DSNE and the lunar plasma environment

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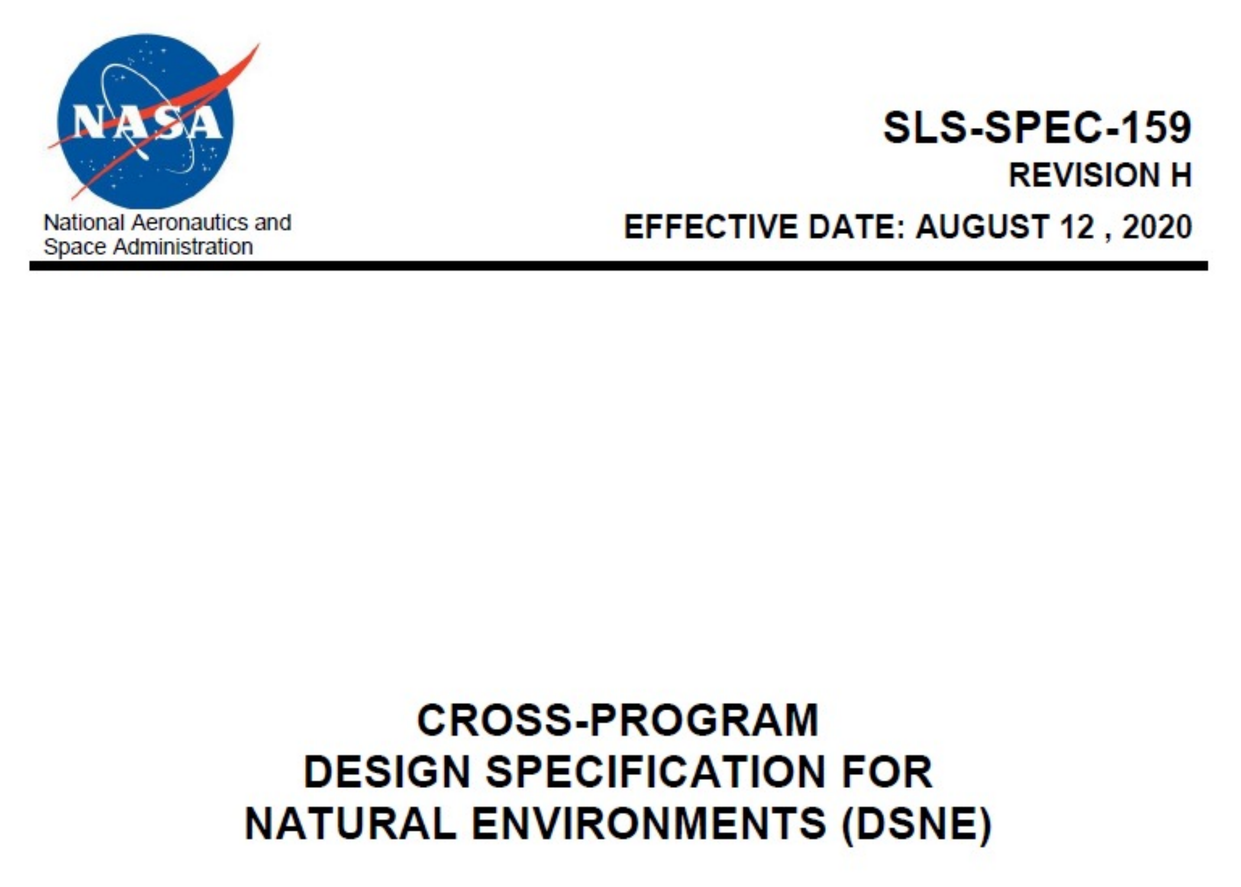
14 September 2021

SLS-SPEC-159 DSNE

- The **Cross-Program Design Specification for Natural Environments** *defines the natural environment for crewed, deep-space NASA programs*
- Latest revision (currently Rev H) available through the NASA Technical Reports Server (NTRS)
  - https://ntrs.nasa.gov/citations/20205007447
  - When searching, latest revision is not always the first result
  - Best to filter by Report Number using “SLS-SPEC-159”

SLS-SPEC-159 DSNE

- Relevant sections for the plasma environment
  - 3.3.3 Plasma Charging (p. 179)
    - In-space phase
  - 3.4.3 Lunar Surface Plasma Environment (p. 255)



National Aeronautics and
Space Administration

SLS-SPEC-159
REVISION H
EFFECTIVE DATE: AUGUST 12 , 2020

CROSS-PROGRAM
DESIGN SPECIFICATION FOR
NATURAL ENVIRONMENTS (DSNE)

SLS-SPEC-159 DSNE

- 3.3.3 Plasma Charging (p. 179)
  - Lunar on-orbit environment collected by THEMIS-ARTEMIS mission from 2012 to 2018
  - Relevant parameters formatted for input into spacecraft charging models

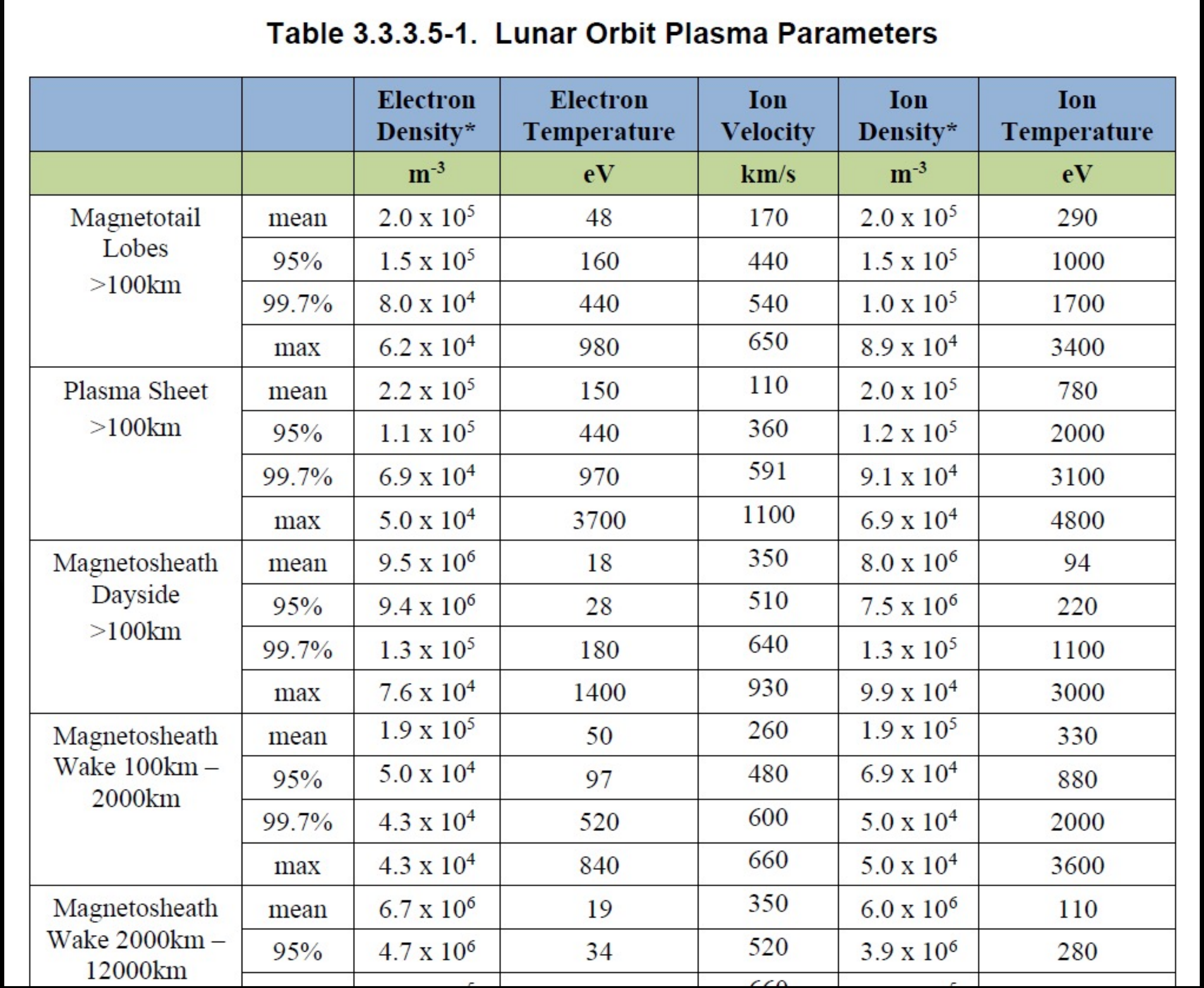


Table 3.3.3.5-1. Lunar Orbit Plasma Parameters

		Electron Density*	Electron Temperature	Ion Velocity	Ion Density*	Ion Temperature
		m^{-3}	eV	km/s	m^{-3}	eV
Magnetotail Lobes >100km	mean	2.0×10^5	48	170	2.0×10^5	290
	95%	1.5×10^5	160	440	1.5×10^5	1000
	99.7%	8.0×10^4	440	540	1.0×10^5	1700
	max	6.2×10^4	980	650	8.9×10^4	3400
Plasma Sheet >100km	mean	2.2×10^5	150	110	2.0×10^5	780
	95%	1.1×10^5	440	360	1.2×10^5	2000
	99.7%	6.9×10^4	970	591	9.1×10^4	3100
	max	5.0×10^4	3700	1100	6.9×10^4	4800
Magnetosheath Dayside >100km	mean	9.5×10^6	18	350	8.0×10^6	94
	95%	9.4×10^6	28	510	7.5×10^6	220
	99.7%	1.3×10^5	180	640	1.3×10^5	1100
	max	7.6×10^4	1400	930	9.9×10^4	3000
Magnetosheath Wake 100km – 2000km	mean	1.9×10^5	50	260	1.9×10^5	330
	95%	5.0×10^4	97	480	6.9×10^4	880
	99.7%	4.3×10^4	520	600	5.0×10^4	2000
	max	4.3×10^4	840	660	5.0×10^4	3600
Magnetosheath Wake 2000km – 12000km	mean	6.7×10^6	19	350	6.0×10^6	110
	95%	4.7×10^6	34	520	3.9×10^6	280

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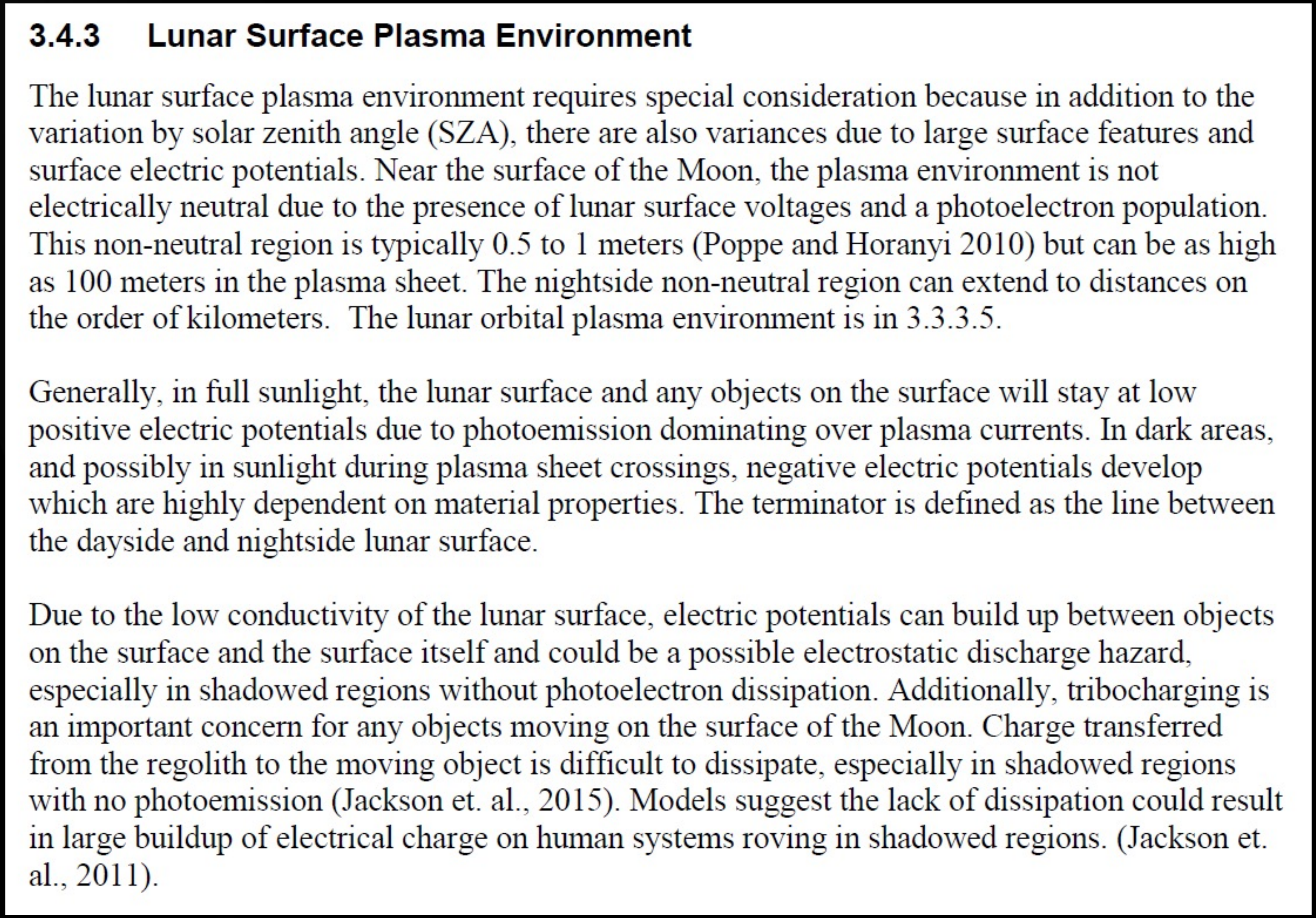
- 3.4.3 Lunar Surface Plasma Environment (p. 255)
  - Derived from in-space environments using research models
  - No known engineering tools to reliably predict spacecraft charging using environment as input



3.4.3 Lunar Surface Plasma Environment

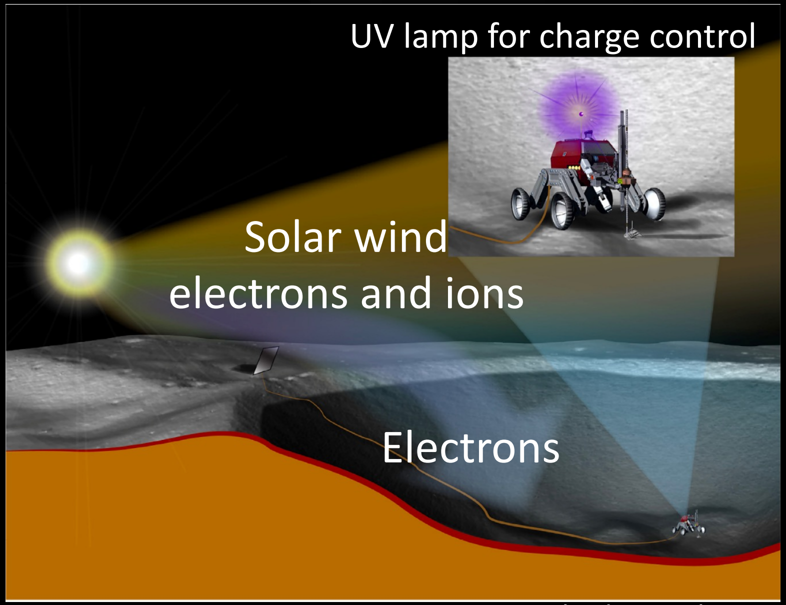
The lunar surface plasma environment requires special consideration because in addition to the variation by solar zenith angle (SZA), there are also variances due to large surface features and surface electric potentials. Near the surface of the Moon, the plasma environment is not electrically neutral due to the presence of lunar surface voltages and a photoelectron population. This non-neutral region is typically 0.5 to 1 meters (Poppe and Horanyi 2010) but can be as high as 100 meters in the plasma sheet. The nightside non-neutral region can extend to distances on the order of kilometers. The lunar orbital plasma environment is in 3.3.3.5.

Generally, in full sunlight, the lunar surface and any objects on the surface will stay at low positive electric potentials due to photoemission dominating over plasma currents. In dark areas, and possibly in sunlight during plasma sheet crossings, negative electric potentials develop which are highly dependent on material properties. The terminator is defined as the line between the dayside and nightside lunar surface.

Due to the low conductivity of the lunar surface, electric potentials can build up between objects on the surface and the surface itself and could be a possible electrostatic discharge hazard, especially in shadowed regions without photoelectron dissipation. Additionally, tribocharging is an important concern for any objects moving on the surface of the Moon. Charge transferred from the regolith to the moving object is difficult to dissipate, especially in shadowed regions with no photoemission (Jackson et. al., 2015). Models suggest the lack of dissipation could result in large buildup of electrical charge on human systems roving in shadowed regions. (Jackson et. al., 2011).

Why do we care about the plasma environment?

- Charge collection
  - Voltage difference resulting from plasma charge collection may cause electrostatic discharge, impacting avionics/equipment
  - Conversely, the plasma environment may dissipate charge generated by movement on the lunar surface (triboelectric charging)



Rhodes et al 2020

Why do we care about the plasma environment?

Charging governed by current balance

$$I_E(V) - \left[I_I(V) + I_{PH}(V) + I_{Secondary}(V)\right] = I_T$$

V = spacecraft surface potential relative to plasma

I_E = incident electron current

I_I = incident ion current

I_{PH} = photoelectric current

$I_{Secondary}$ = electron currents from secondaries, other sources

I_T = total current to spacecraft

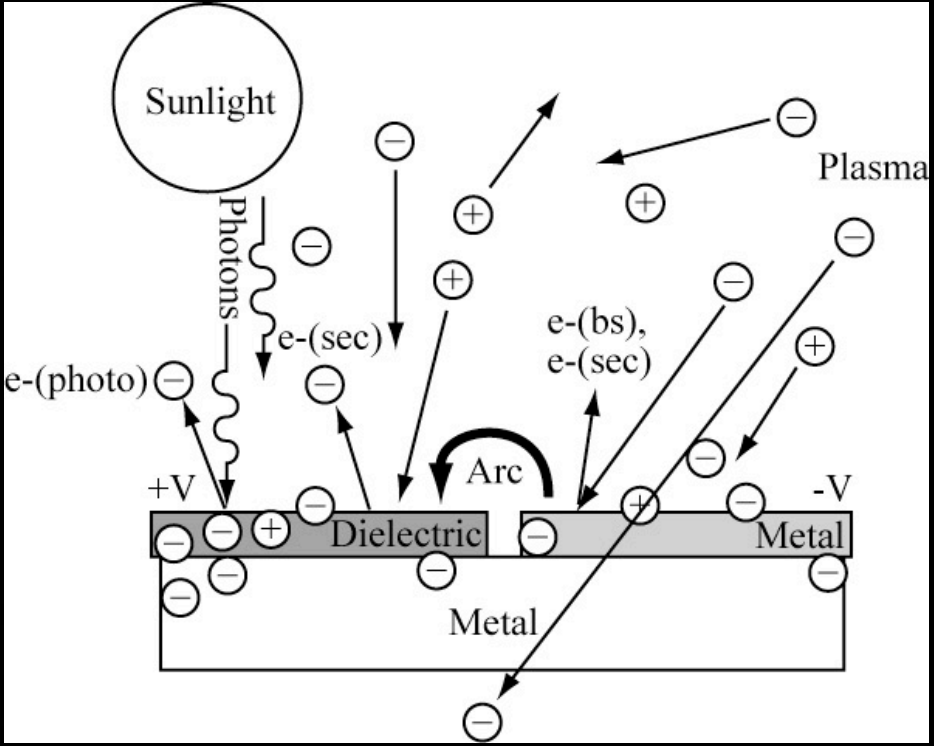
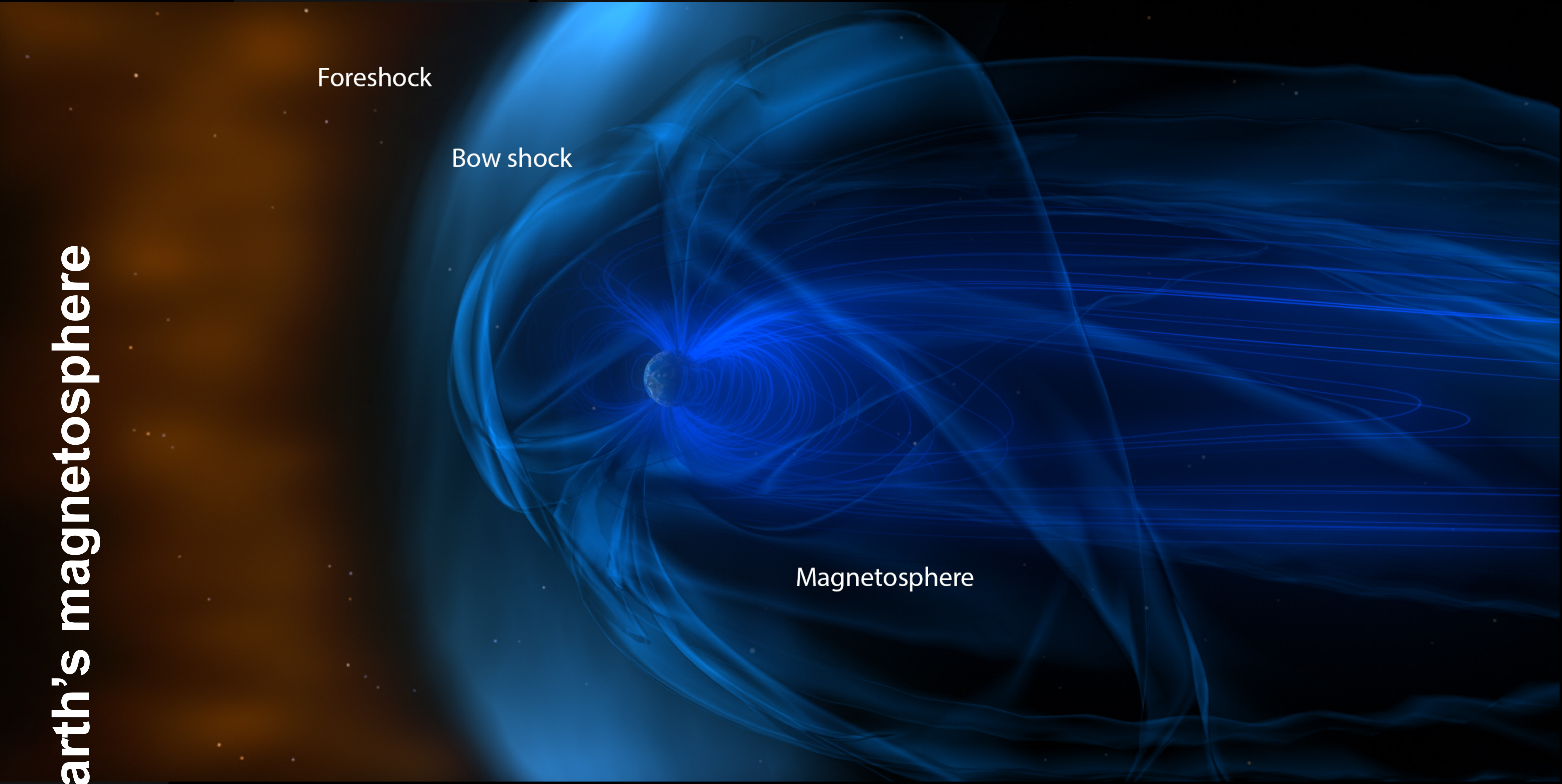


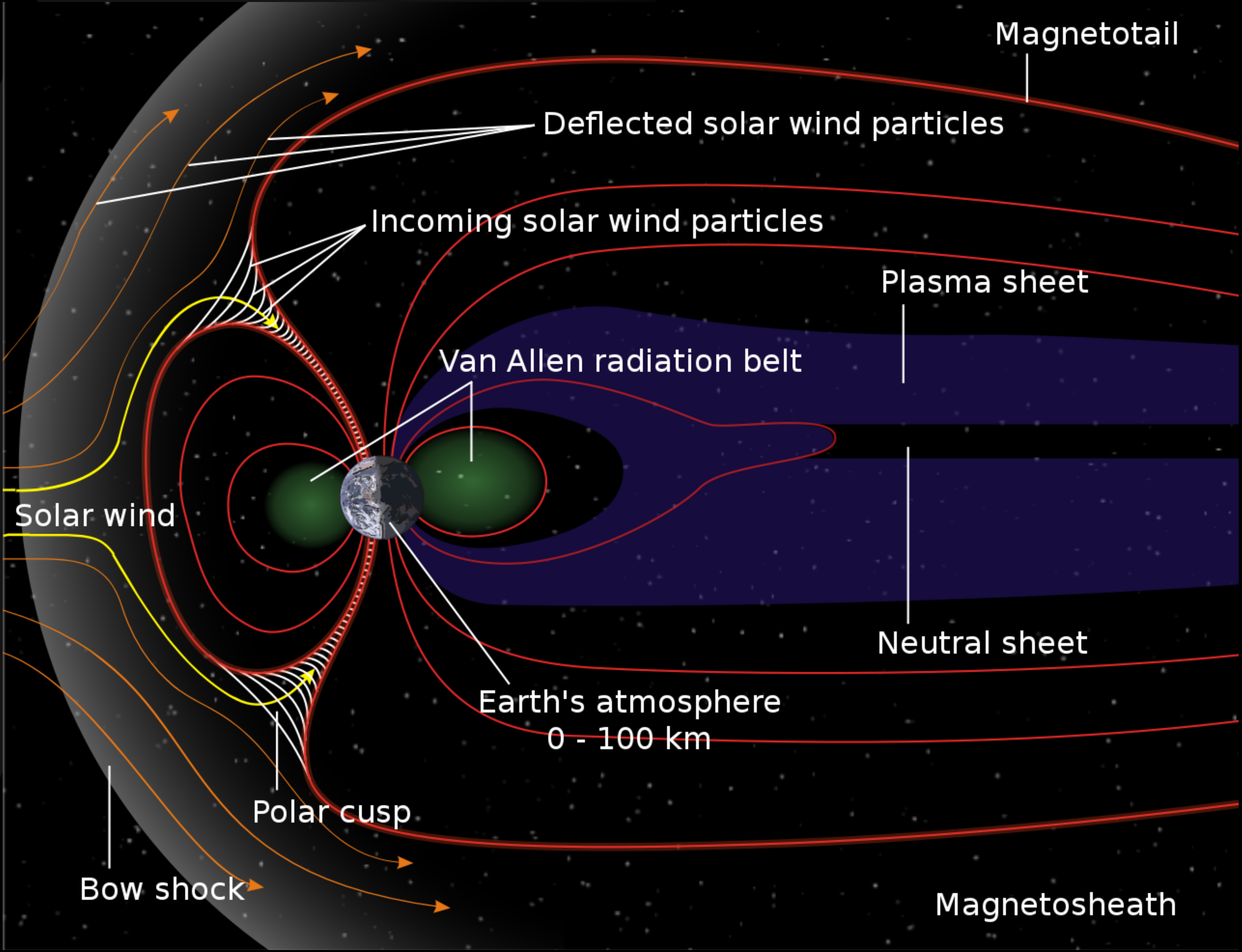
Figure from NASA-HDBK-4002

Earth’s magnetosphere



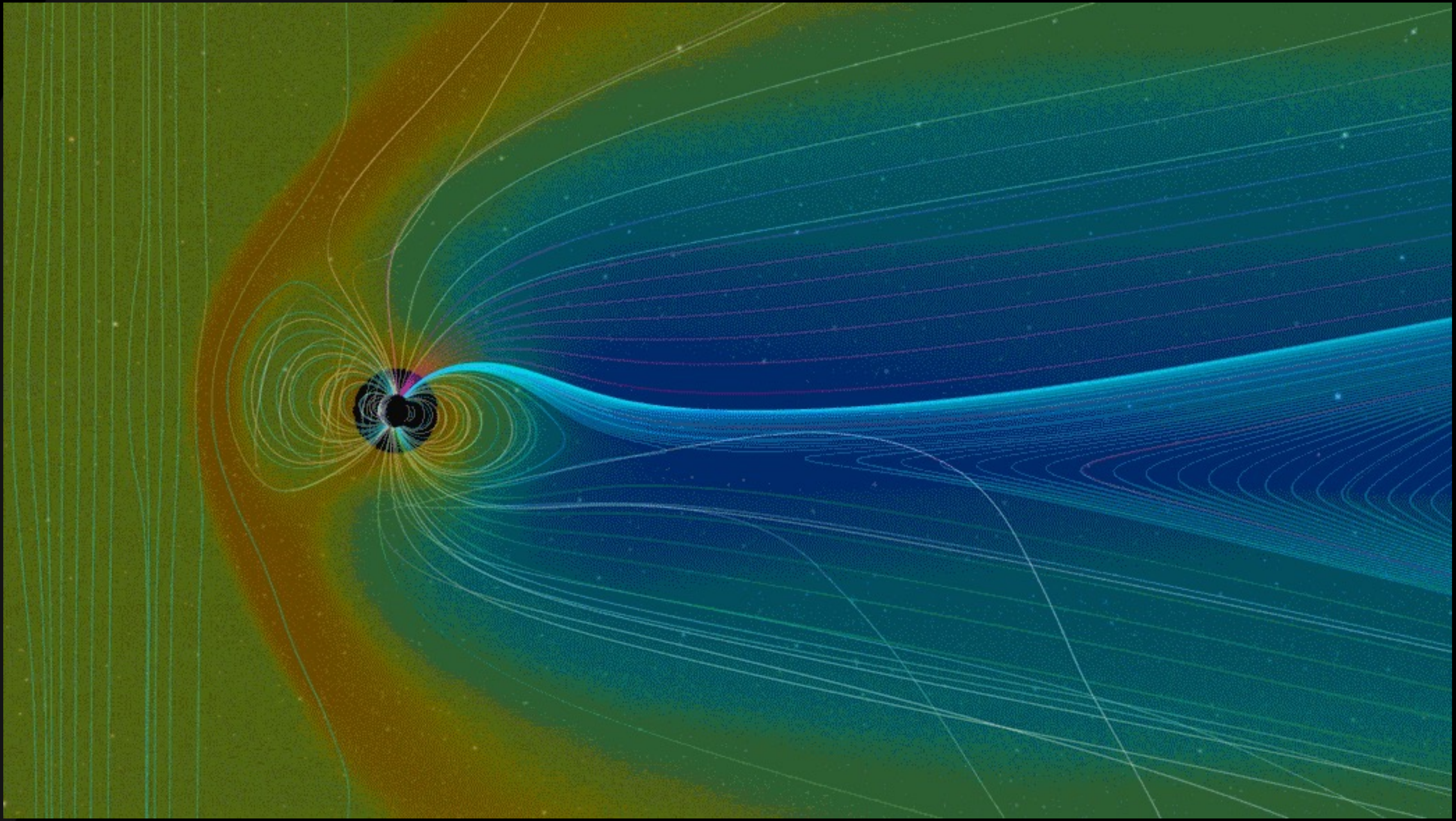
NASA/GSFC

Earth’s magnetosphere



NASA

Earth’s magnetosphere

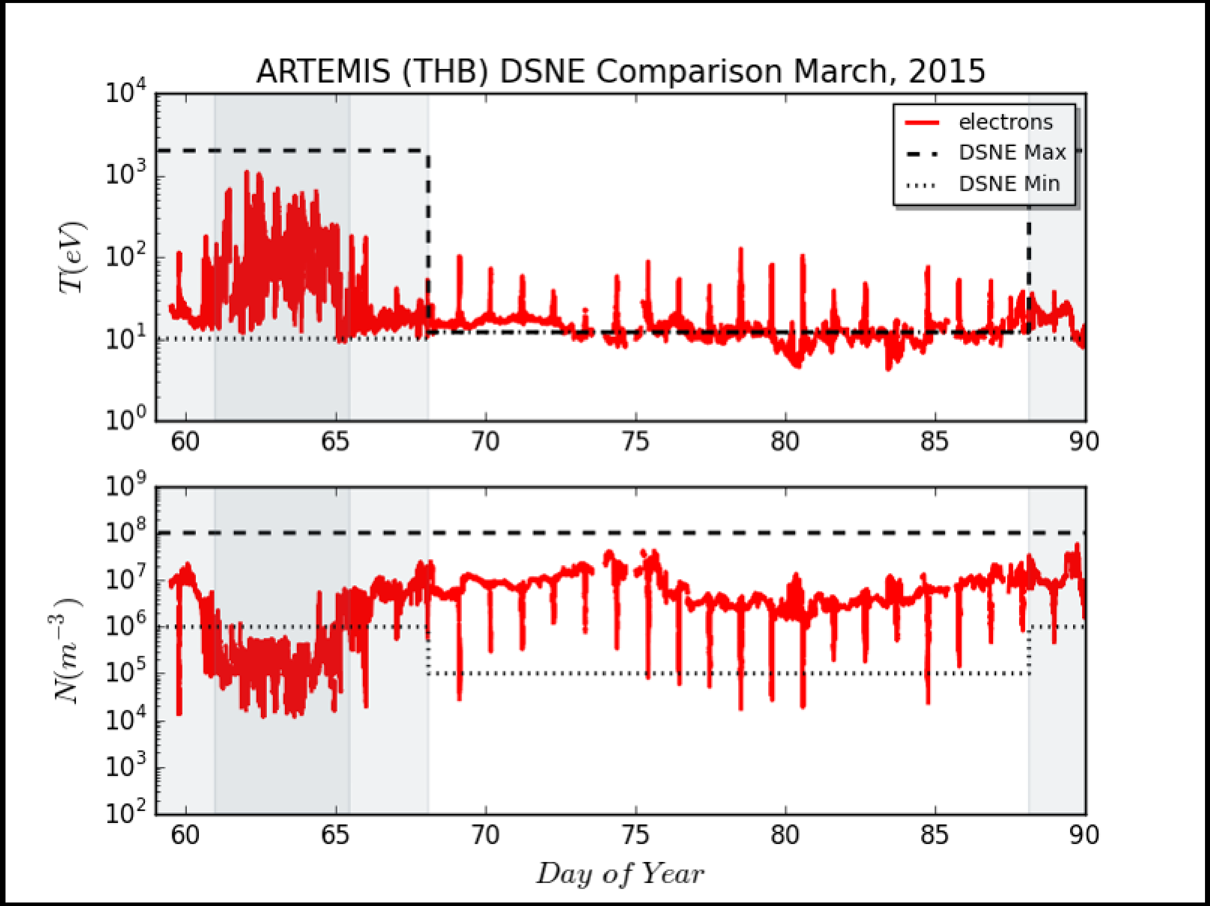


NASA/GSFC

Earth's magnetosphere

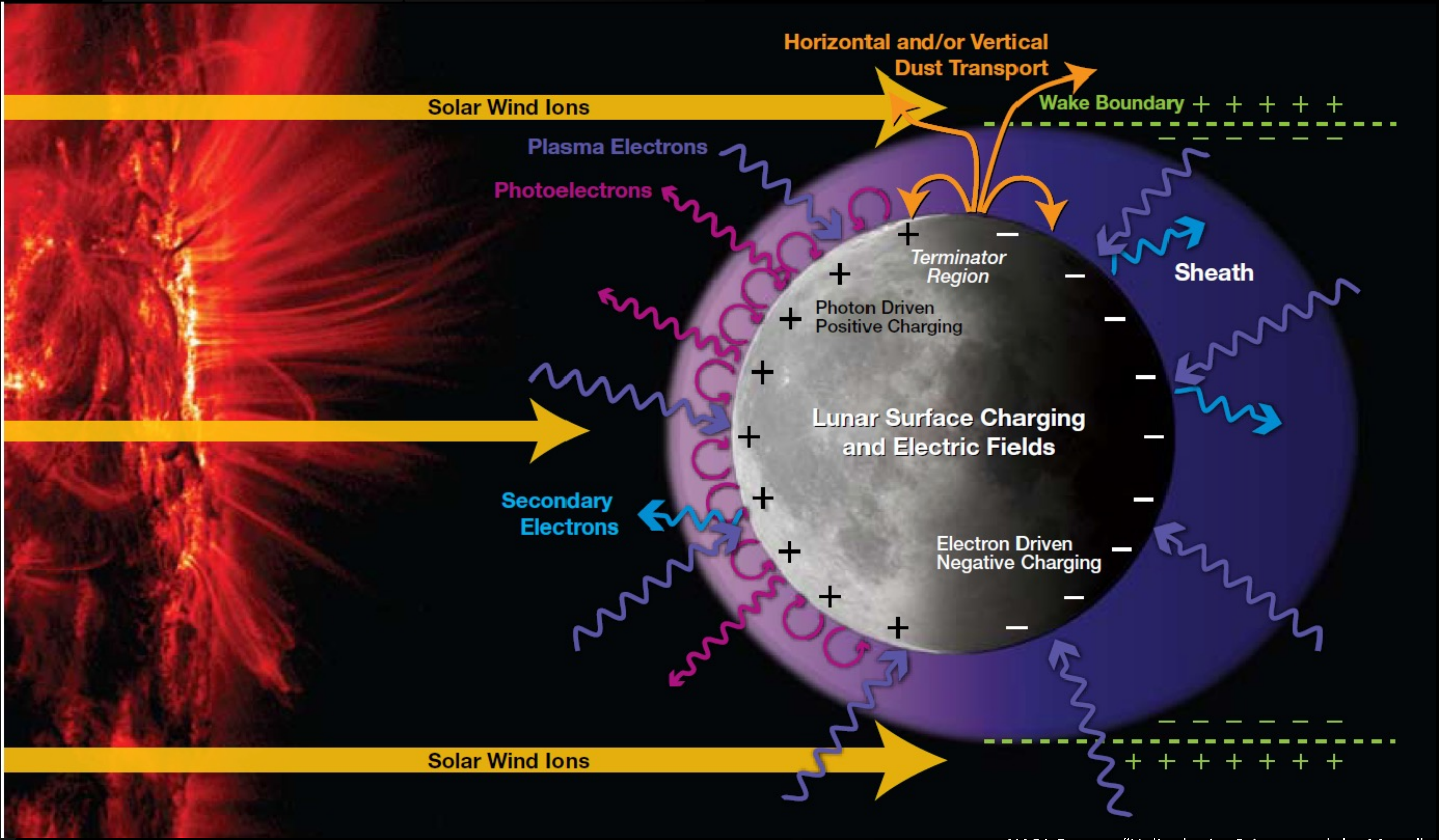
- ARTEMIS data taken during one Earth orbit
  - Light grey region = magnetosheath
  - Dark grey region = magnetotail
  - No shading = solar wind

- Electron temperature increases in magnetosheath
- Electron density decreases



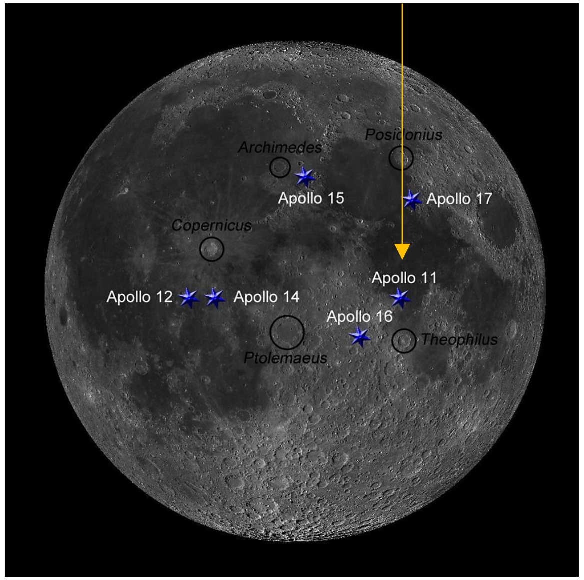
THEMIS-ARTEMIS data/Willis et al.

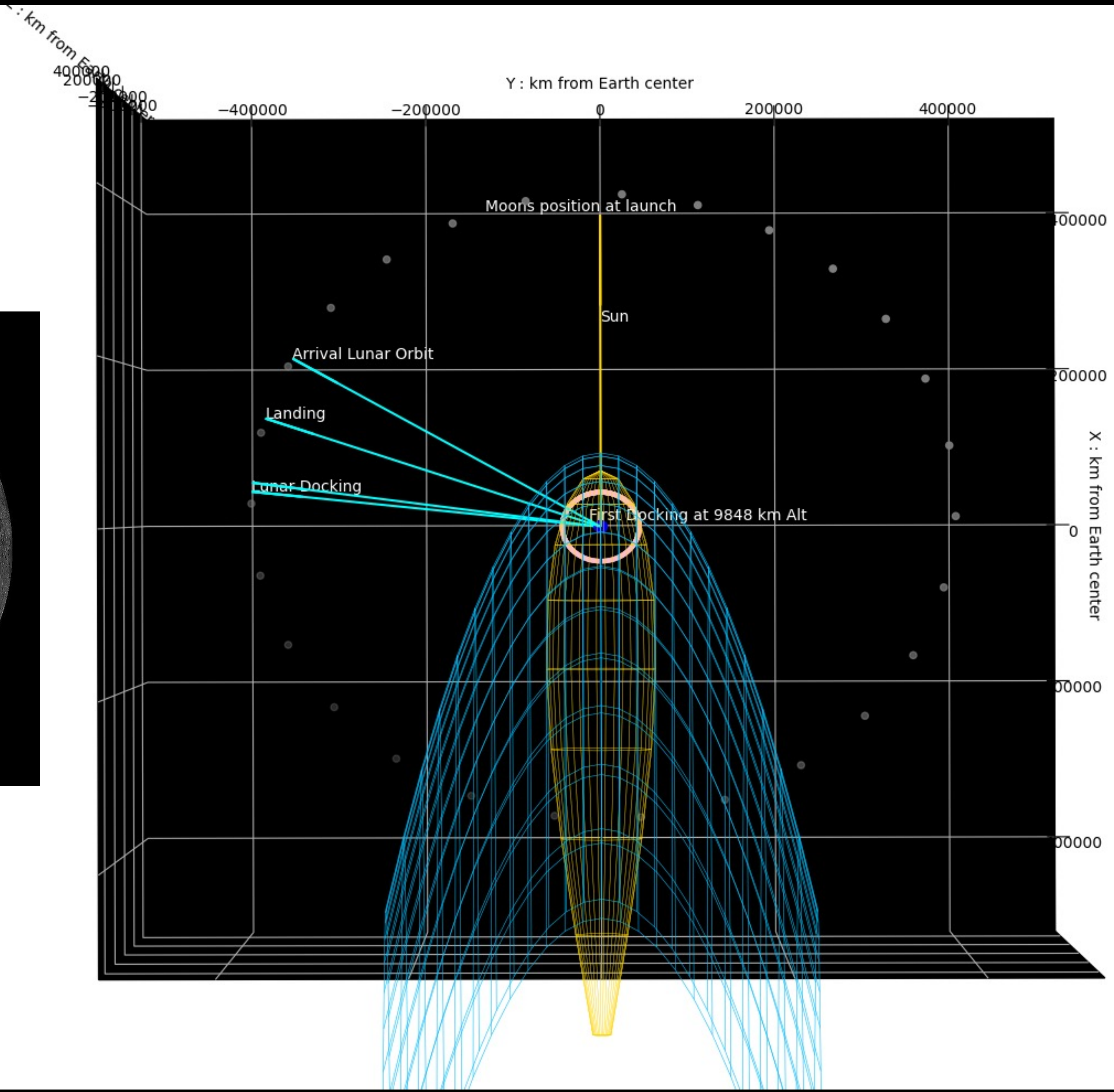
Lunar plasma environment



NASA Report: “Heliophysics Science and the Moon”

APOLLO 11
1969 JULY 16 – 24

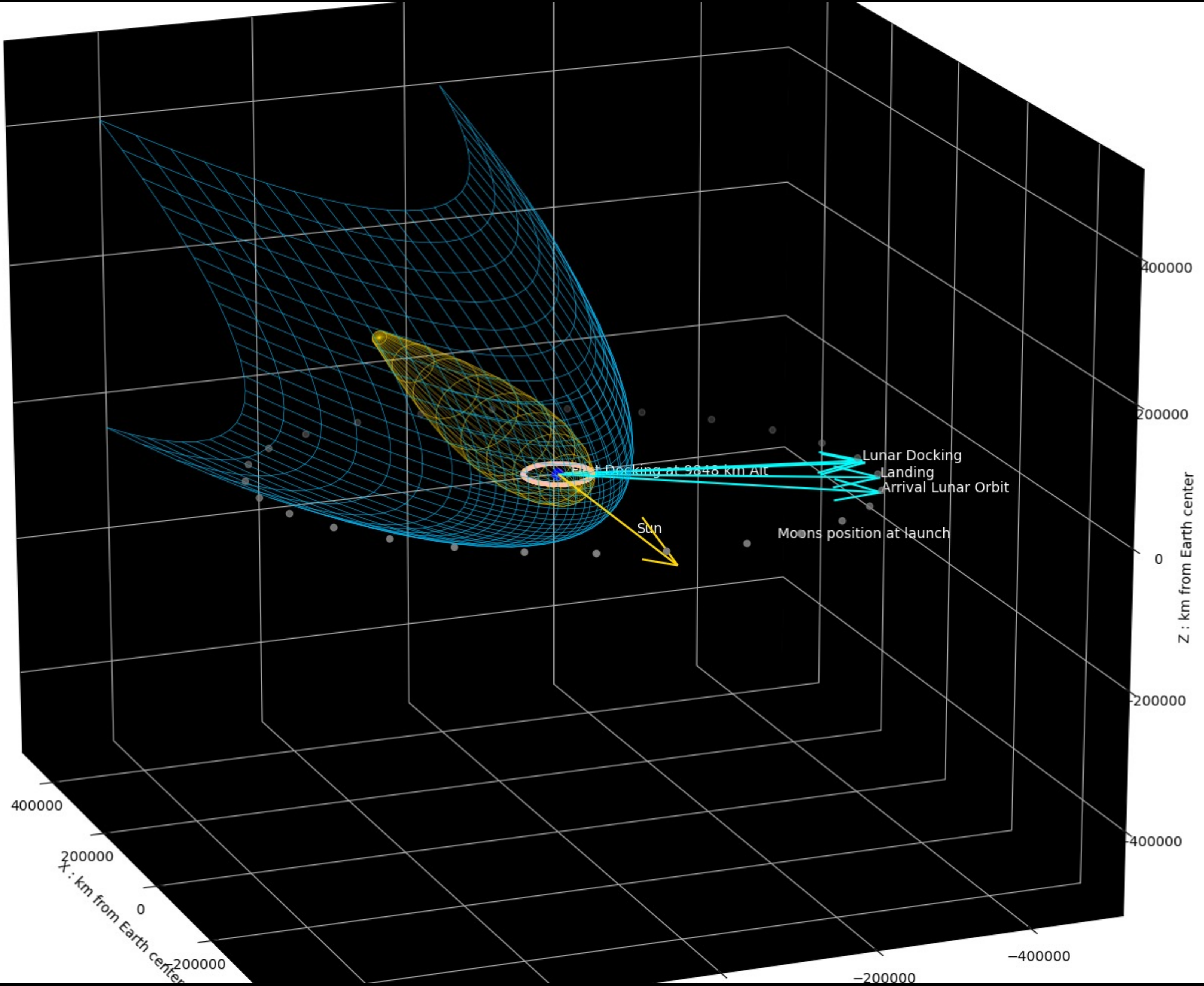




- Regions and locations are approximate
- Magnetopause is dynamic and changes

NASA/MSFC/Aurelio Paez

APOLLO 11
1969 JULY 16 – 24



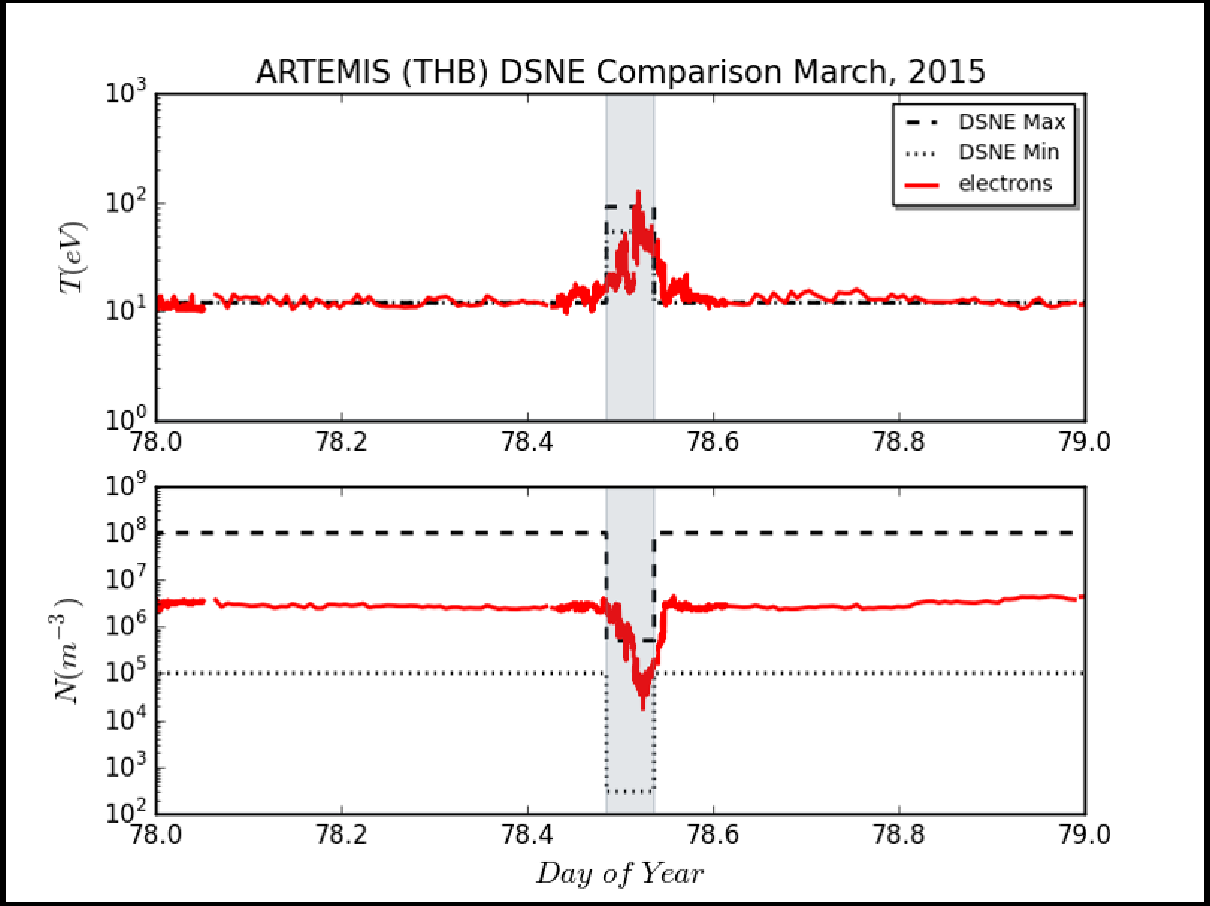
- Regions and locations are approximate
- Magnetopause is dynamic and changes

NASA/MSFC/Aurelio Paez

Lunar plasma environment

- ARTEMIS data taken during one Lunar orbit
  - No shading = solar wind
  - Grey region = solar wind obstructed by Moon

- Electron temperature increases, electron density decreases in lunar wake



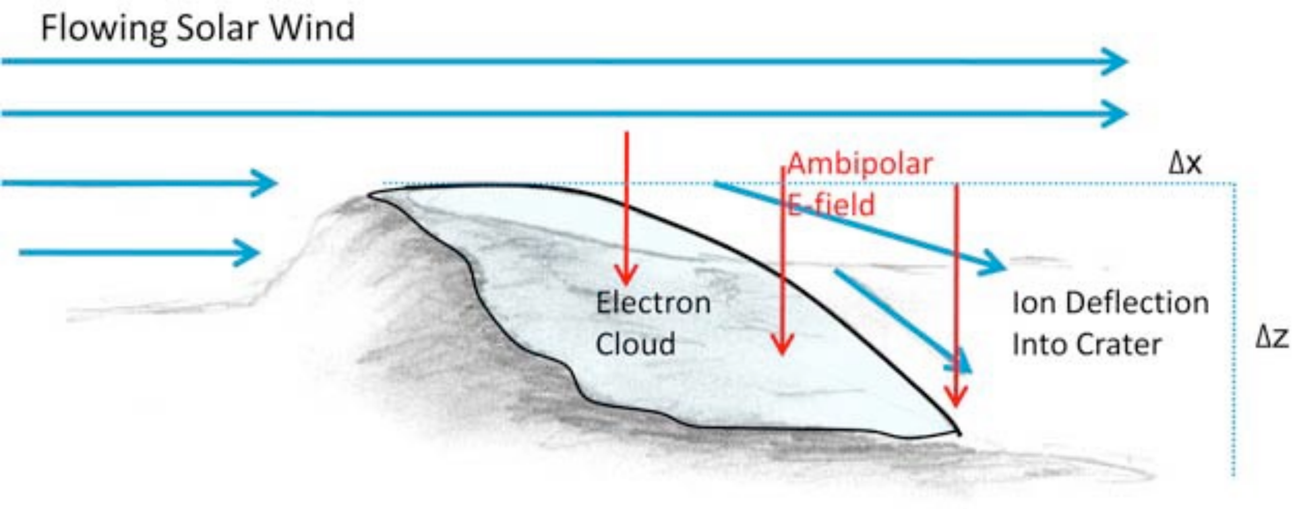
THEMIS-ARTEMIS data/Willis et al.

Lunar surface plasma environment

- Near-surface plasma environment
  - Dayside non-neutral region typically .5 to 1 meters above surface (Poppe and Horanyi 2010)
    - Can be up to 100 meters in plasma sheet
  - Nightside non-neutral region on order of kilometers
- Surface potentials
  - Sunlit regions: low positive potentials
  - Dark regions: negative potentials dependent on material properties
    - Electrostatic buildup without photoelectron dissipation

Lunar surface plasma environment

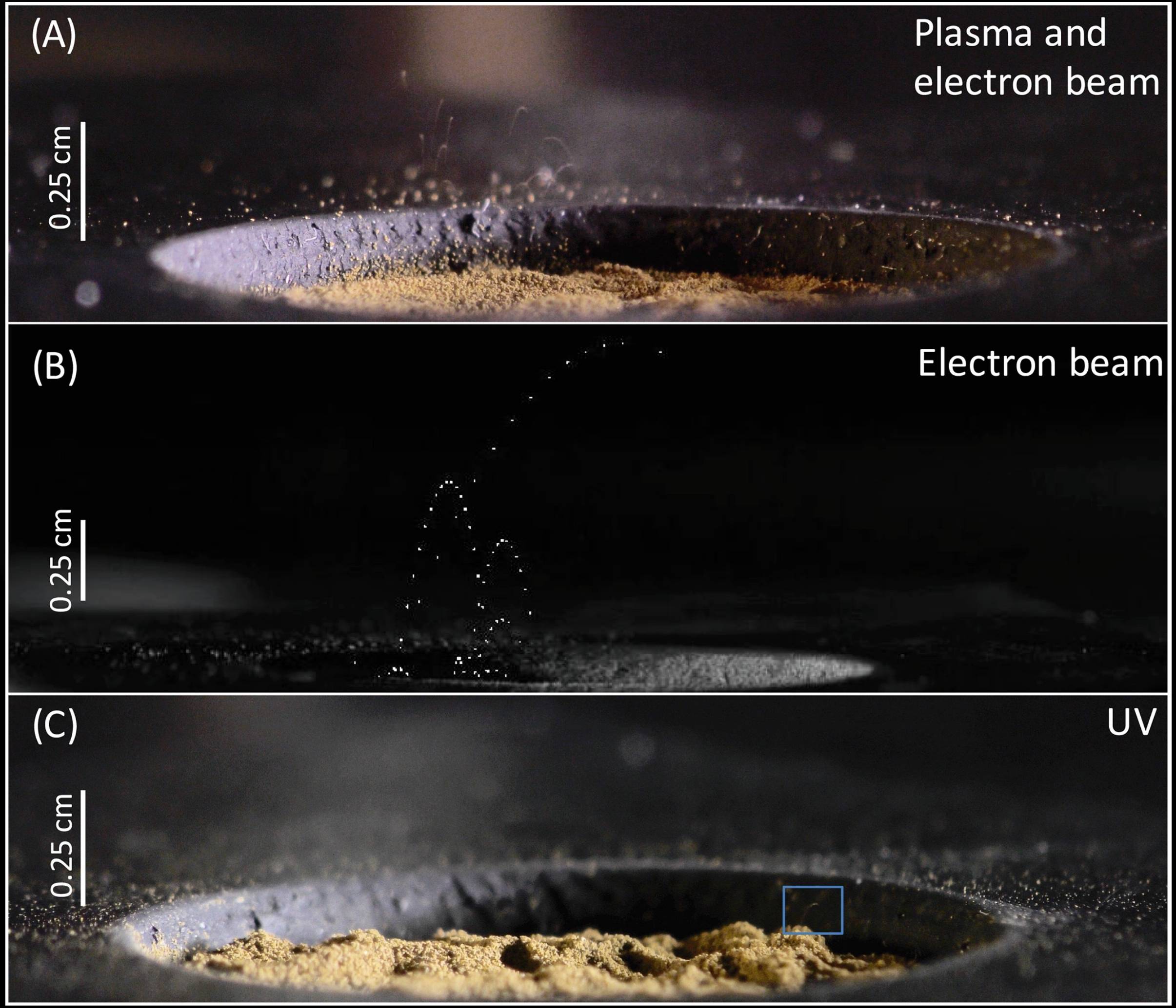
- Environment at lunar poles/terminator more complex
  - Low solar zenith angle
  - Wake effects behind large surface features
    - Reduced plasma density; increased temperature



Farrell et al. 2010

Lunar surface plasma and dust transport

- Plasma charging is thought to contribute to dust transport on the surface
- Experimental results estimate charged particles could loft to ~10 cm above surface (Wang et al. 2016)
- Area of ongoing research



Wang et al. 2010

Uncertainty and limitations

- Engineering limitations
  - No known engineering tools exist that can take surface plasma environments as input and reliably predict spacecraft charging
- Environment uncertainties and knowledge gaps
  - Plasma populations and spatiotemporal variation at the lunar surface
  - Plasma interactions with the surface and surface features
  - Plasma conditions on the night side
  - Charging during solar energetic particle events
  - Dust behavior and interactions with the plasma environment