantum Yield

Poisson's equation

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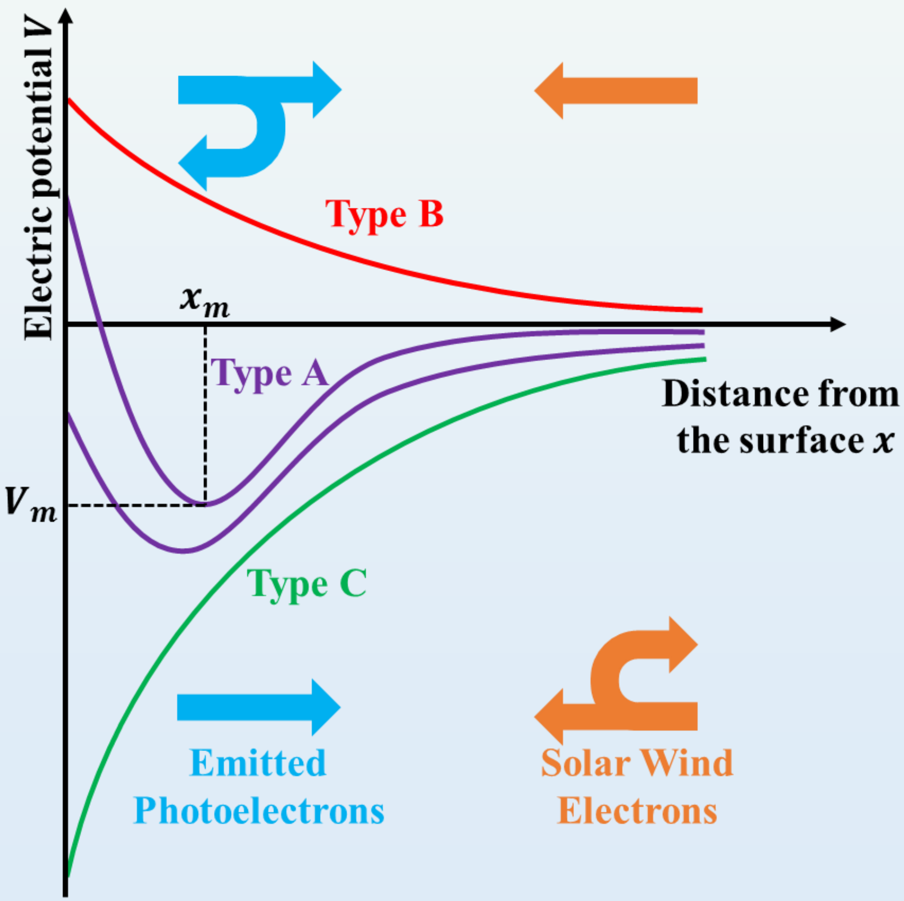

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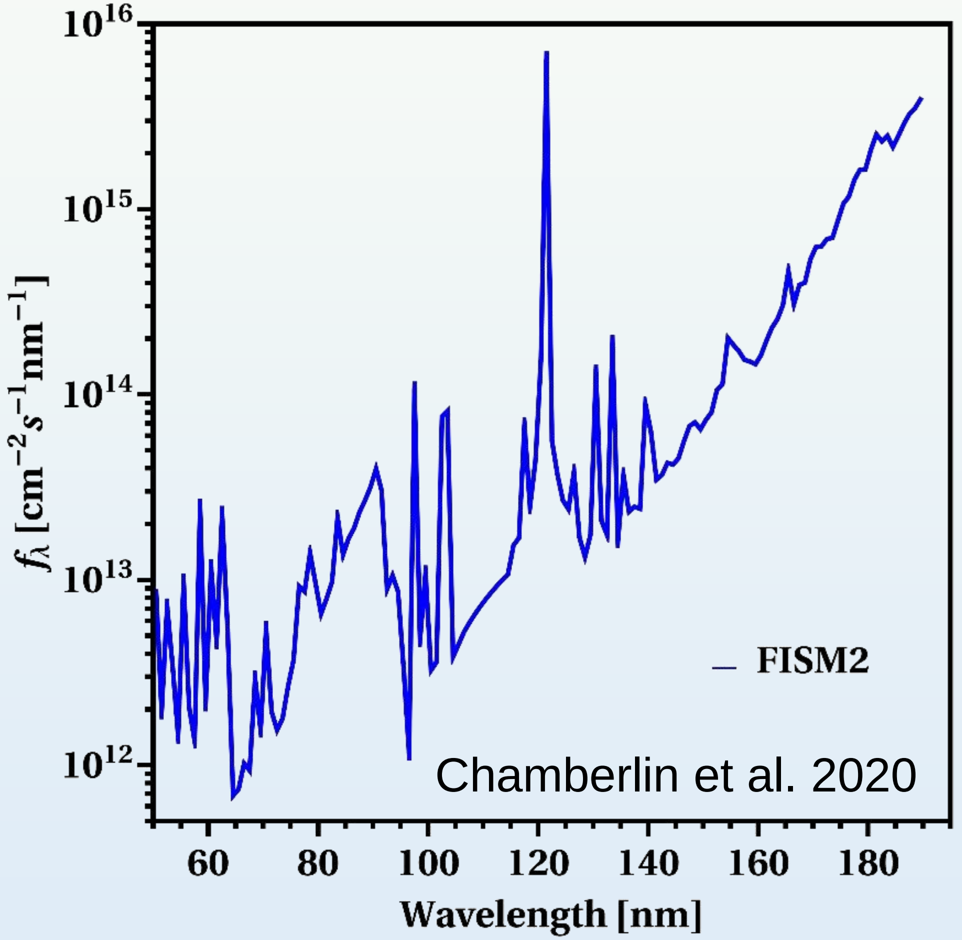
- ✓ Regolith Temperature
- ✓ VDF of lattice electrons
- ✓ Lunar Surface Potential

Solar Photon Flux



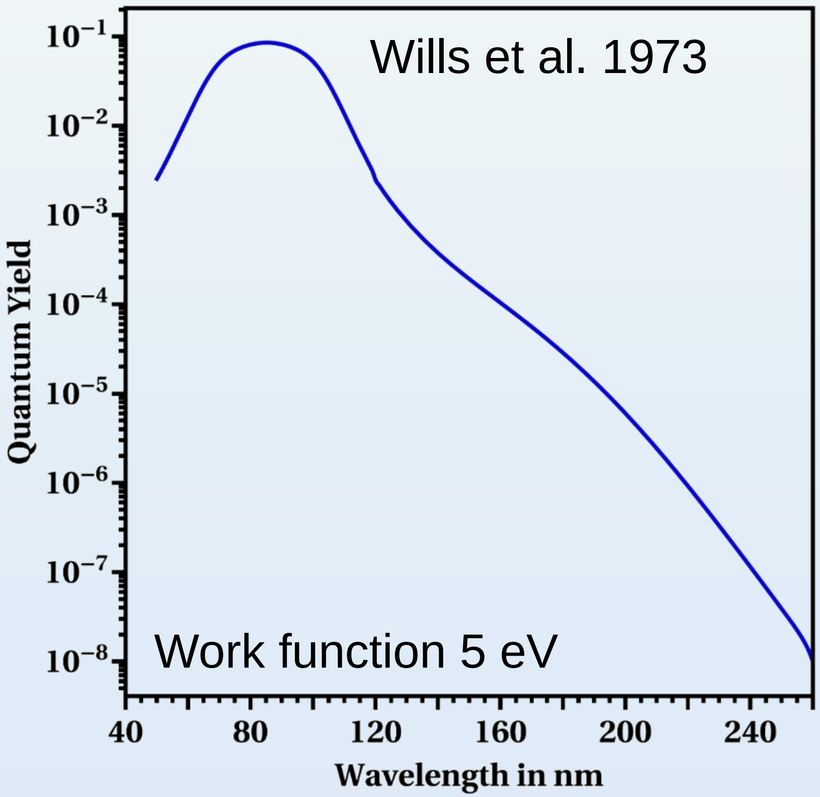
Effective Photon Flux

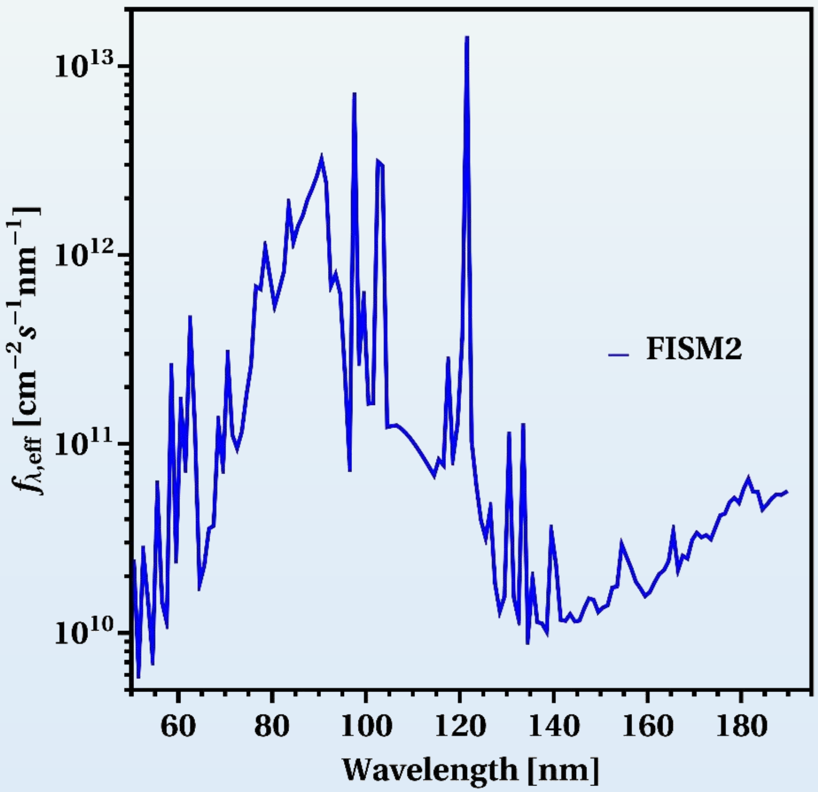
Quantum Yield:

✓ Depends on the energy of the radiation

✓ Depends on work function

? Regolith Temperature



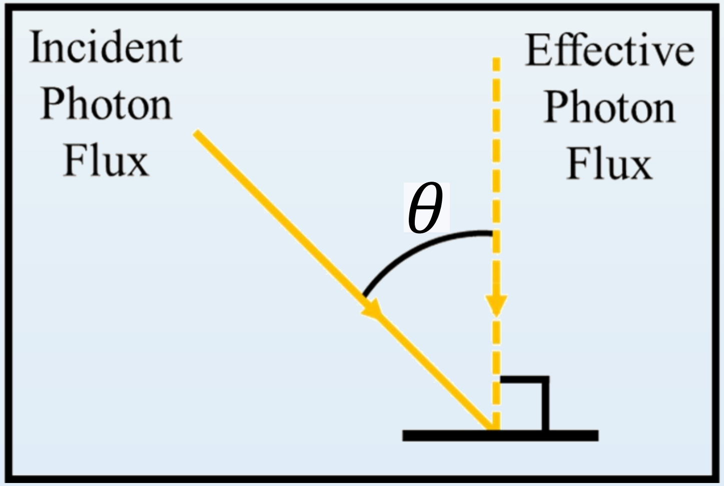


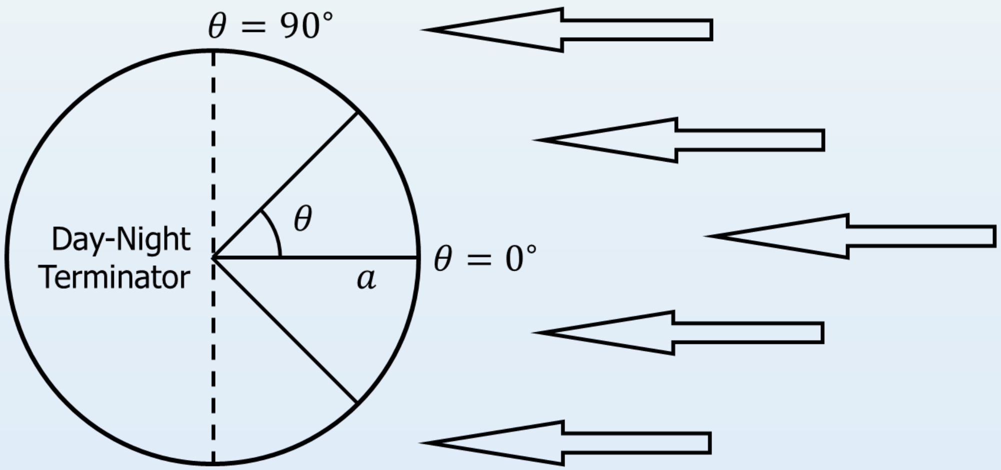
Regolith Temperature and Fermi Dirac Statistics

- Lunar Surface Temperature varies within 400 – 150 K over the equator (0°) to terminator (90°) (Williams et al 2017).
- Simple empirical relation given by Mishra and Bhardwaj 2019

$$T_0(\theta) = T_0(\theta = 0)\left[1 - \left(\frac{5}{4\pi}\right)\theta\right]$$

Here, θ is in radian



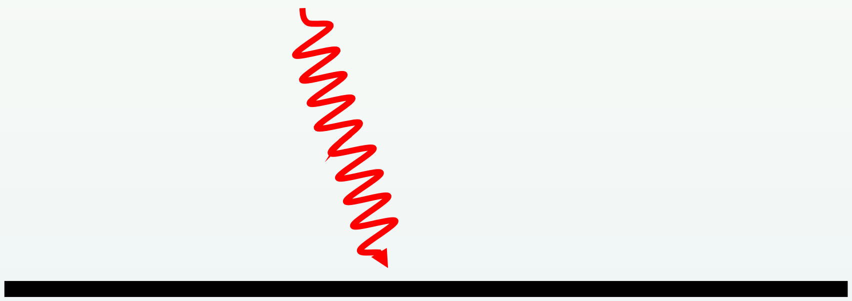


- Fowler's Theory of Photoelectron emission
  - Fermi-Dirac statistics of electrons within the lattice

Photoelectron Contribution

This Theory Includes

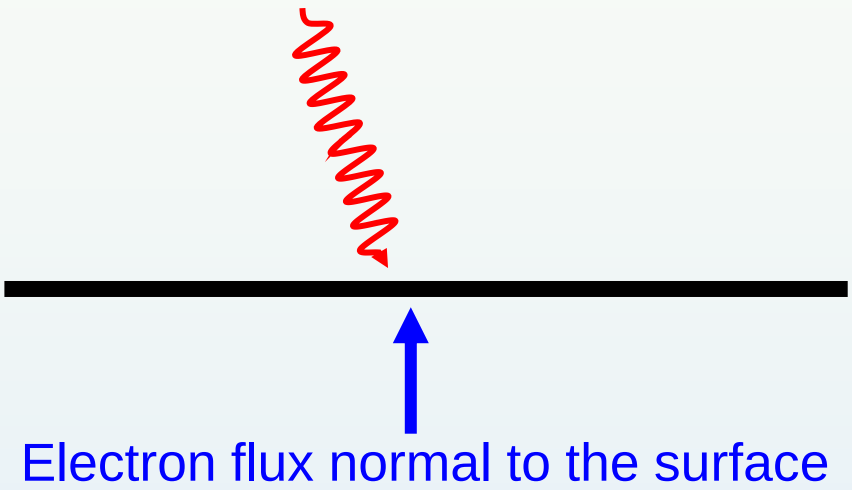
Photoelectron Contribution



This Theory Includes

- ✓ Solar photon flux
- ✓ Regolith Work function

Photoelectron Contribution



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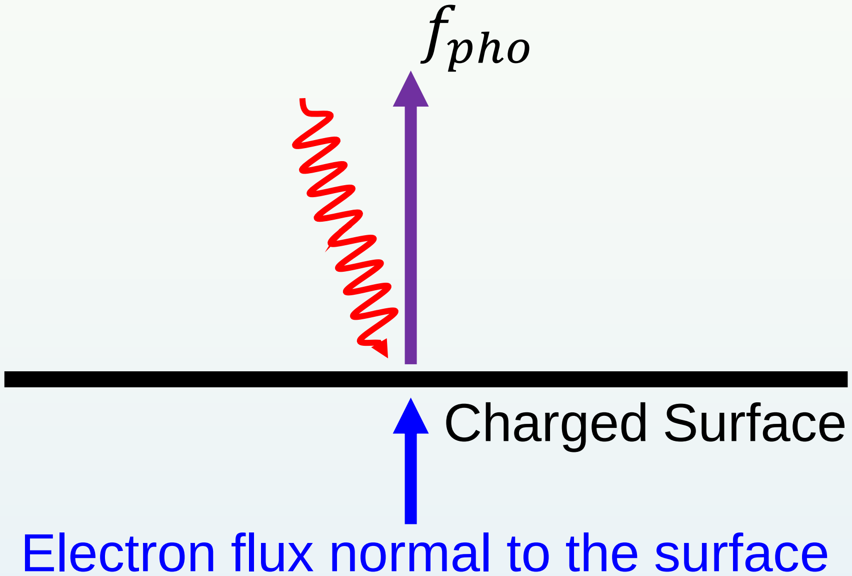
- ✓ Regolith Temperature
- ✓ VDF of lattice electrons

Photoelectron Contribution



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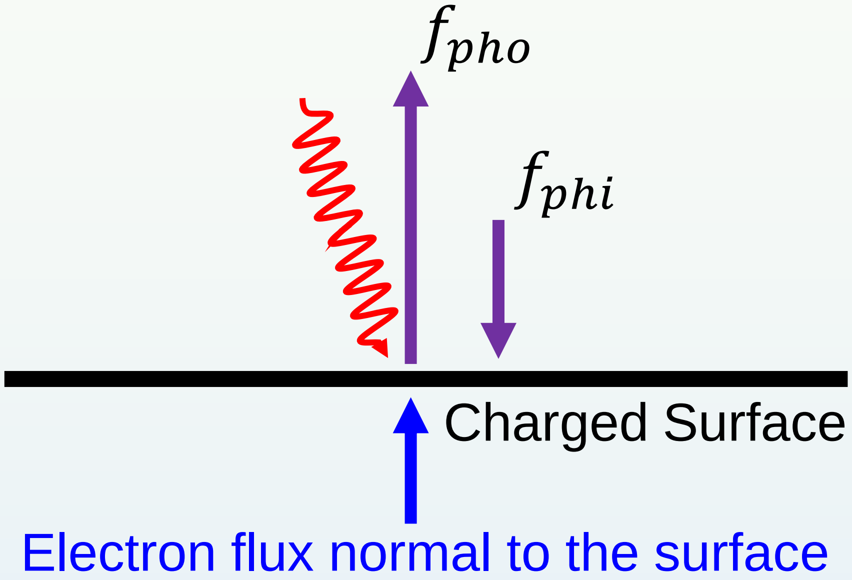

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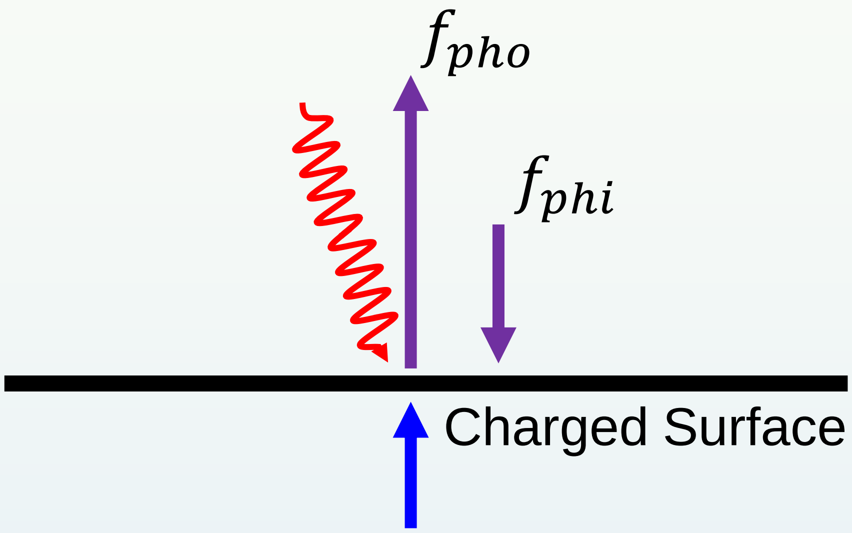
Photoelectron Contribution



This Theory Includes

- ✓ Solar photon flux
- ✓ Regolith Work function
- ✓ Regolith Temperature
- ✓ VDF of lattice electrons
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- ✓ Lunar Surface Potential

New expression:

$$dn_{pe}(v) = \left(\frac{m_e}{2kT_0}\right)^{1/2} \cos\theta \int_{\lambda_{min}}^{\lambda_{max}} \left[\frac{\chi(\lambda) f_\lambda \, d\lambda}{\Phi(\xi_\lambda)}\right] \varepsilon_x^{-1/2} \ln[1 + \exp\{\xi_\lambda - \varepsilon_x + v_0 - v\}] d\varepsilon_x \,,$$

$\lambda_{max} = \frac{hc}{\phi}$ for Type C, $\lambda_{max} = \frac{hc}{\phi + eV_0}$ for Type B and $\lambda_{max} = \frac{hc}{\phi + e(V_0 - V_m)}$ for Type A.

- This expression has been used to derive the photoemission current and photoelectron population.

Boundary conditions

✓ Charge neutrality at the sheath edge.

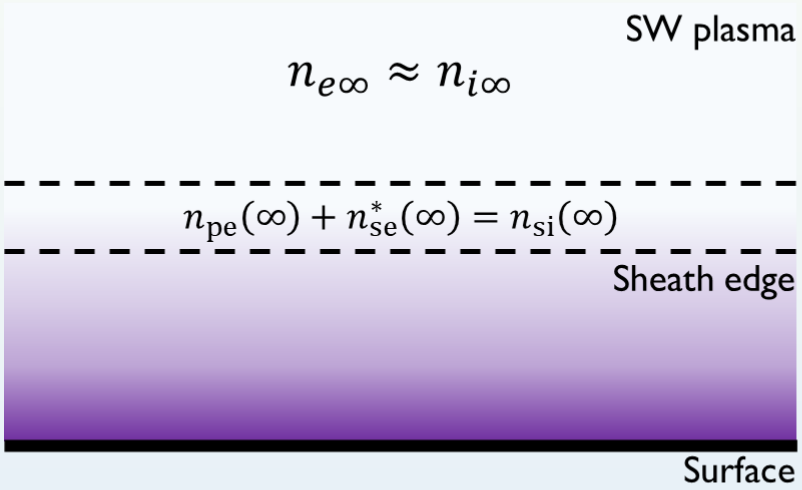
$$n_{\rm pe}(\infty) + n_{\rm se}^*(\infty) - n_{\rm si}(\infty) = 0,$$

✓ Zero net flux within the sheath

$$f_{\rm ph}(\infty) - f_{\rm se}(\infty) + f_{\rm si}(\infty) = 0,$$

✓ Zero fields at $x = x_m$ and ∞.

$$\int_0^{V_m} \left[n_{\rm pef} + n_{\rm sef} + n_{\rm sec} - n_{\rm si}\right] dV = 0.$$

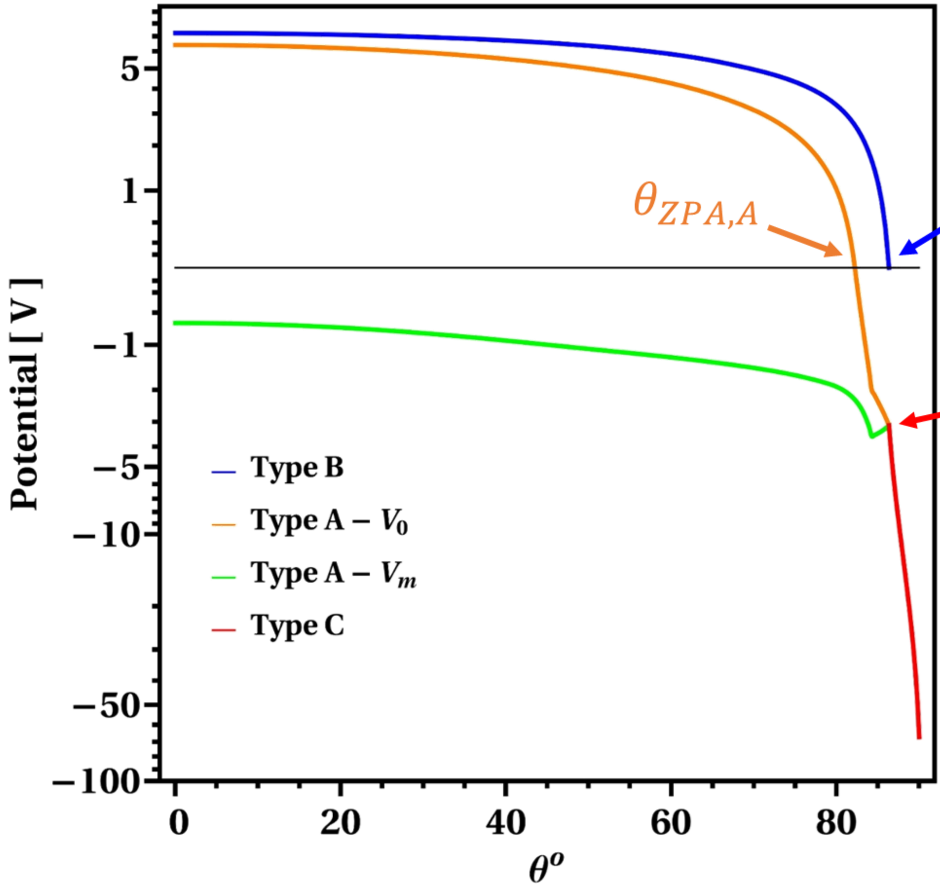


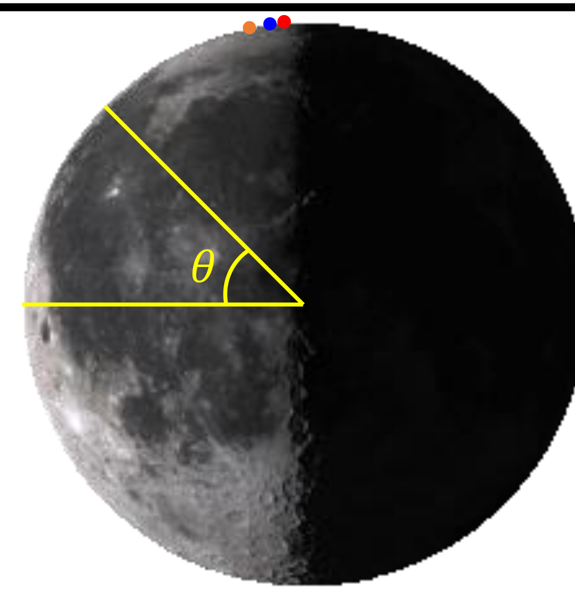
Computation time in Mathematica

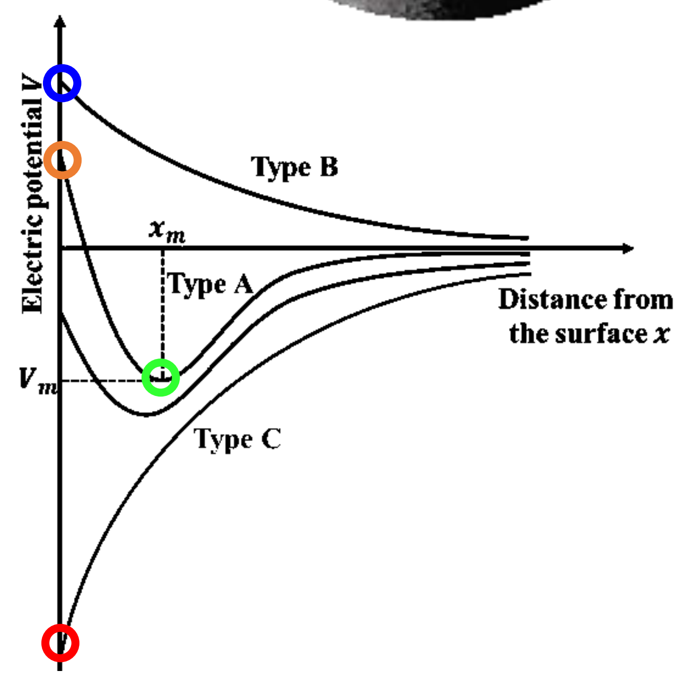
Type A	1-2 h
Type B	15 min
Type C	Less than 5 min

- Unknown parameters: V_0, $n_{se}^*(\infty)$, V_m.
- Poisson's equation has been solved using these parameters

Surface and Dip Potential





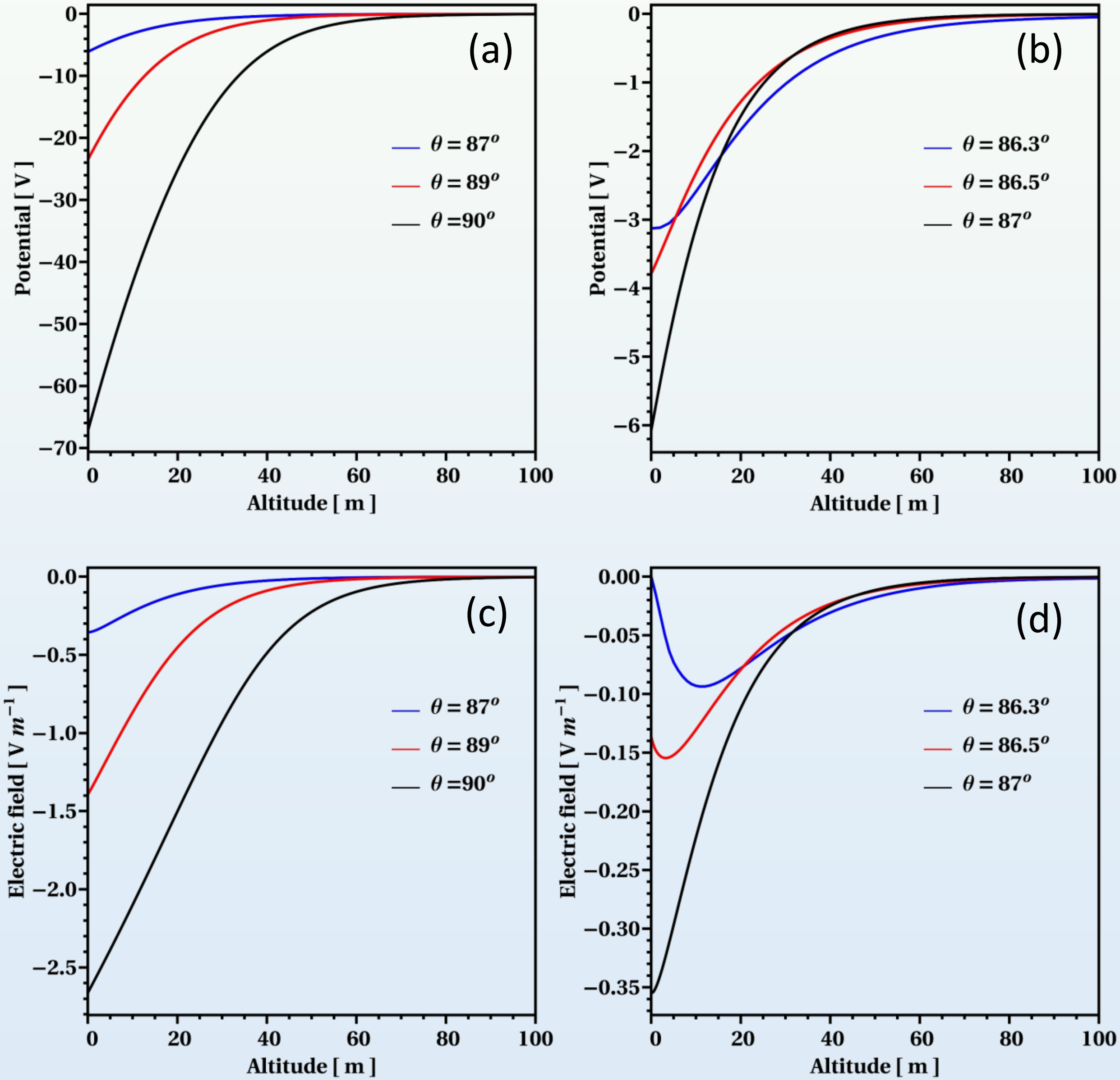


Parameter used:

$\phi = 5$ eV, $n_{i\infty} = 10$ cm^{-3}, $T_e = 15$ eV,

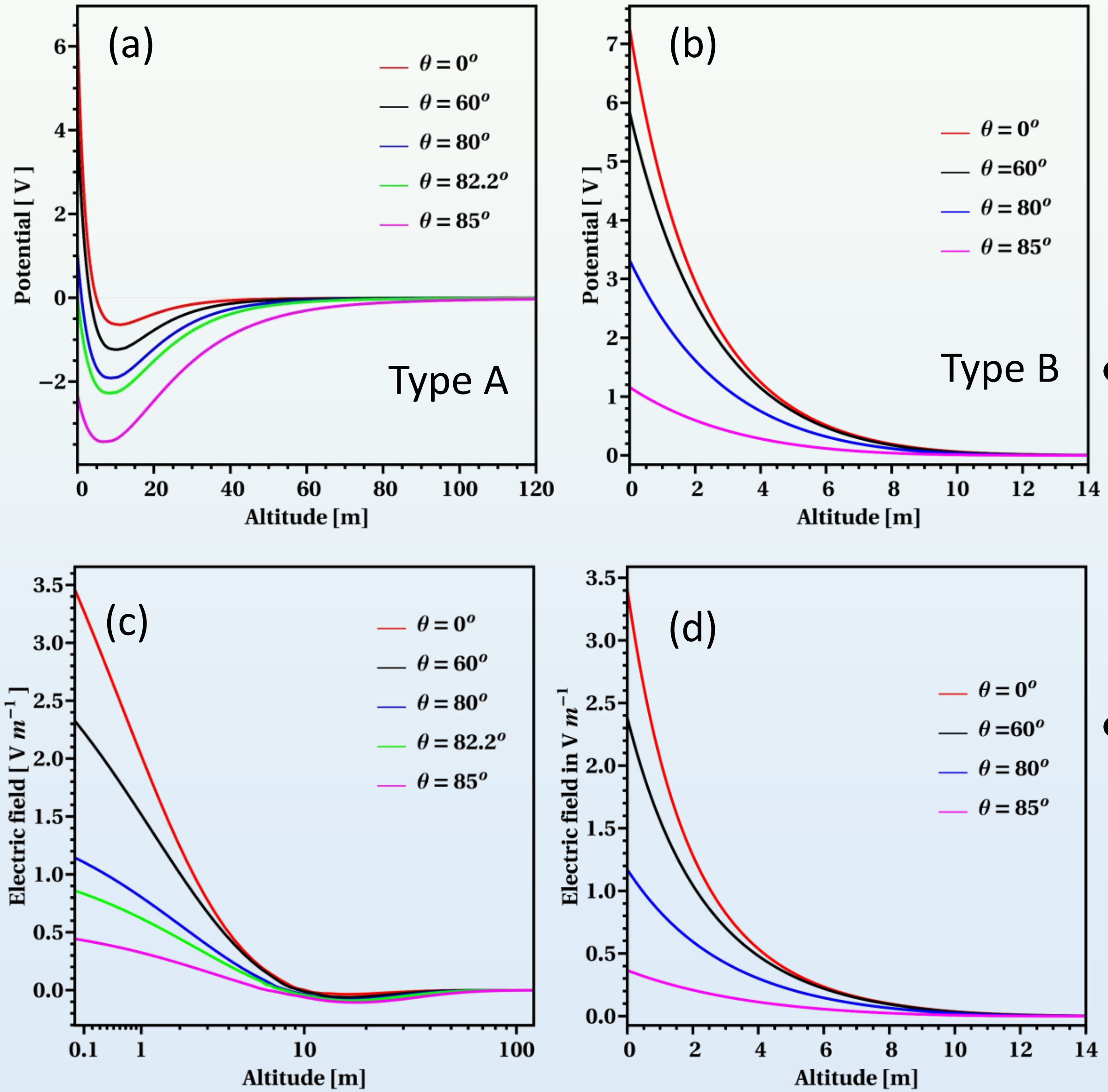
$\frac{u_{i\infty}}{u_B} = 10, \kappa = 3$

Type C solution



- A Type C can stretch up to $\sim$ 100m
- At $86.3°$, the surface electric field becomes zero, Type C transform to Type A

Type A & B soultions



- A ~ 60 m and ~ 120 m vertical extension of Type A sheath near the equator and terminator, respectively

- Type B sheath has small thickness ~ 12 m

On the Stability

Total potential energy of the system

(Guernsey and Fu 1970)

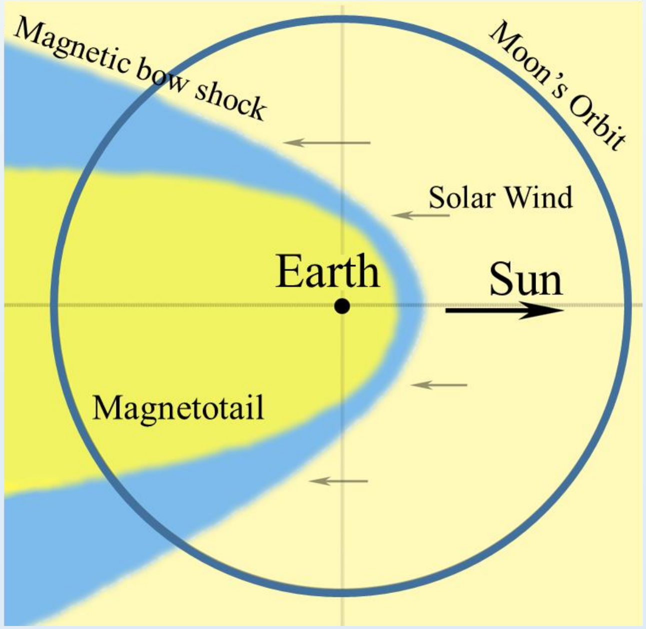
$$U = -\frac{\varepsilon_0}{2}\int_0^\infty \left(\frac{dV}{dx}\right)^2 dx$$

Angle (θ) (degree)	$n_{i\infty} = 5\,\mathrm{cm}^{-3}$ $T_e = 15\,\mathrm{eV}$	$n_{i\infty} = 10\,\mathrm{cm}^{-3}$ $T_e = 15\,\mathrm{eV}$	$n_{i\infty} = 5\,\mathrm{cm}^{-3}$ $T_e = 30\,\mathrm{eV}$
0°	1.00	0.97	0.92
20°	1.00	0.94	0.92
40°	1.00	1.01	0.97
60°	1.01	1.02	1.01
80°	1.01	1.02	0.94
82.5°	0.96	0.92	0.82
85°	0.77	0.43	0.51

Ratio of the total potential energy of Type B and Type A sheath (U_B / U_A) for different values of θ

Exotic cases

- Type A sheath (negative surface potential) is found to be a more stable throughout the photoemission dominated region
- Entire Moon acquires high negative potential
- Detrimental situation for rover/astronaut activity



	Tail lobe $n_{i\infty} = 0.5\ \text{cm}^{-3}$ $T_e = 100$ eV	Plasma sheet $n_{i\infty} = 1\ \text{cm}^{-3}$ $T_e = 1$ keV
Type B		
$\theta = 0°$	$V_0 = 10.9$ V	$V_0 = 9.8$ V
$\theta_{ZPA,B}$	89.8°	89.5°
Type A		
$\theta = 0°$	$V_0 = -0.65$ V	$V_0 = -147.2$ V
	$V_m = -10.64$ V	$V_m = -154.9$ V
$\theta_{ZPA,A}$	-	-
$\theta_{A\to C}$	89.6°	87.9°
	$V_0 = -43.9$ V	$V_0 = -570.9$ V
Type C		
$\theta = 90°$	$V_0 = -446.8$ V	$V_0 = -4468.2$ V

Monthly Notices
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MNRAS **520,** 233–246 (2023) https://doi.org/10.1093/mnras/stad155
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Plasma sheath around sunlit moon: monotonic and non-monotonic structures

Trinesh Sana [1,2]★ and S. K. Mishra [1]★

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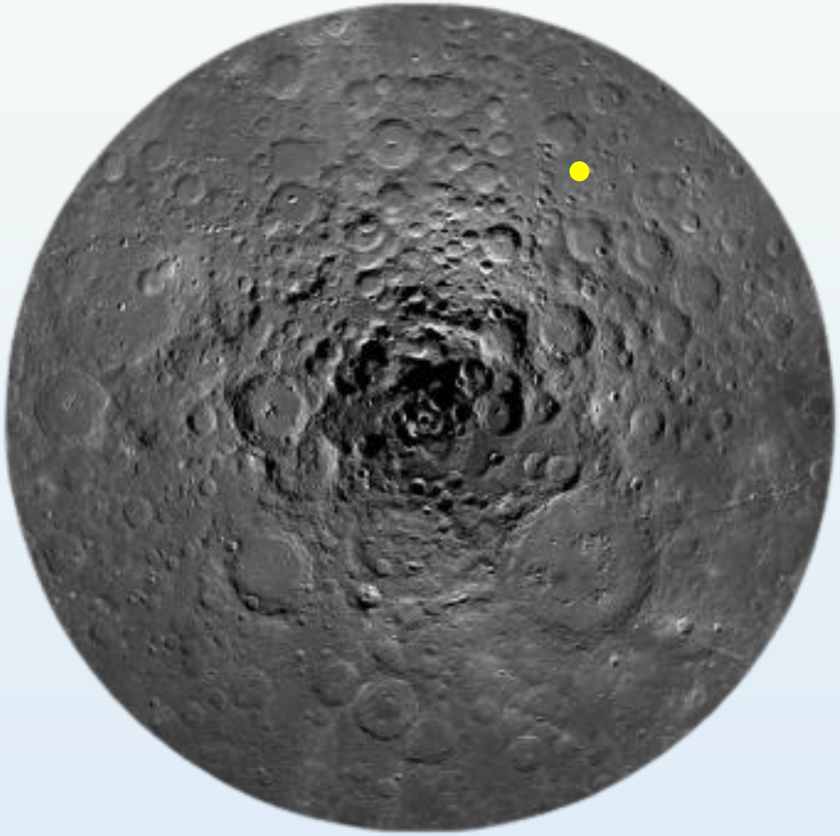
[2] *Indian Institute of Technology Gandhinagar, Gandhinagar, Gujarat 382355, India*

Accepted 2023 January 12. in original form 2022 November 28

Chandrayaan 3 (Ch3) Landing Site (LS)

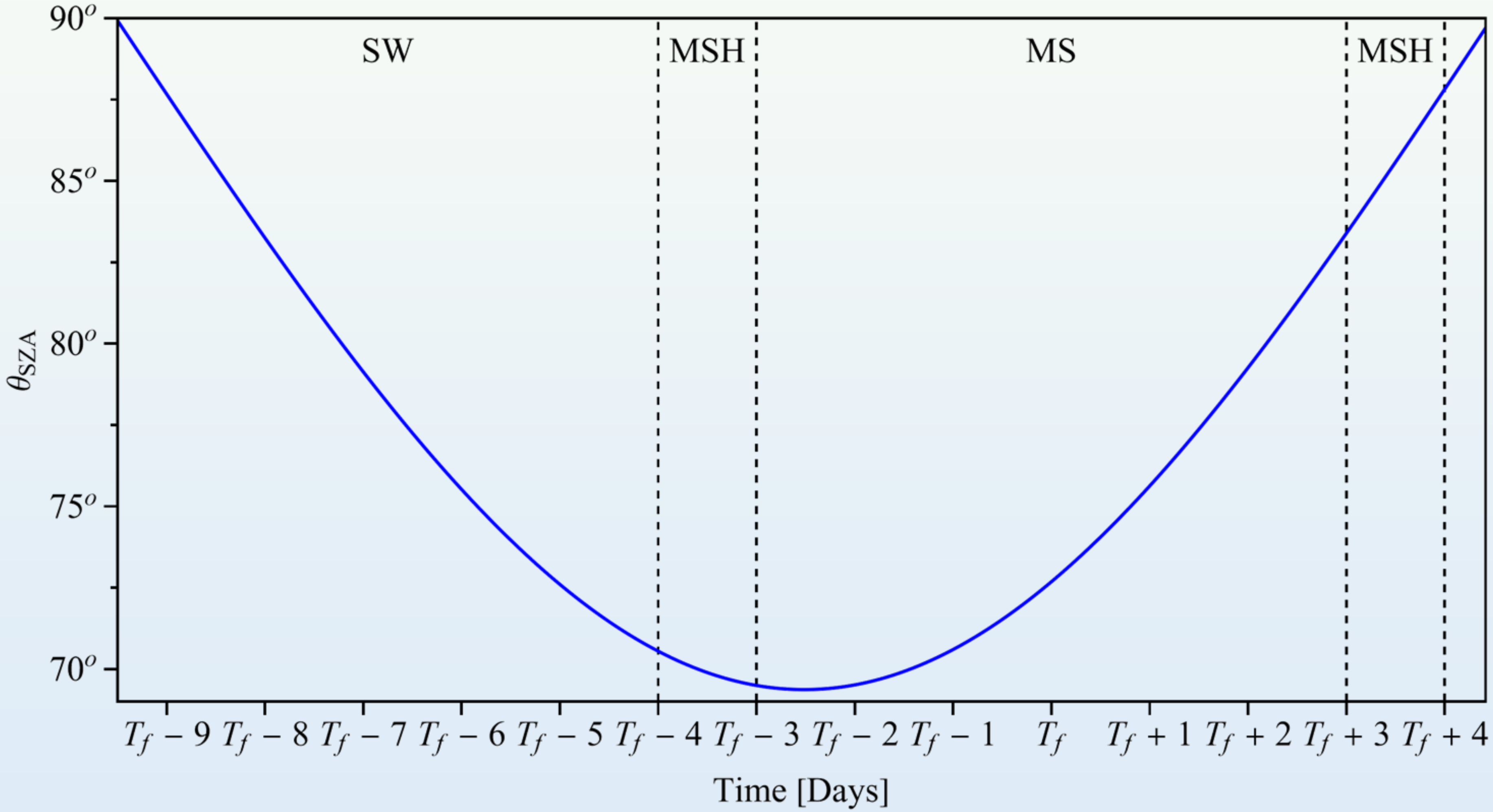
South Poler View



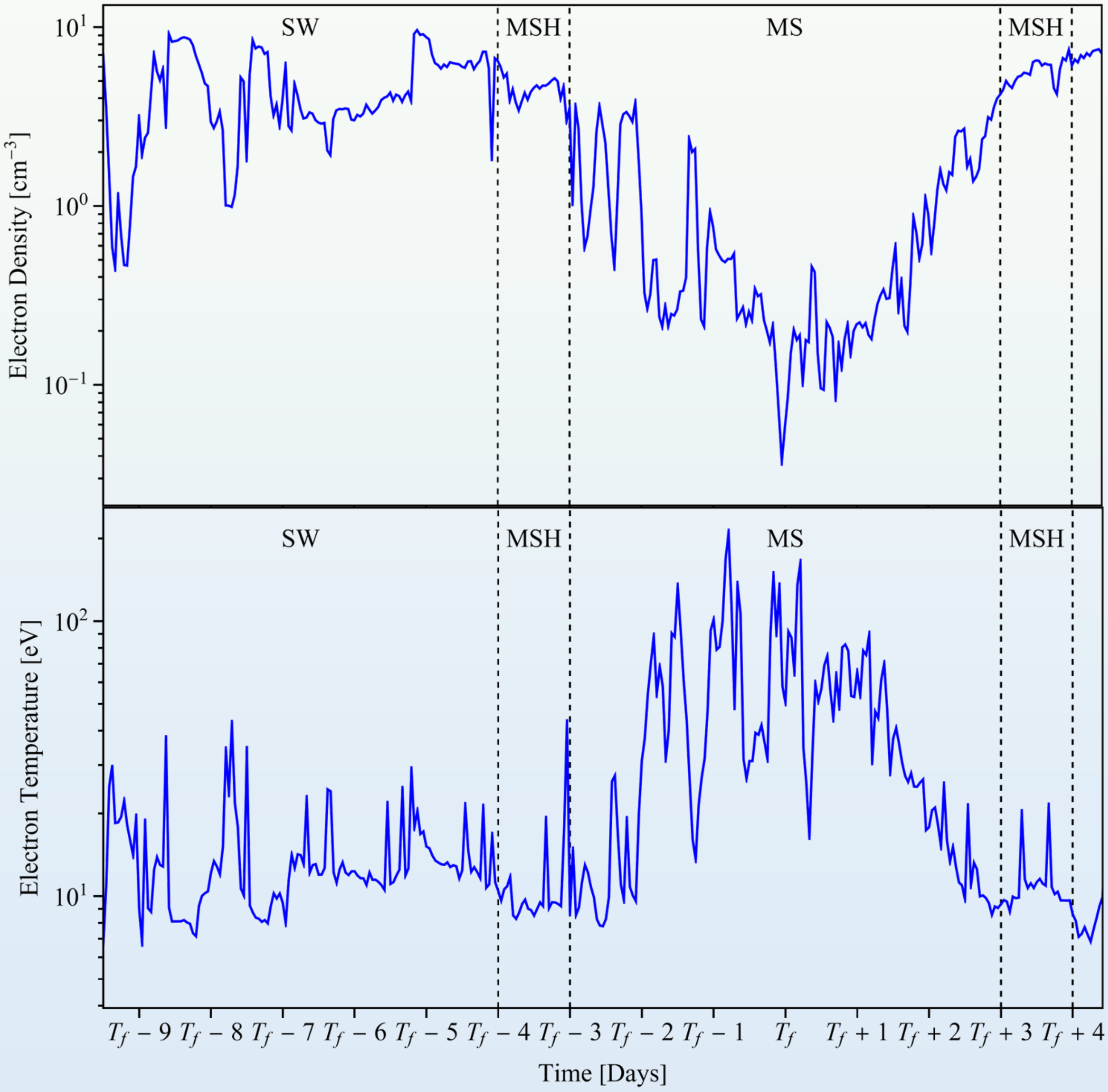
Near Side View

69.367621 S, 32.348126 E

Illumination Condition Around Ch 3 LS

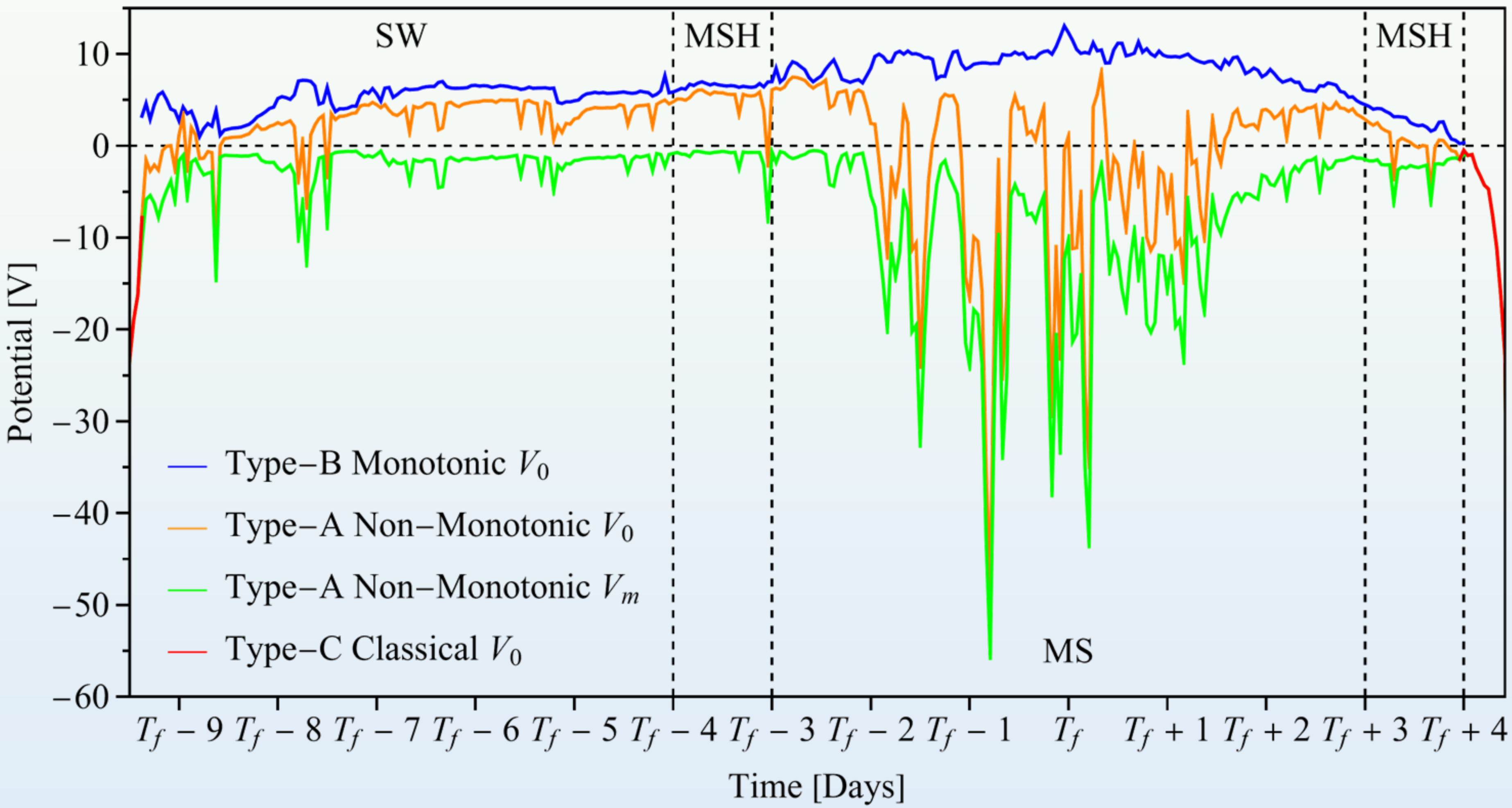


Plasma Parameters Around Ch 3 LS



We have used 1 hour averaged data from the ARTEMIS P2 spacecraft (former THEMIS-C probe) orbiting the Moon. (Angelopoulos 2011)

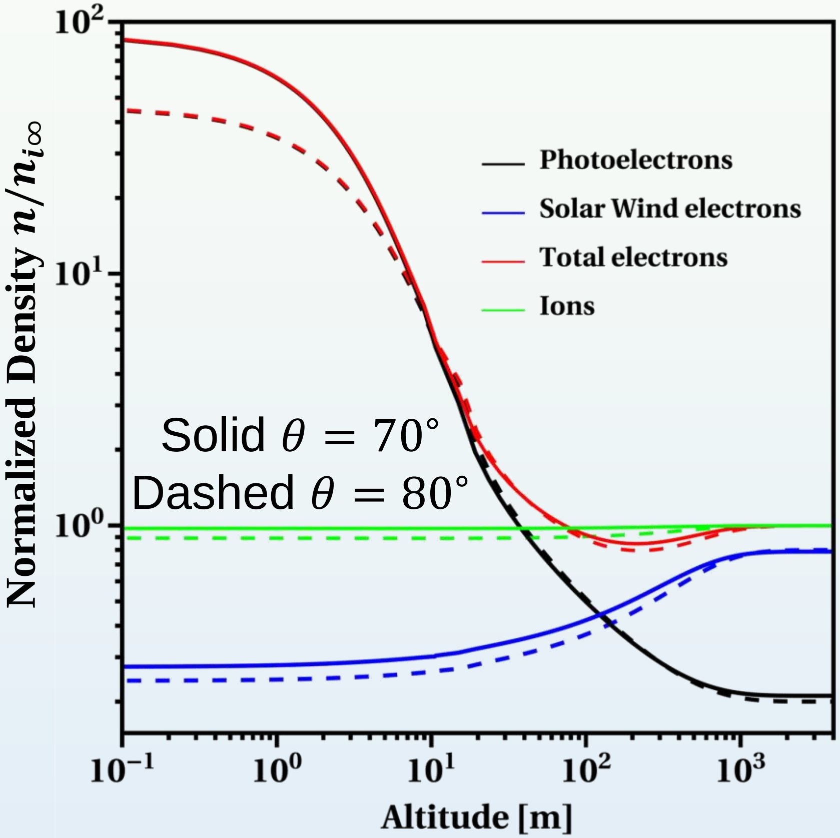
Potential Around Ch 3 LS



Parameter used:

$\phi = 5 \text{ eV}, \dfrac{u_{i\infty}}{u_B} = 10, \kappa = 3$

Predictions for Langmuir Probe onboard on Ch 3



Parameter used based on the plasma sheet parameters reported by Halekas et al. 2008:
$\phi = 5\ \text{eV}, n_{i\infty} = 0.5\ \text{cm}^{-3}, T_e = 1\ \text{keV},$
$\frac{u_{i\infty}}{u_B} = 10, \kappa = 3$

Near the Ch3 LS

$n_{pe} \sim 10 - 40\ \text{cm}^{-3}$

$E_m \sim 2.6 - 3\ \text{eV}$

The mean energy of the photoelectrons (Mishra 2020):

$$E_m = \left(\frac{kT_0}{ef_{ph}}\right)\cos\theta \int_0^{\infty}\int_{\lambda_{min}}^{\lambda_{max}} \frac{\varepsilon^2 \chi(\lambda) f_\lambda\, d\lambda\, d\varepsilon}{[1 + \exp(\varepsilon - \xi_\lambda - \upsilon_0 + \upsilon_m)]}$$

Paper Under Review

Summary

- A new theory has been developed, applicable to various plasma conditions such as solar wind, Earth's tail lobe, Earth's plasma sheath, and SEP/CME events.
- The new theory quantifies three types of sheaths and their possibilities:
  - Near equator (both Type A & B), mid latitude (Type B), near the terminator (Type A), very close to the terminator (Type C) for nominal solar wind condition
  - In exotic cases, the Type A sheath with negative surface potential remains stable throughout the photoemission dominated region, resulting in the entire Moon acquiring a high negative potential.
- Based on the new theory, the potential around Ch 3 LS exhibits highly dynamic variations throughout the passage.
- The theory also predicts probable electron density and temperature in the vicinity of the Ch 3 LS.

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Prof. Jan Deca, Prof. Addie Dove, Prof. Jorge Nunez

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Director
Physical Research Laboratory, India

Thank You