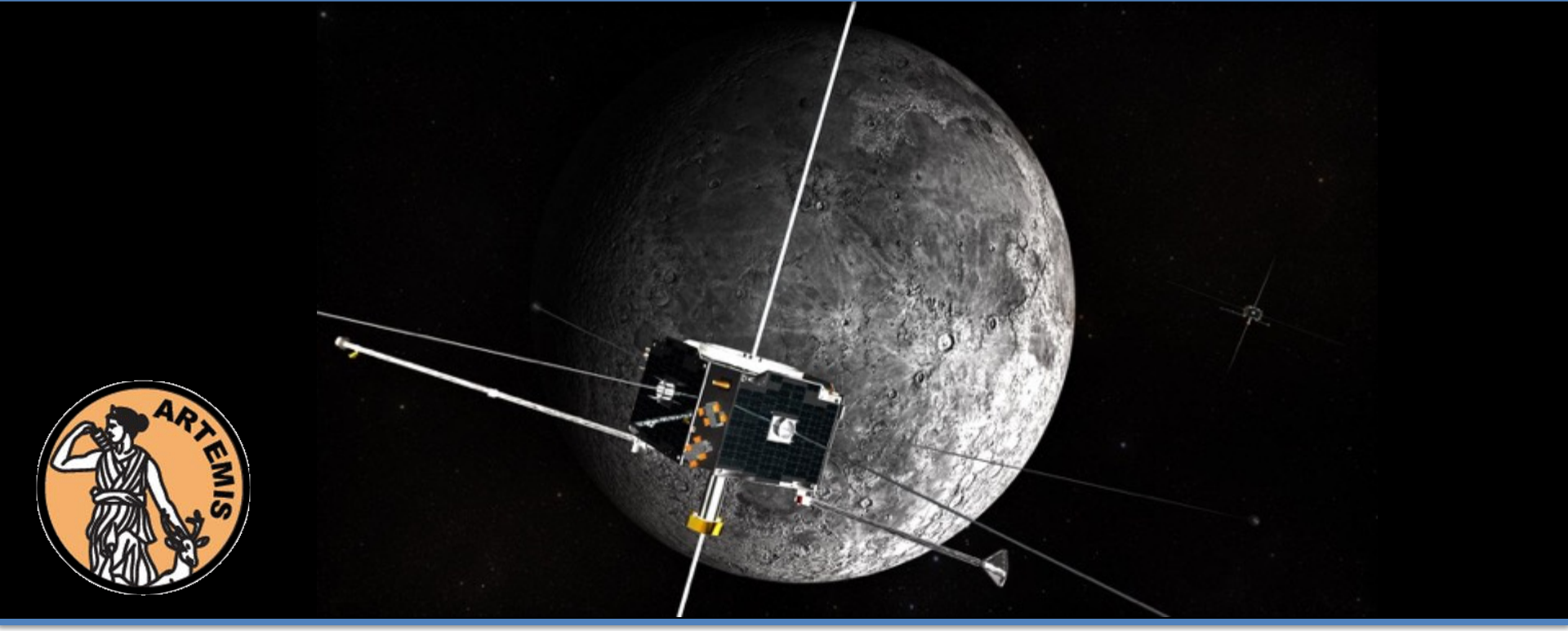

A multi model investigation of the lunar interior: a Hot Topic

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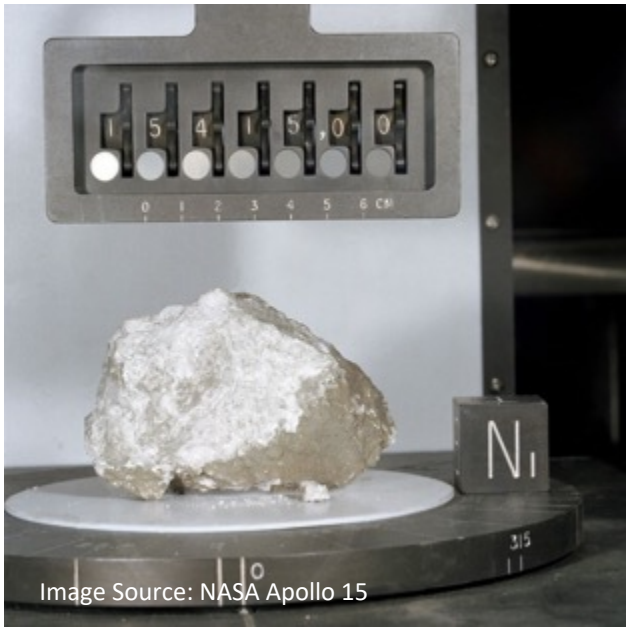
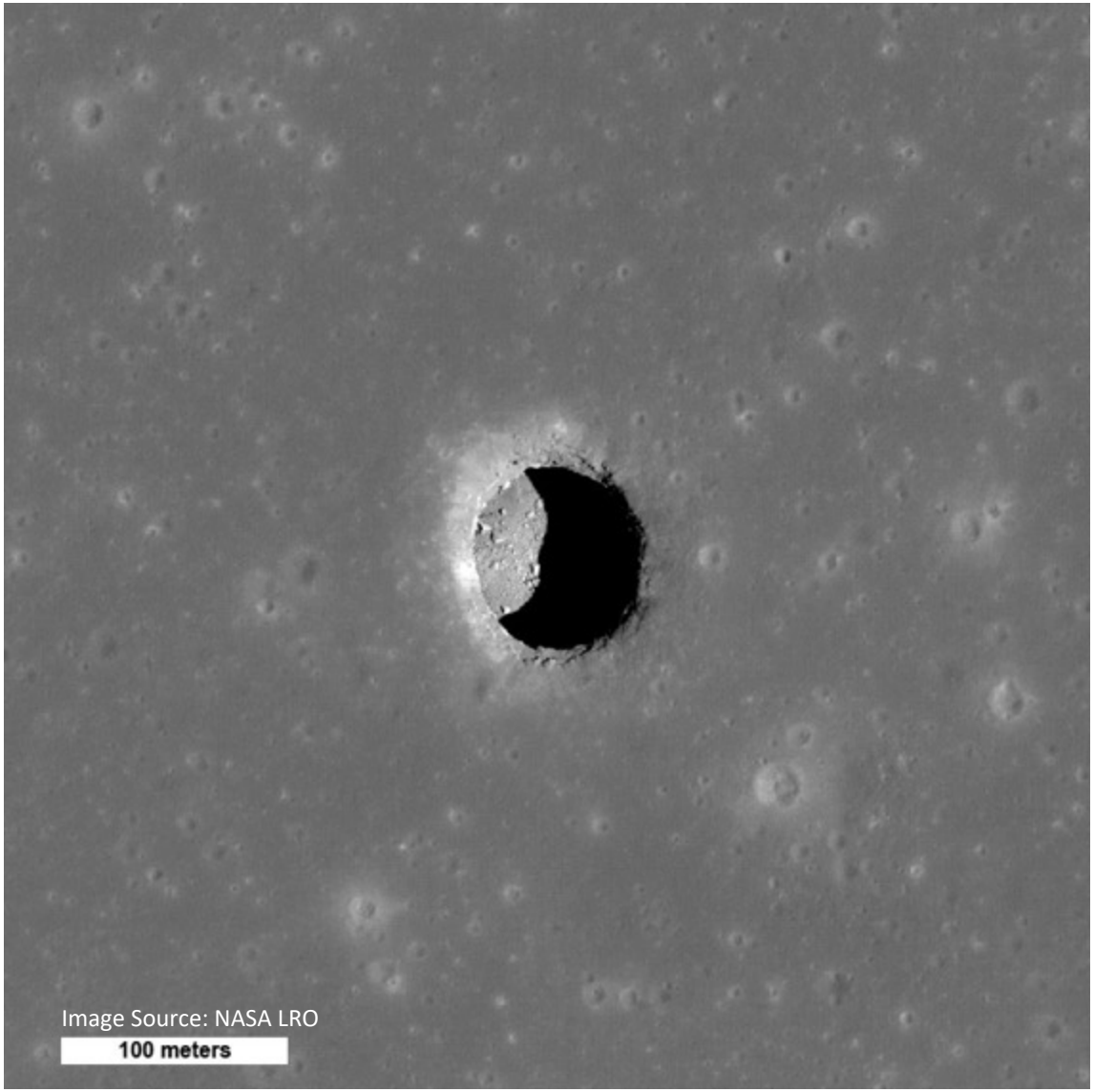
(ST13) Heliophysics and Planetary Science Branch

What is Planetary Science?
Why & how do we study planets?

What do we know about the Moon?
What is there left to learn?

What is planetary science?





Human Remote Sensing

Image Source: Pixabay

Image Source: NASA

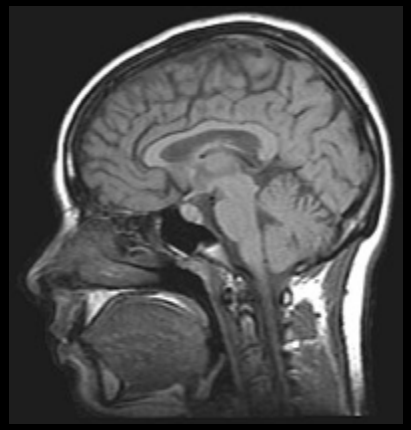


Image Source: NASA

Image Source: Pixabay

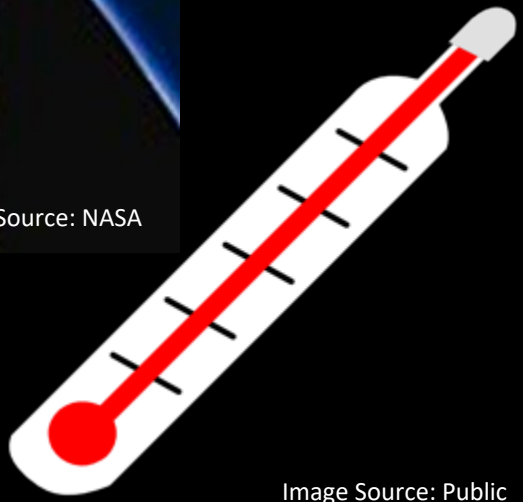


Image Source: Public Domain Clip Art

Geophysics Remote Sensing

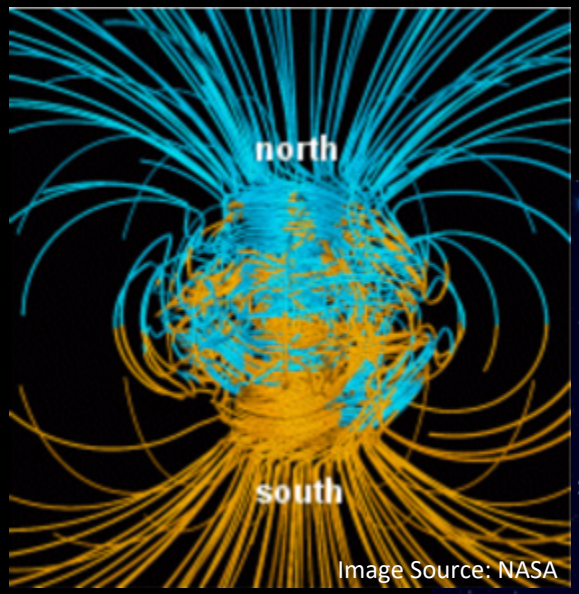


Image Source: NASA

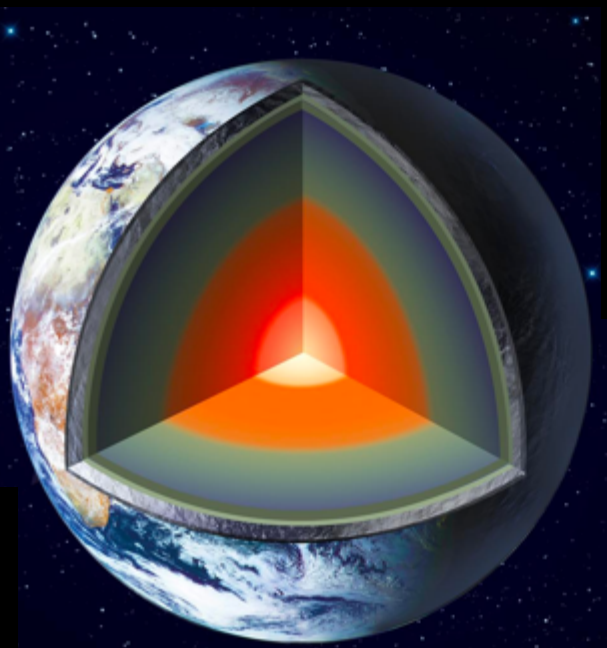


Image Source: NASA

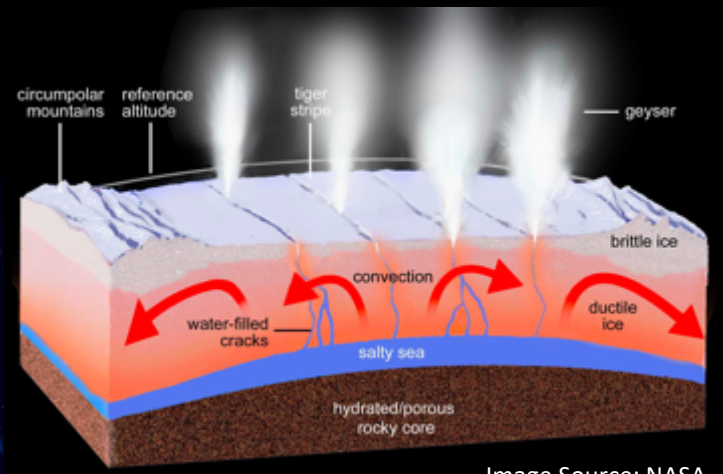


Image Source: NASA

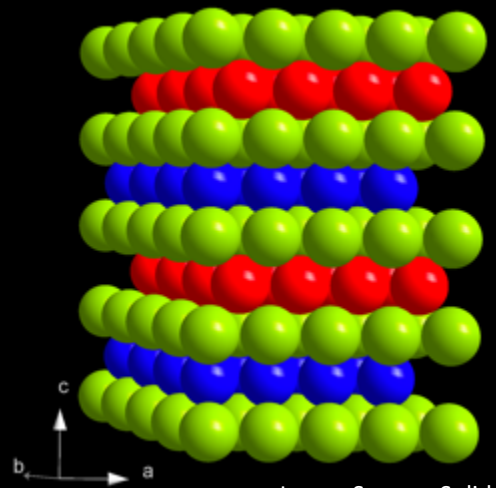


Image Source: Solid State, public domain

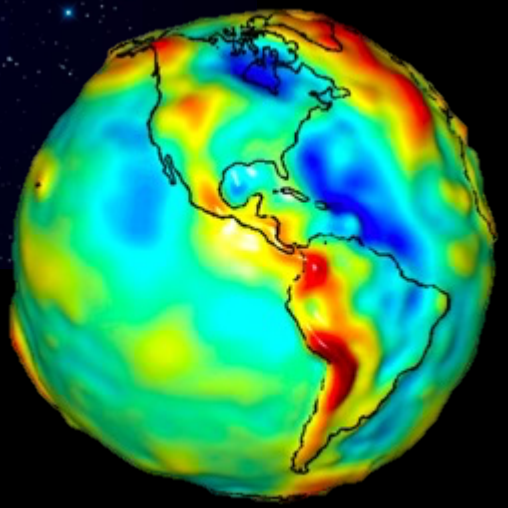
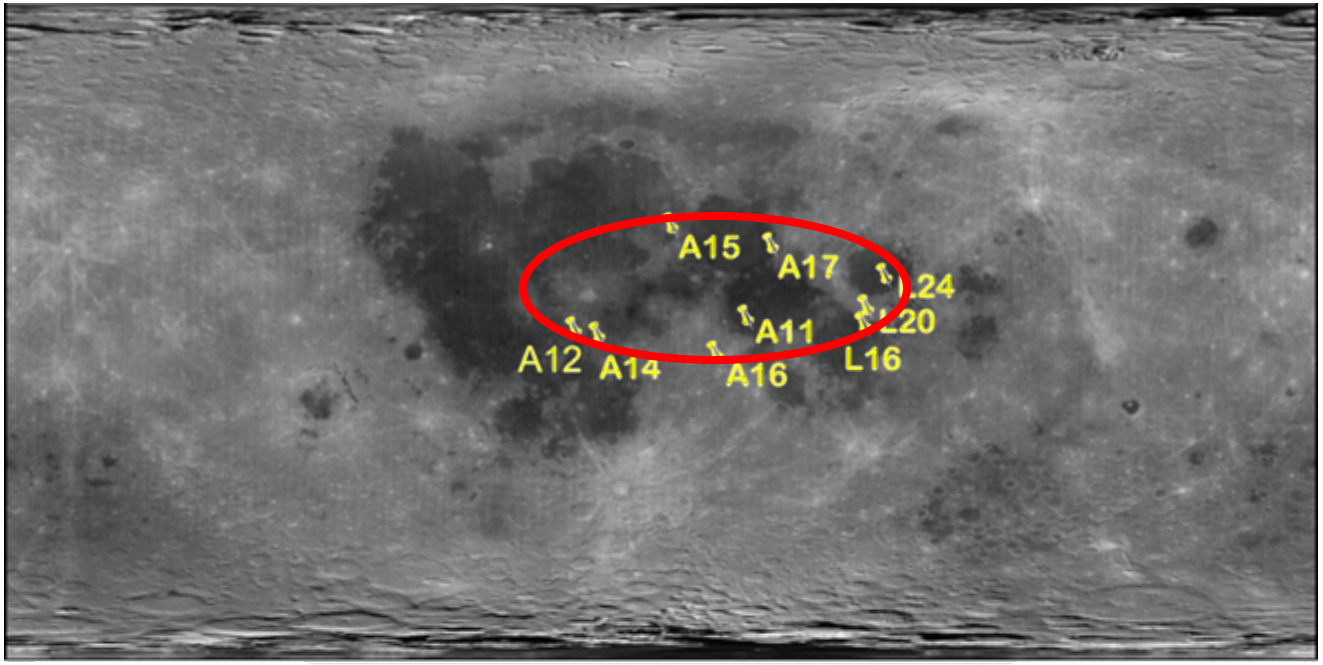


Image Source: GRACE NASA



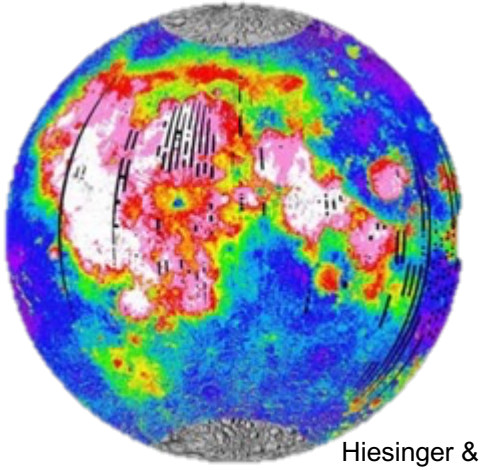
Apollo + Luna sampling sites = ~6% of the total lunar surface area

6% of the total terrestrial surface ≈ North America

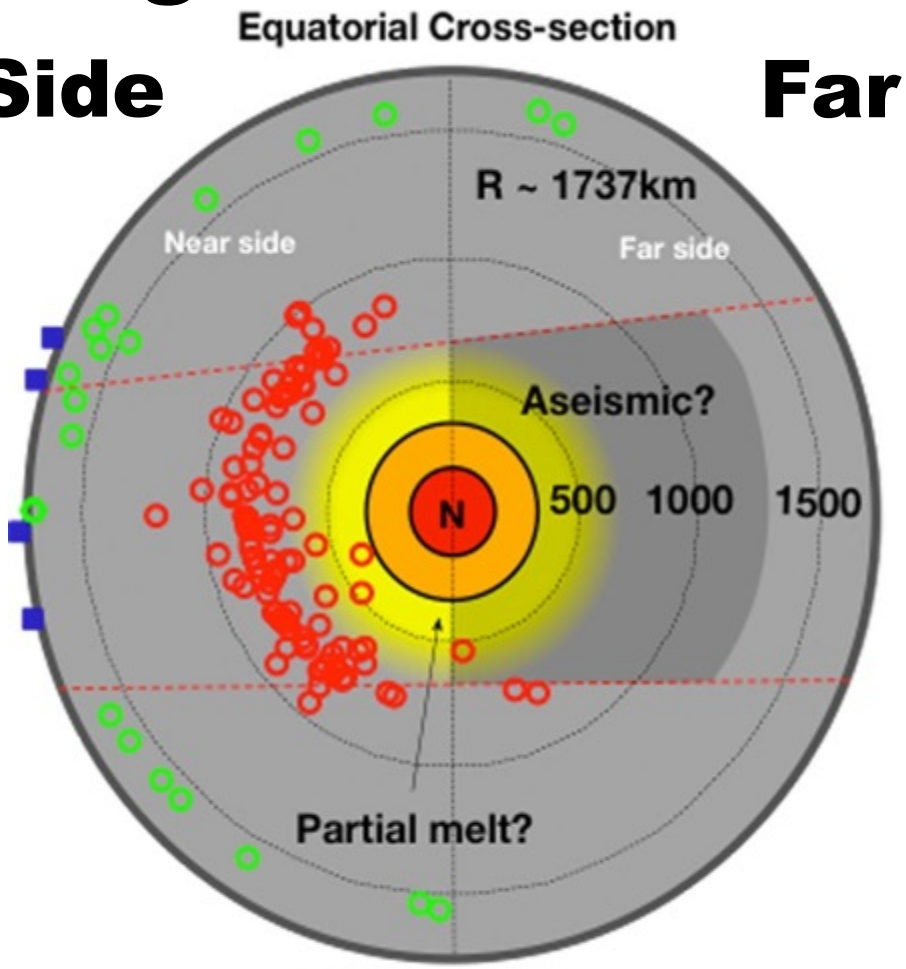
Michael Zanetti, 2019

Driving Science Question

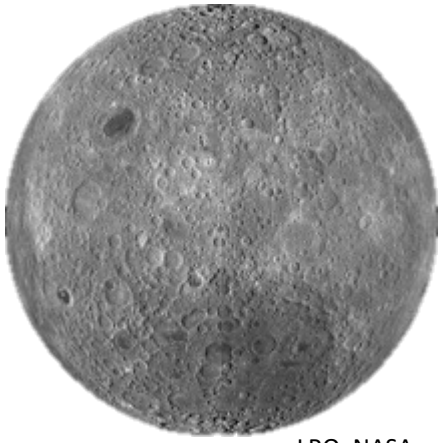
Near Side



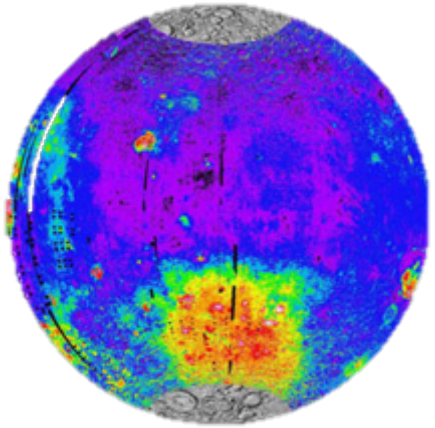
Hiesinger & Head, 2006.



Far Side

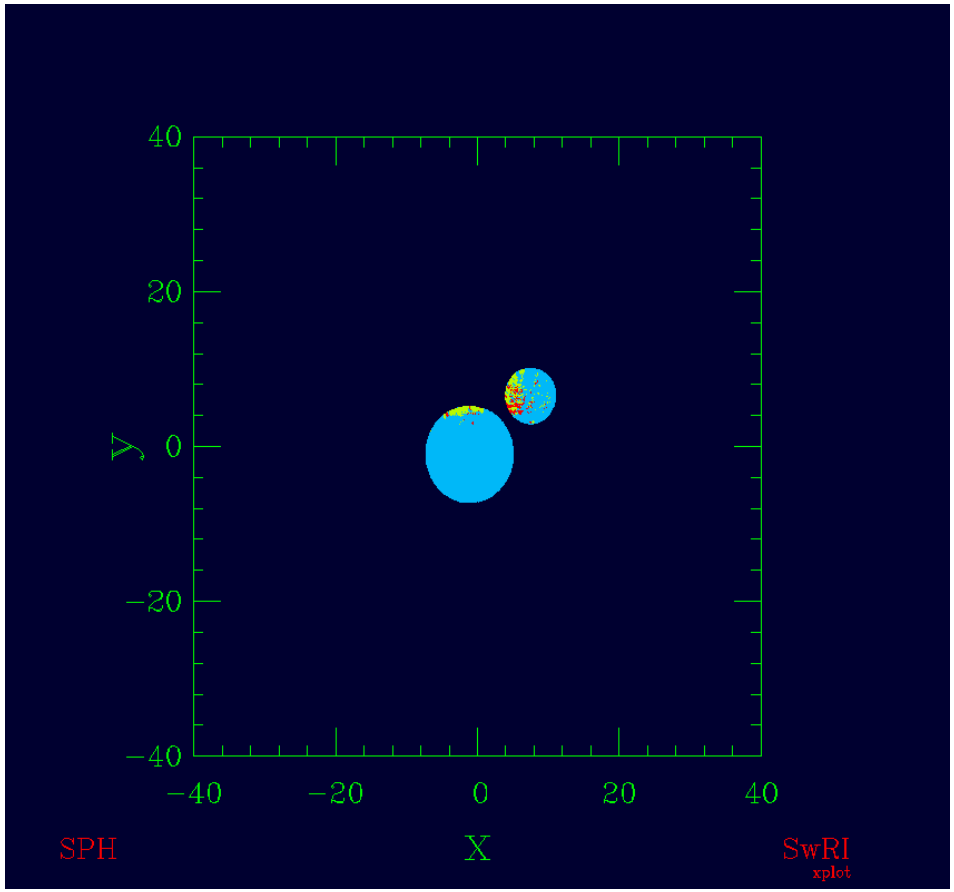


LRO, NASA

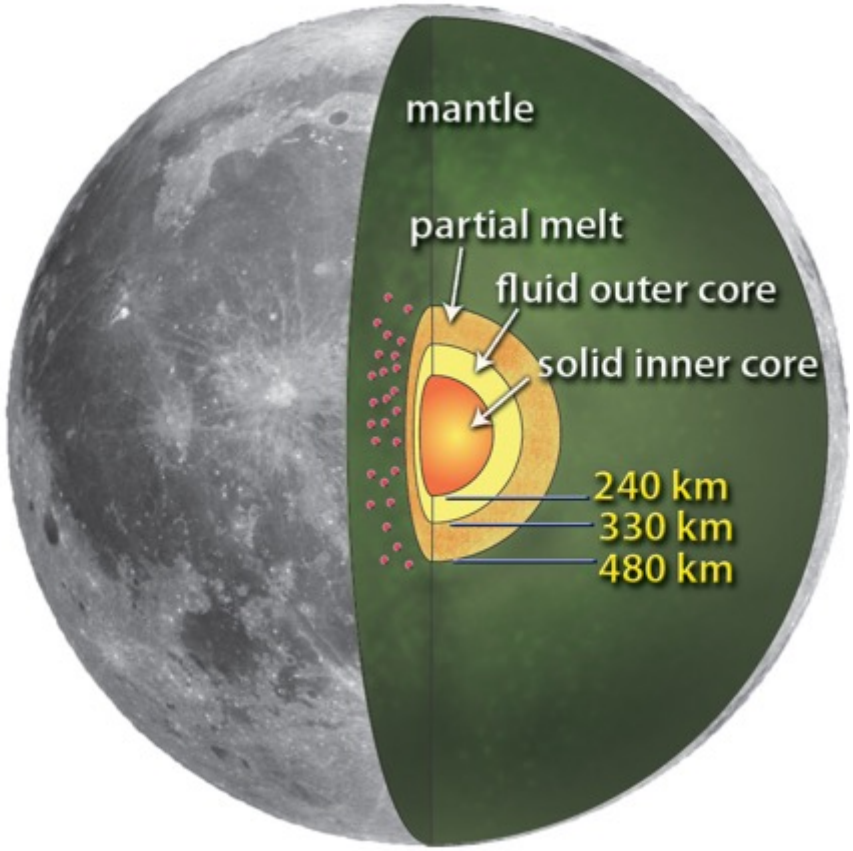


What is the current state and structure of the global lunar interior?

Lunar Origin Theories



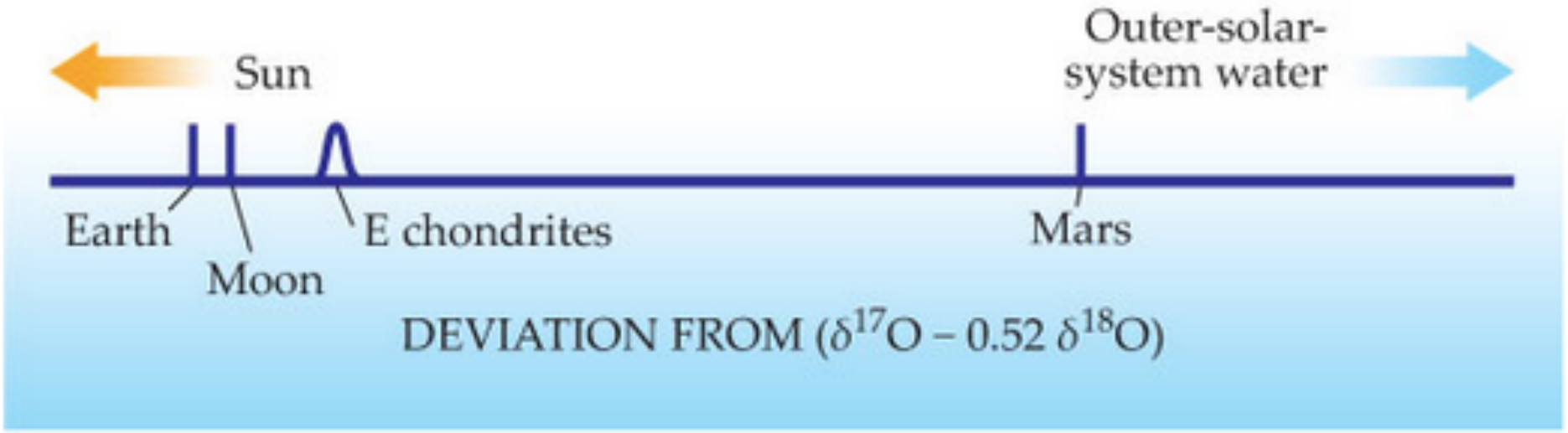
Canup et al., 2016



Weber et al., 2011

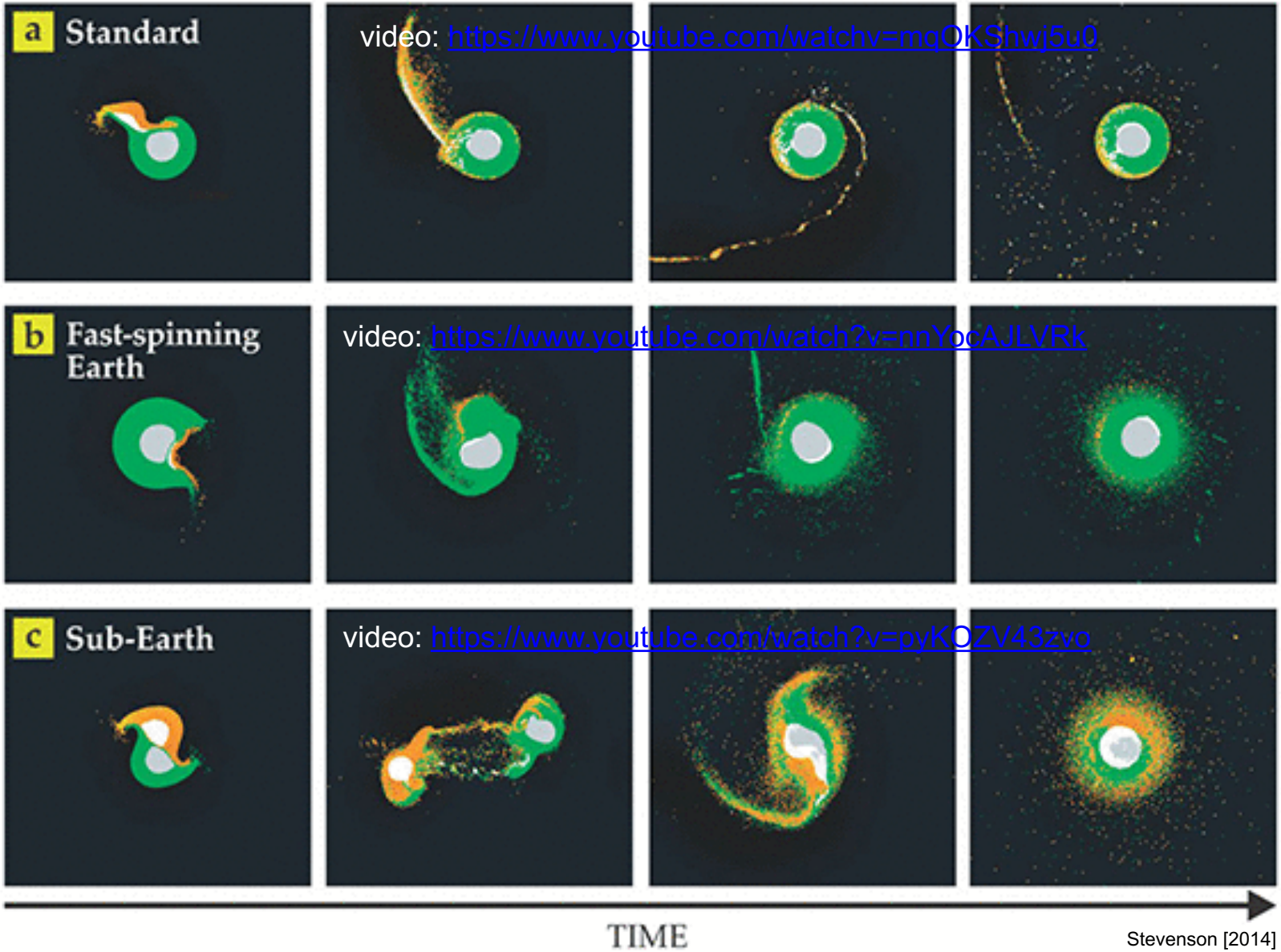
The current state is key to constraining origin theories.

Oxygen Isotopic Signatures



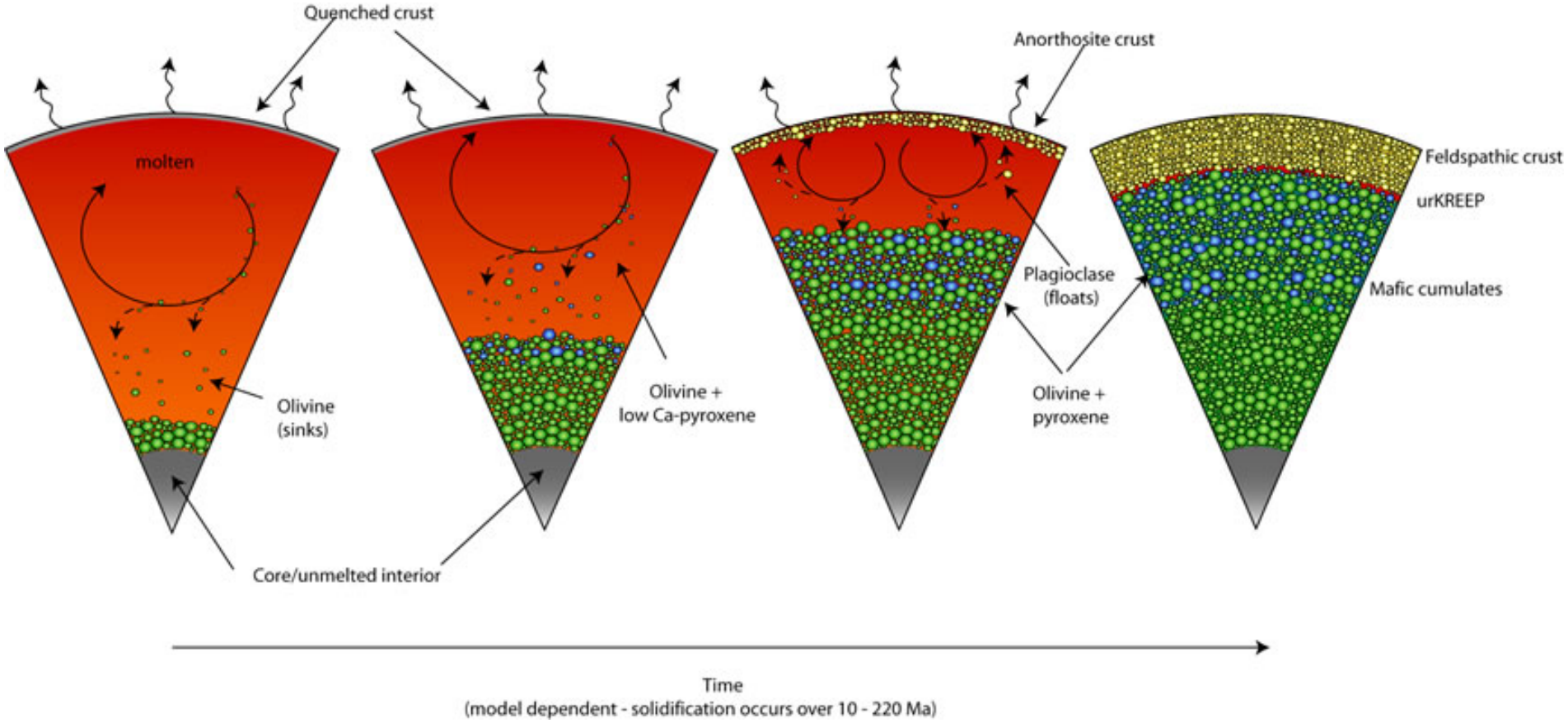
Stevenson [2014]

Giant Impact Scenarios:



Stevenson [2014]

Magma Ocean Crystallization Models



The current state of the lunar interior is the first step to constraining formation.

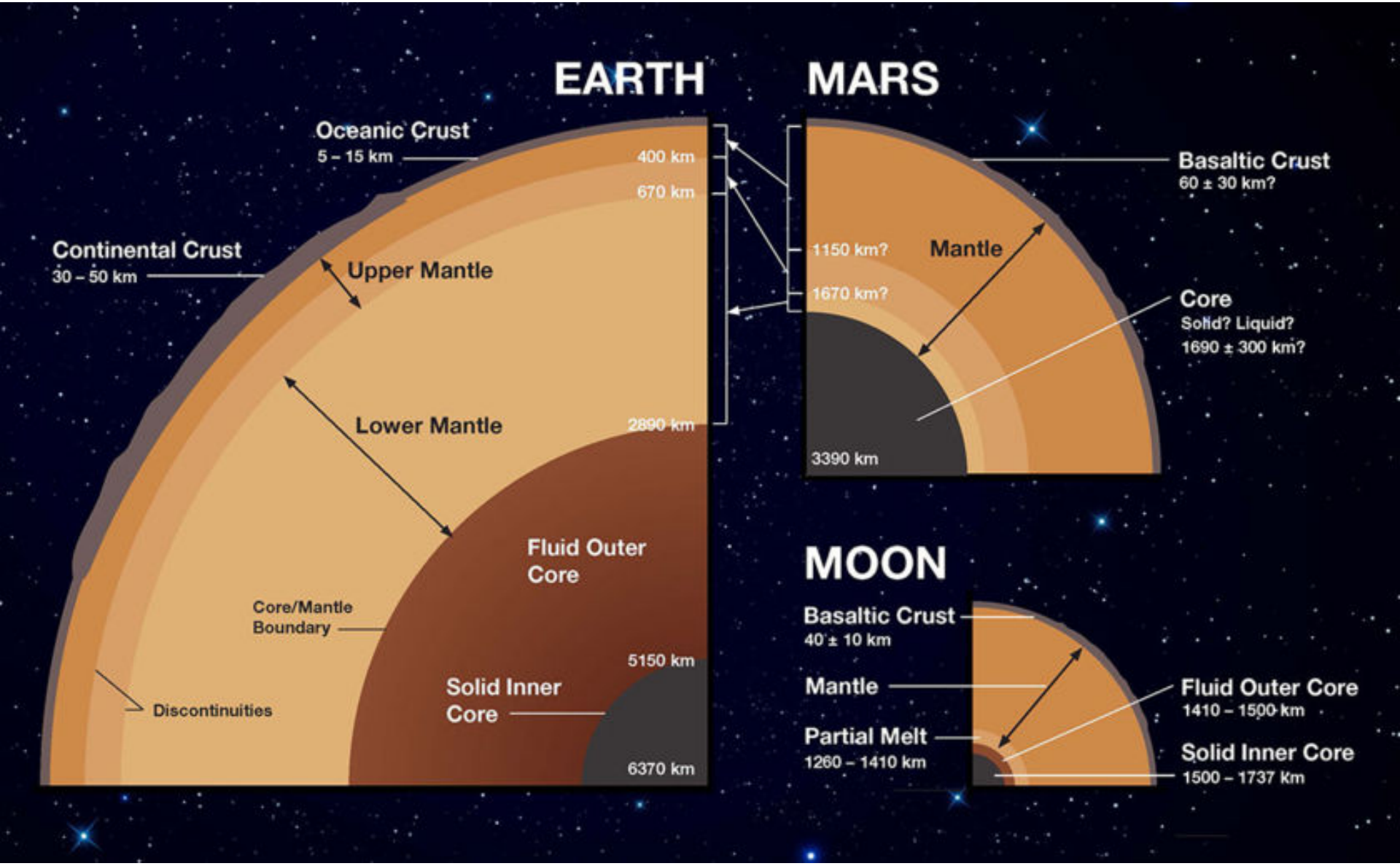


Image source: NASA

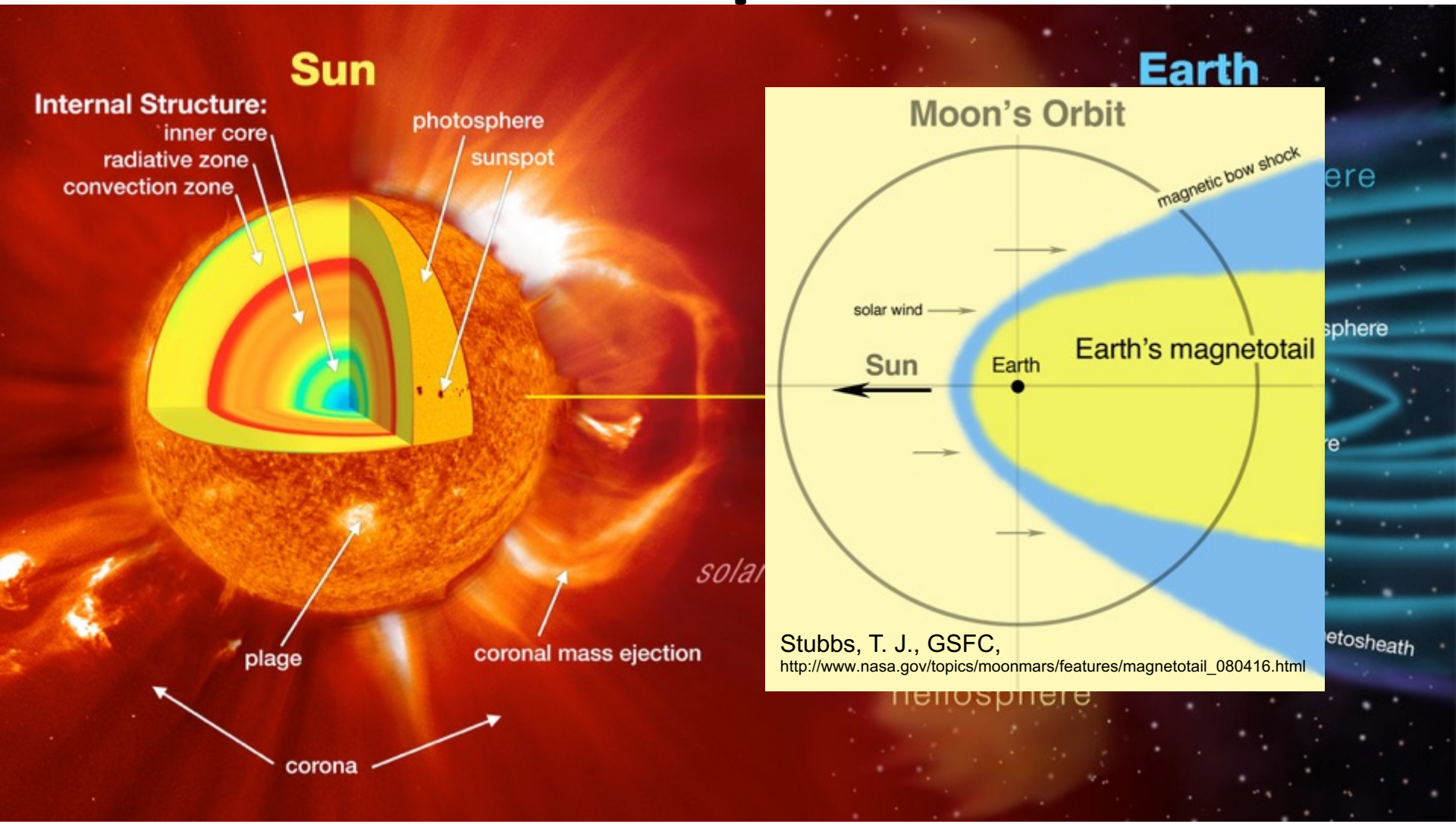
Is the Moon Made of Cheese?

	Seismic velocities (km/s)
Cheeses	
Sapsago (Switzerland)	2.12
Romano (Italy)	1.74
Cheddar (Vermont)	1.72
Muenster (Wisconsin)	1.57
Lunar rocks	
Basalt 10017	1.84
Basalt 10046	1.25
Near-surface layer	1.20
Terrestrial rocks	
Granite	5.90
Gneiss	4.90
Basalt	5.80
Sandstone	4.90

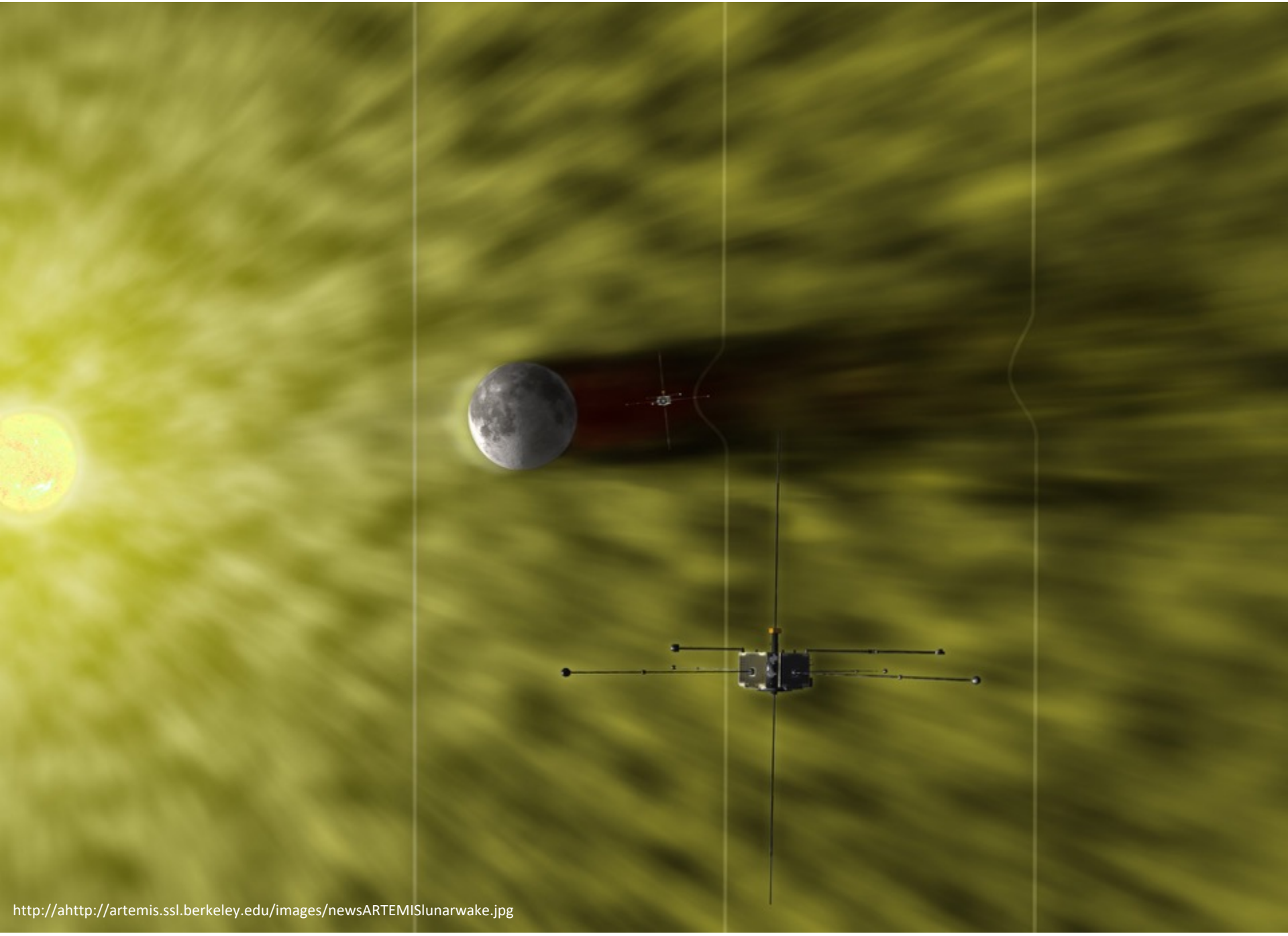
Stevenson [2014]

Electromagnetic (EM) Sounding of the Moon - Theory

Earth-Sun-Moon Space Environment

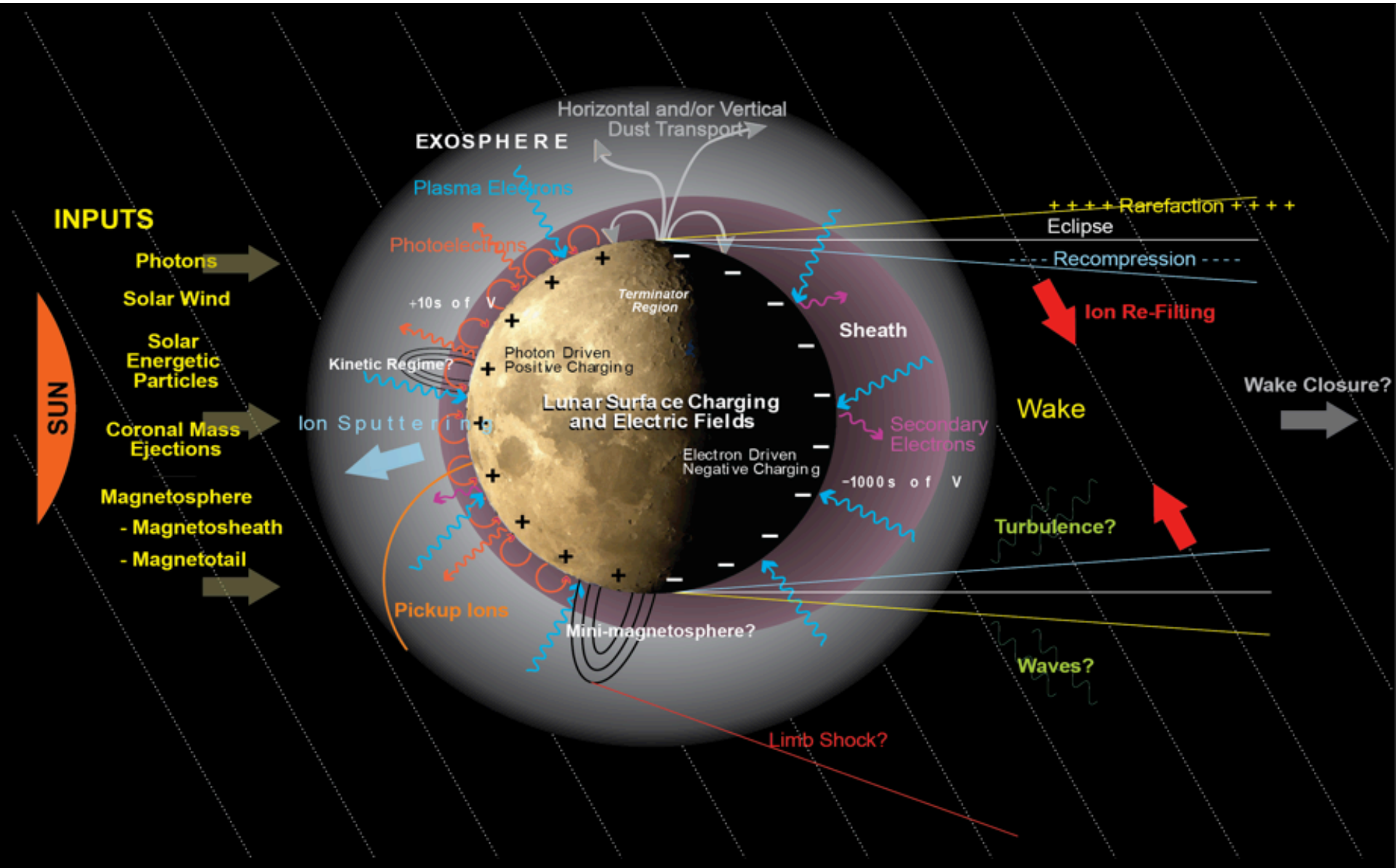


Credit: NASA's Goddard Space Flight Center

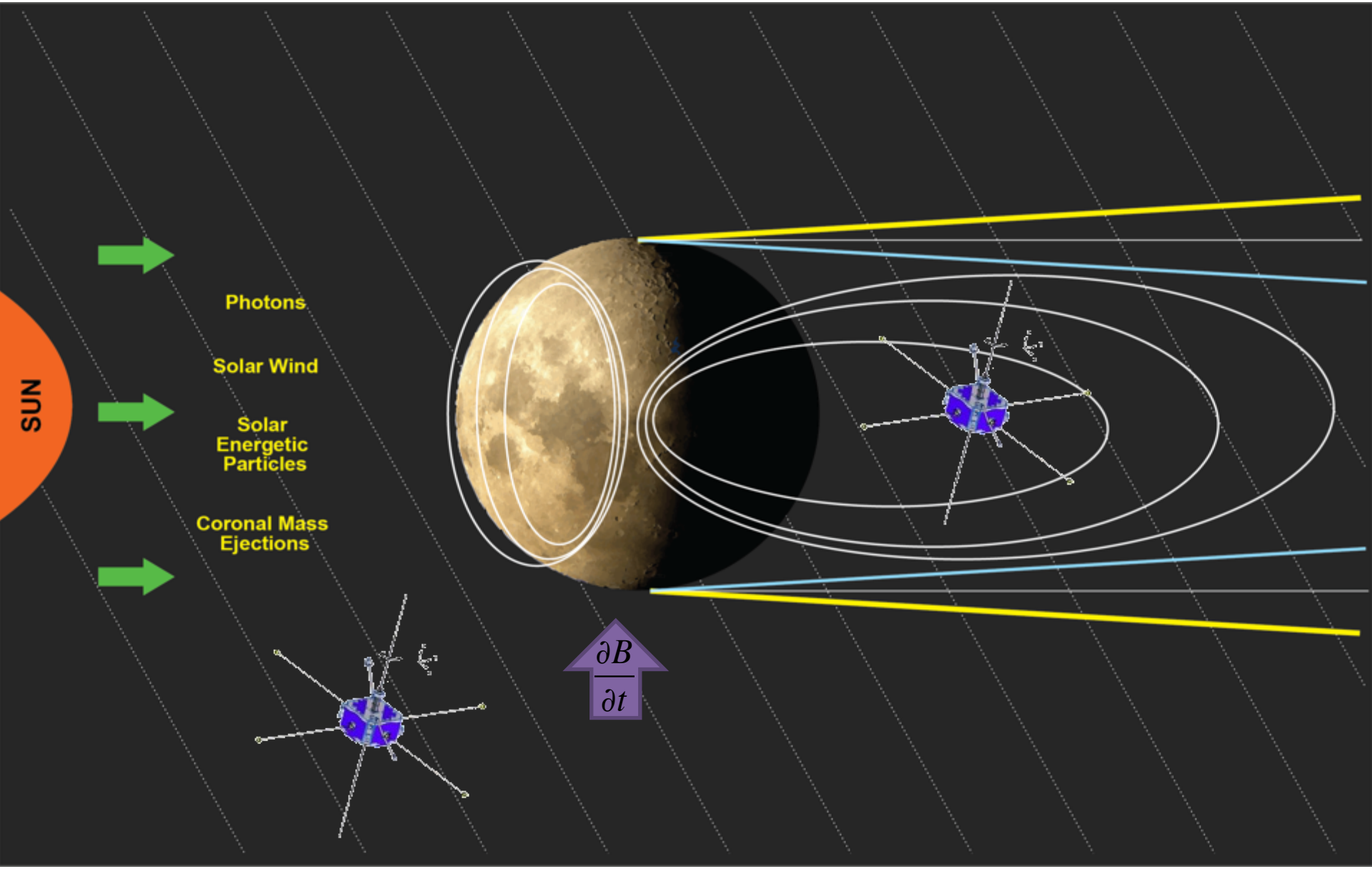


http://ahttp://artemis.ssl.berkeley.edu/images/newsARTEMISlunarwake.jpg

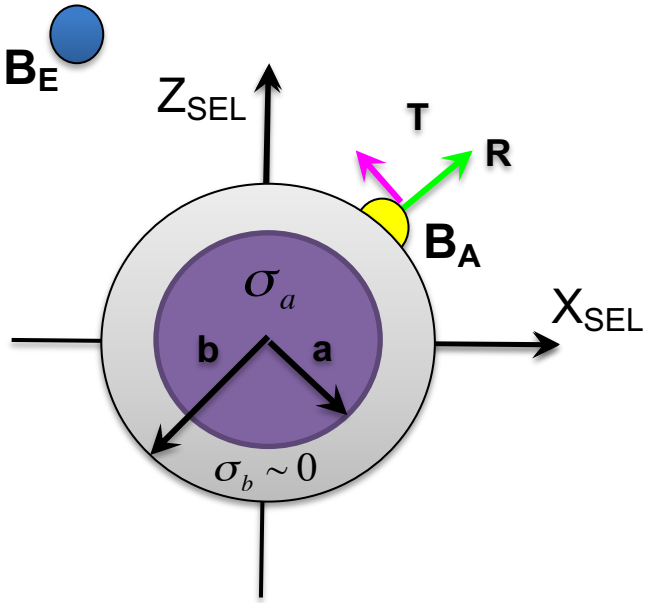
Lunar Space Plasma Environment



Asymmetric Plasma Confinement



Vacuum Model



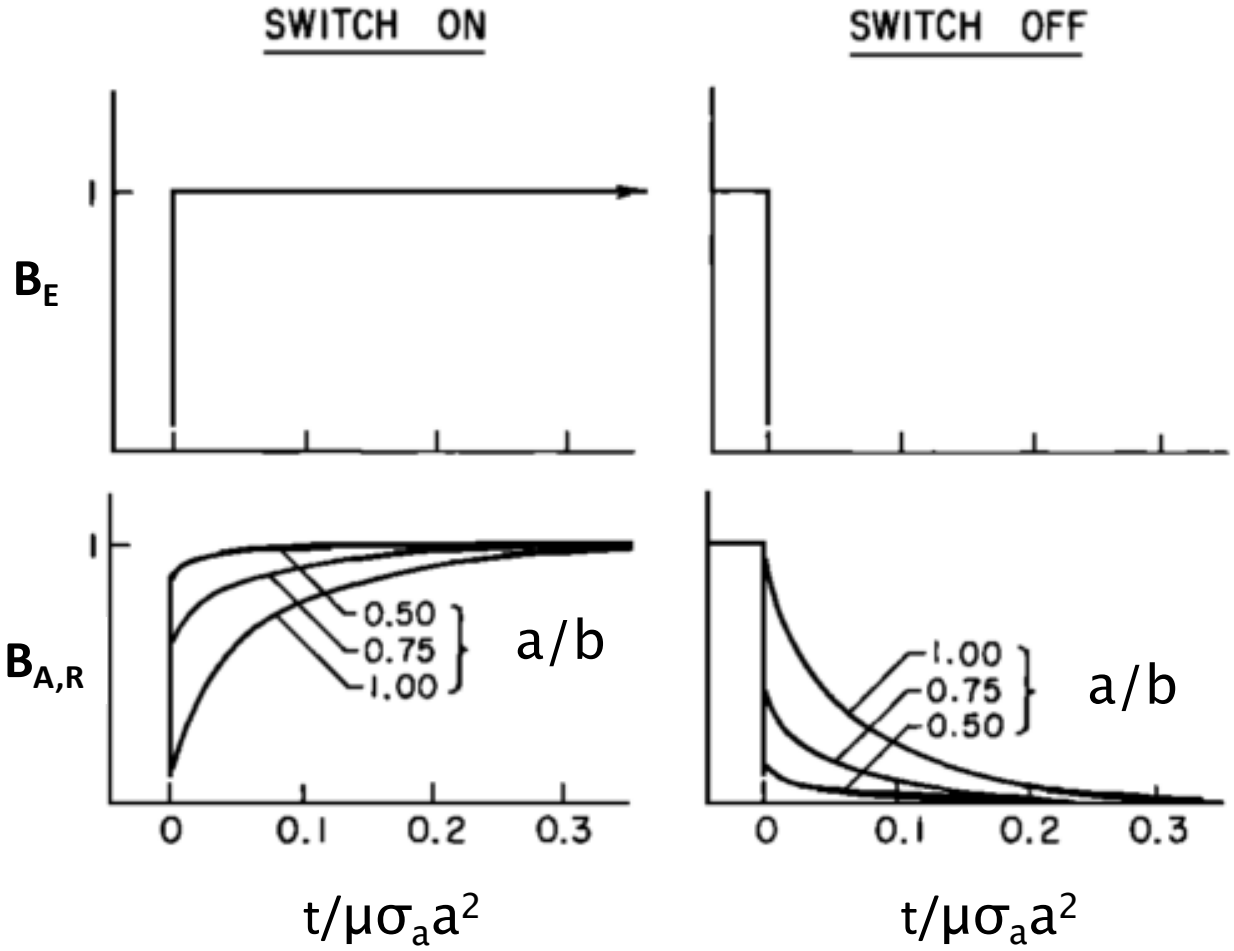
$$B_{A,R}(t) \propto -\left(\frac{a}{b}\right)^3 \Delta B_{E,R} F(t)$$

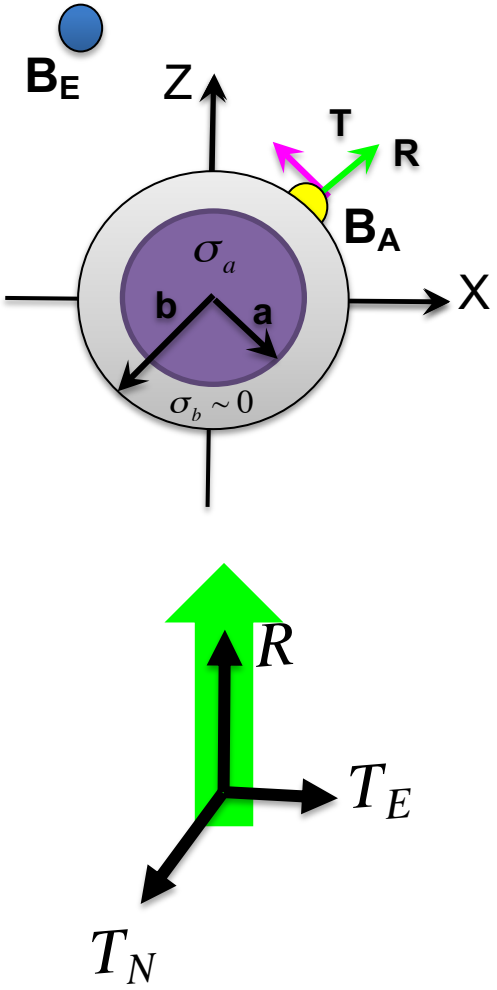
$$B_{A,T}(t) \propto \left(\frac{a}{b}\right)^3 \Delta B_{E,T} F(t)$$

$$F(t) \propto \exp\left(-t / \sigma_a a^2\right)$$

Dyal & Parkin, 1971

Night Side Time Domain EM Sounding

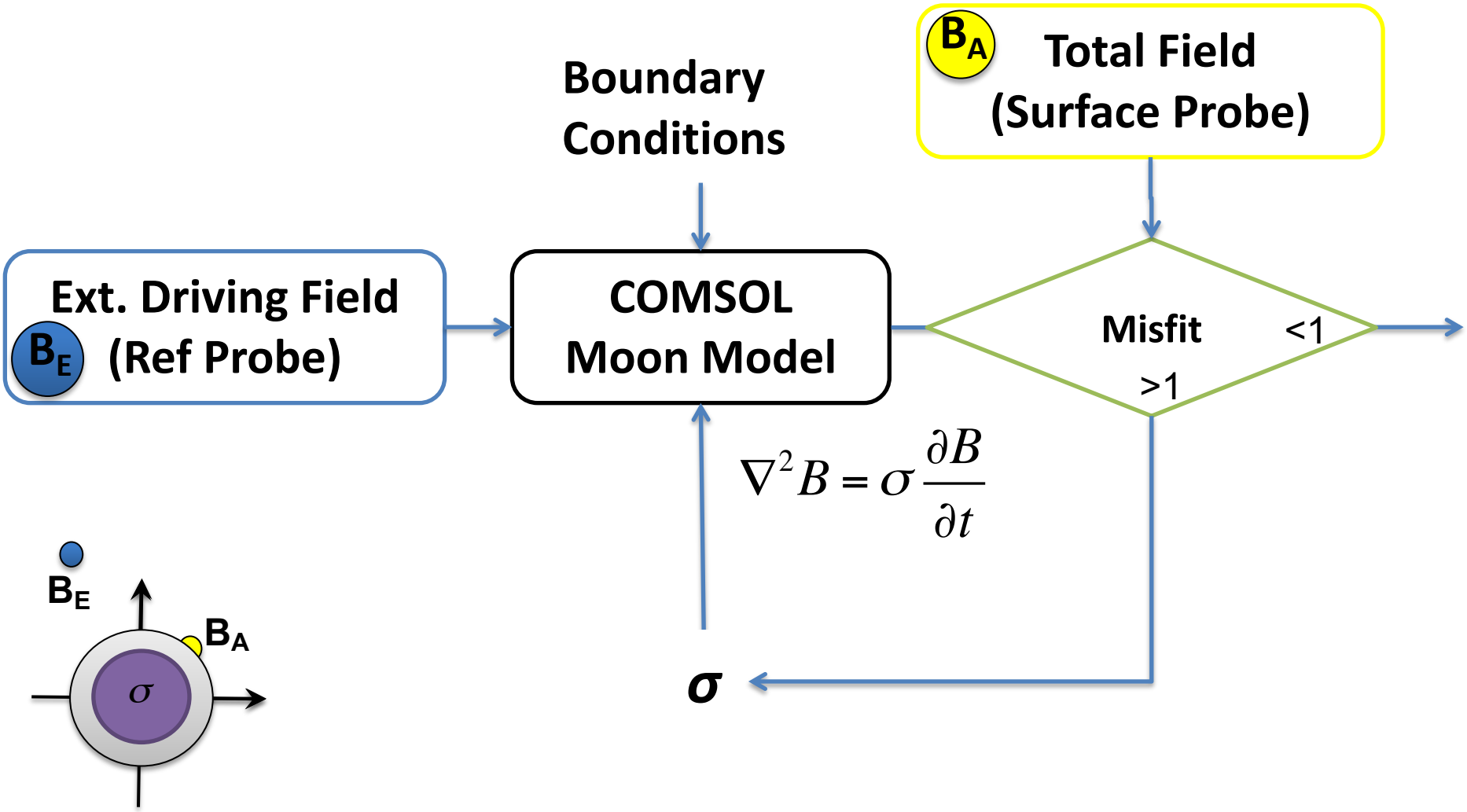




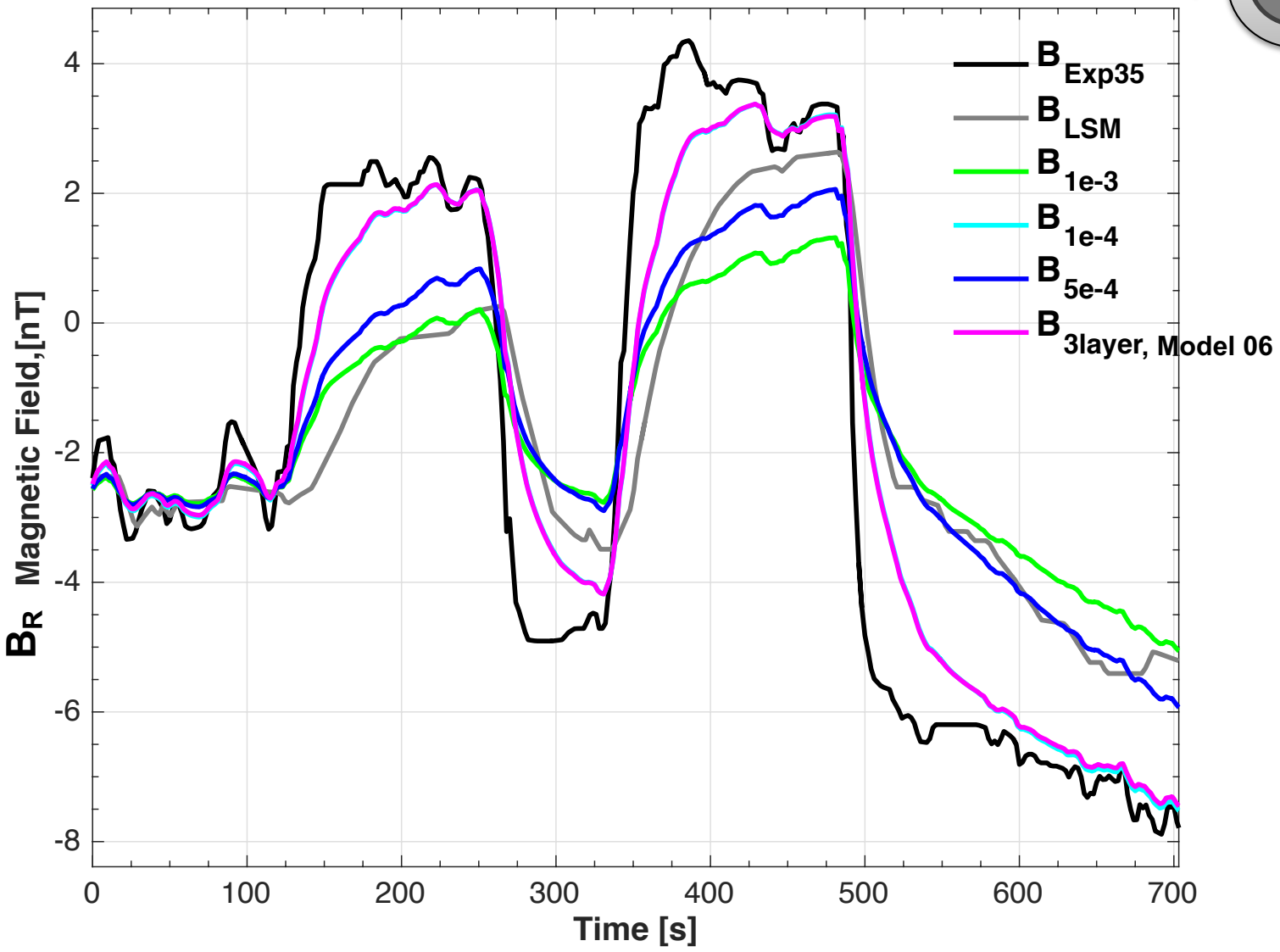
Dyal & Parkin, 1971

Sonett, 1982

COMSOL Time Domain (TD) EM Forward Model, implementation



Apollo Event #1



Fuqua Haviland et al. 2019, ASR

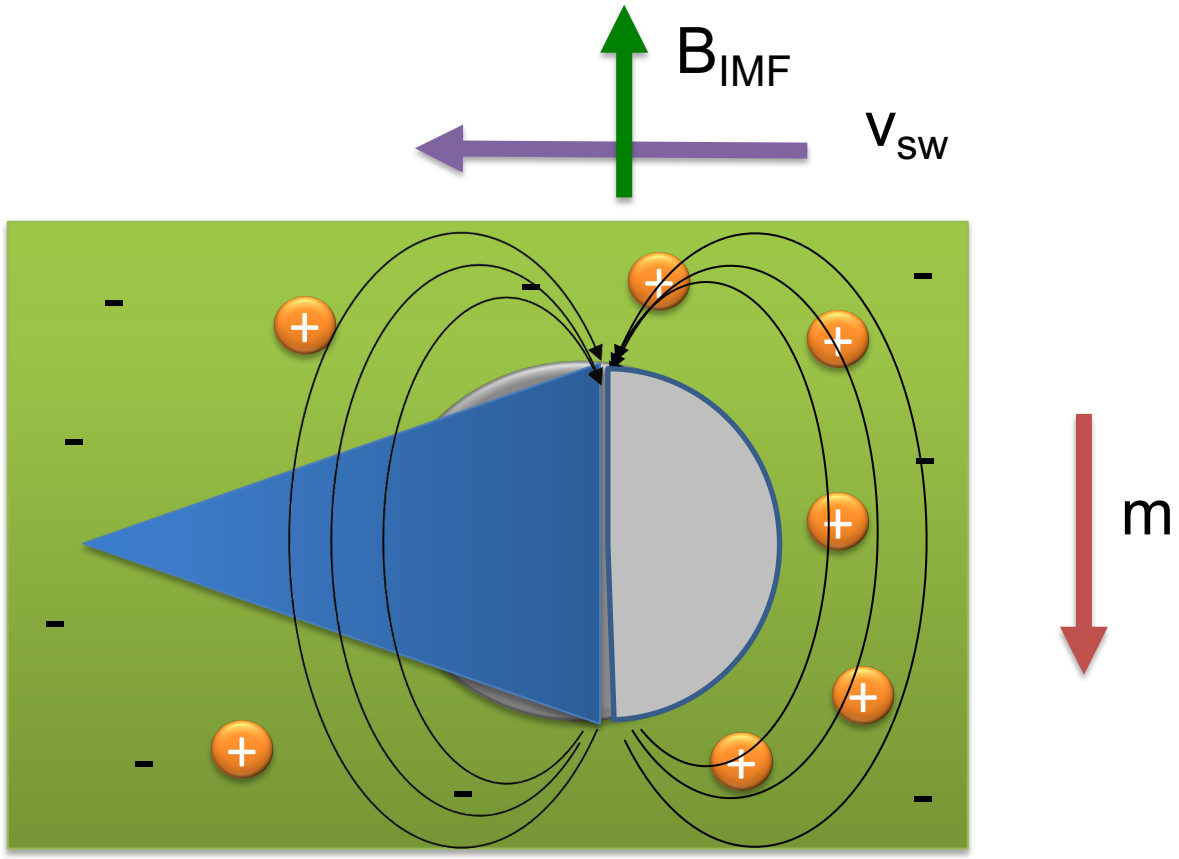
Challenges for TDEM

- Cannot fully capture all Apollo surface observations.
- Apollo magnetometer data not available. Restoration efforts in work.
- Do not consistently observe the radial damping and tangential overshoot predicted by vacuum TDEM analytic theory.

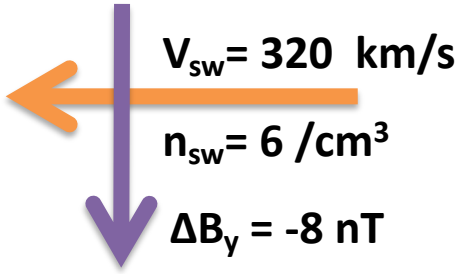
How do induced magnetic fields interact with ambient plasma? Is wake confinement accurate? When can the vacuum approximation be applied?

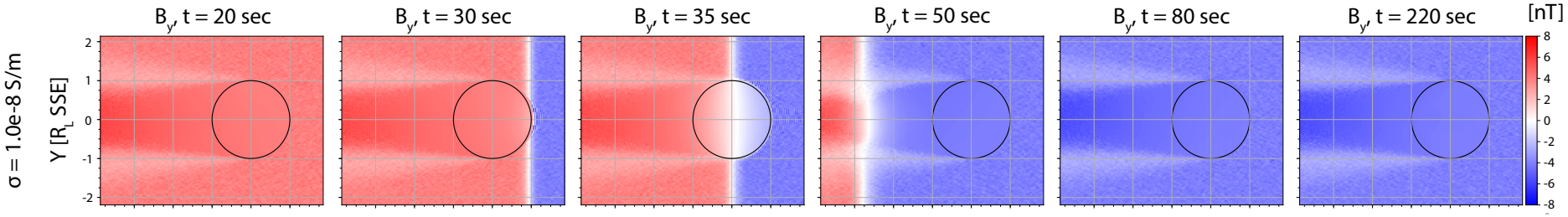
- Transient (time dependent) Plasma-induction hybrid model

Transient Plasma Hybrid Kinetic Model



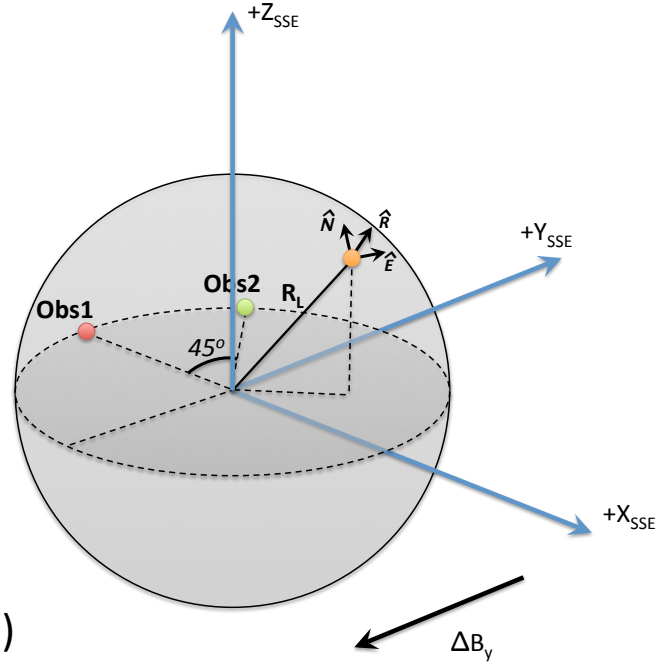
Case Study – Spatial Effects



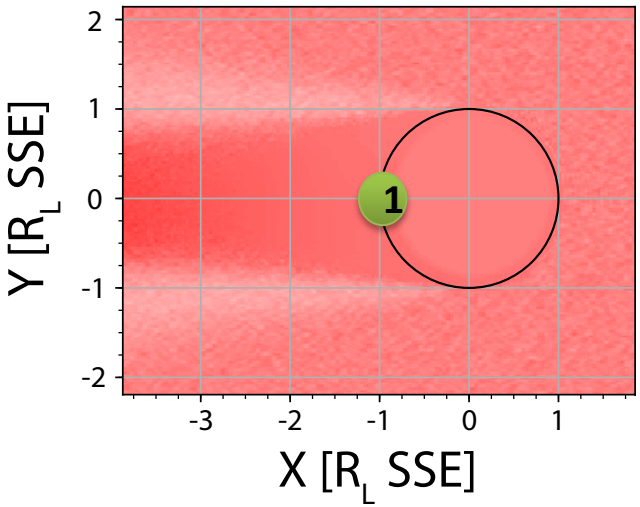


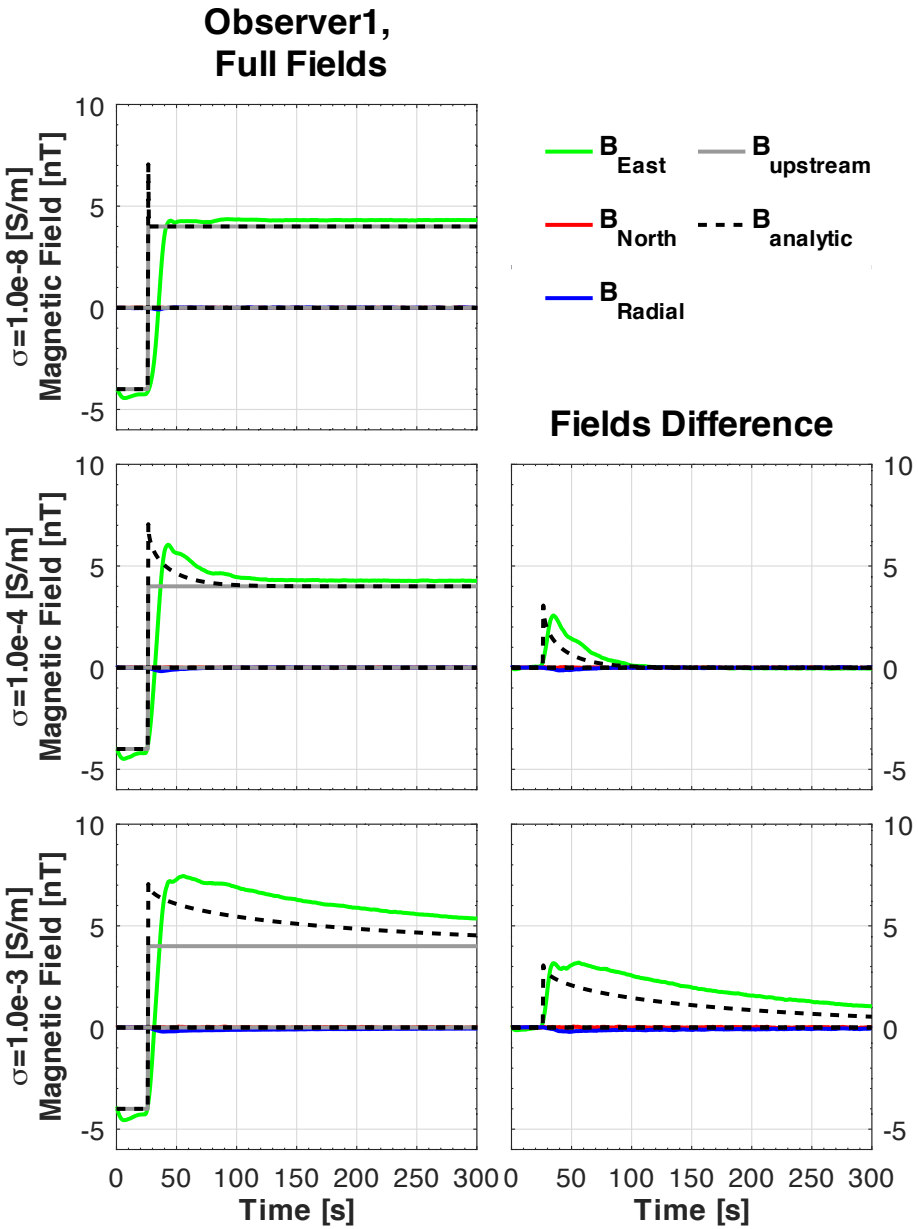
Fuqua Haviland et al. 2019, GRL

Case Study – Temporal Effects



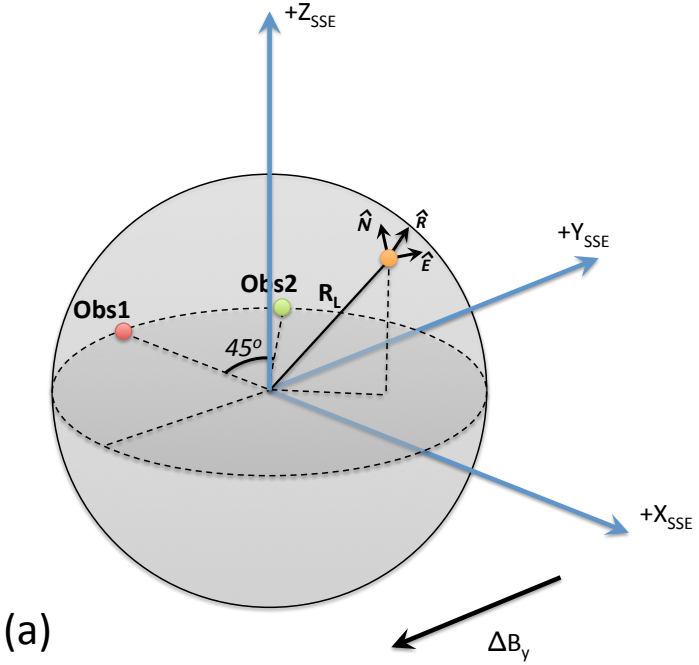
(a)



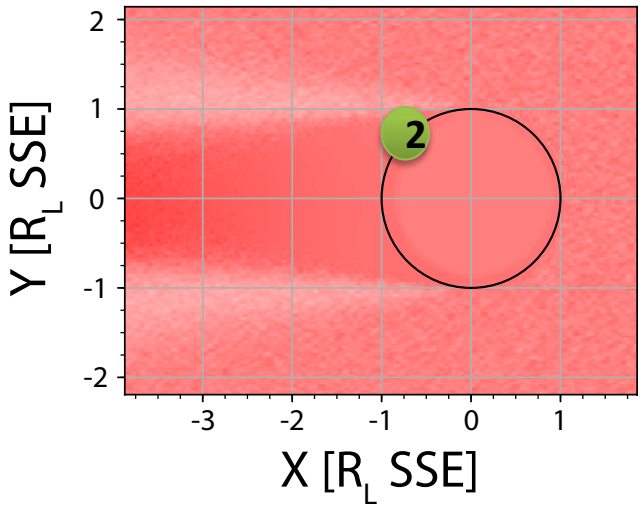


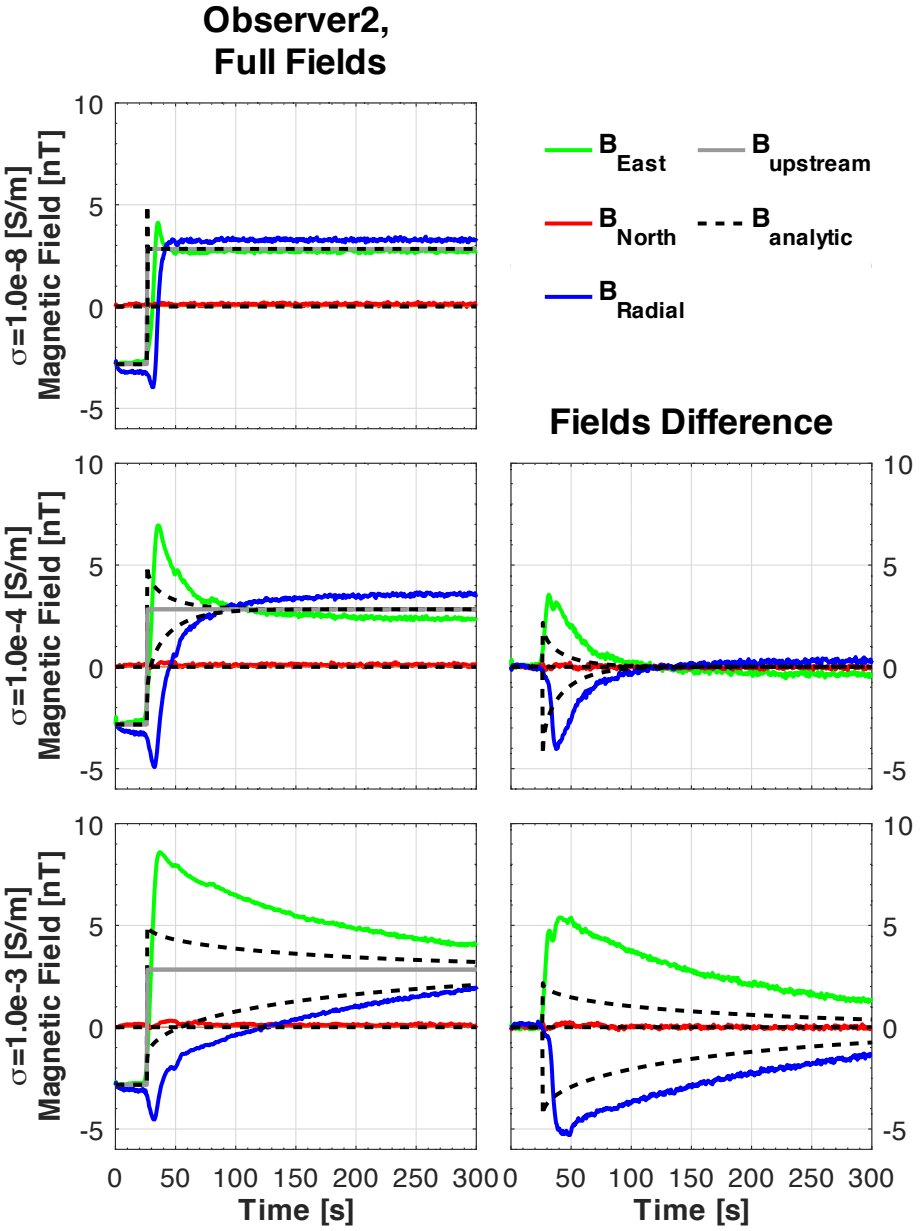
Fuqua Haviland et al. 2019, GRL

Case Study – Temporal Effects



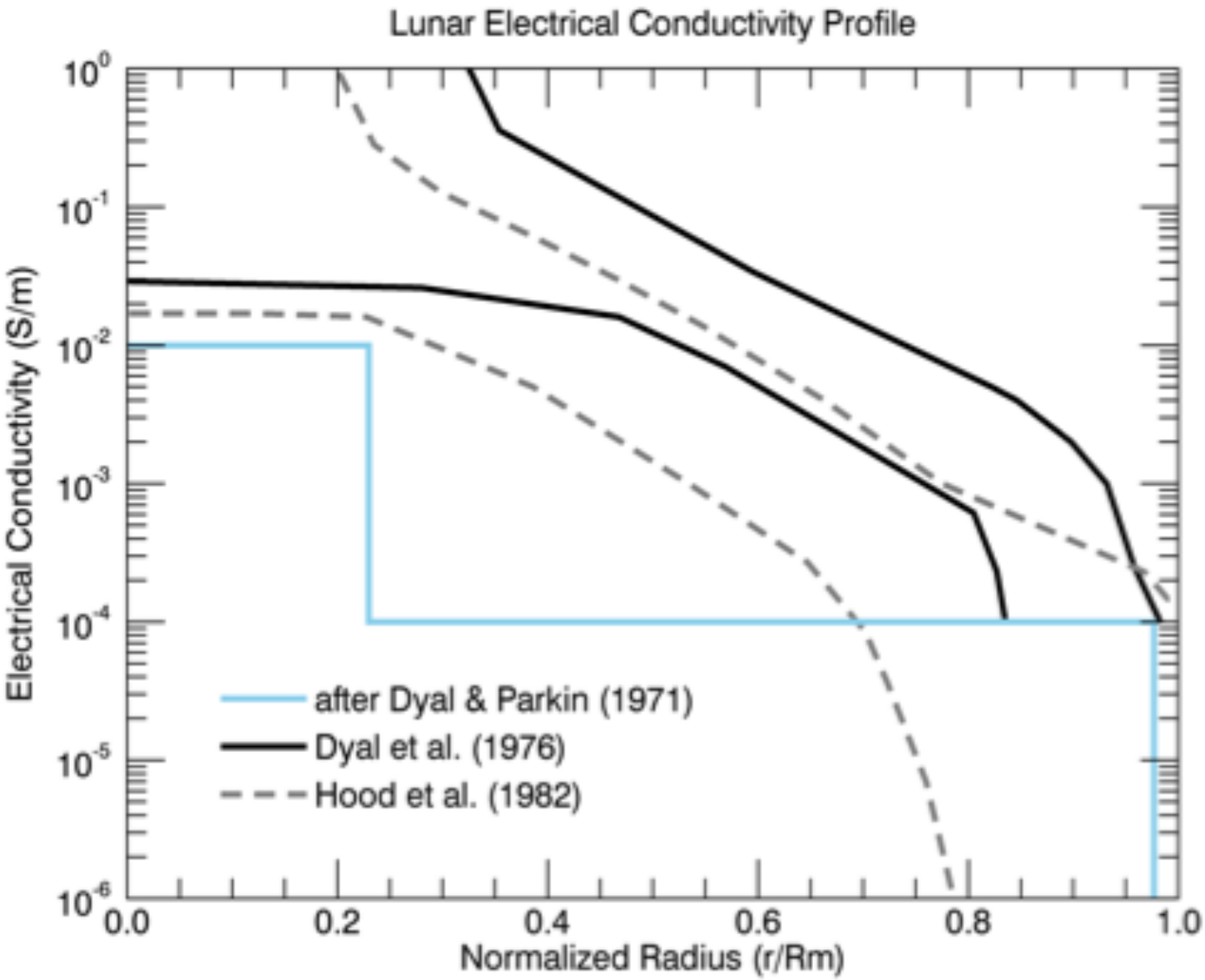
(a)





Fuqua Haviland et al. 2019, GRL

Electrical Conductivity Profile



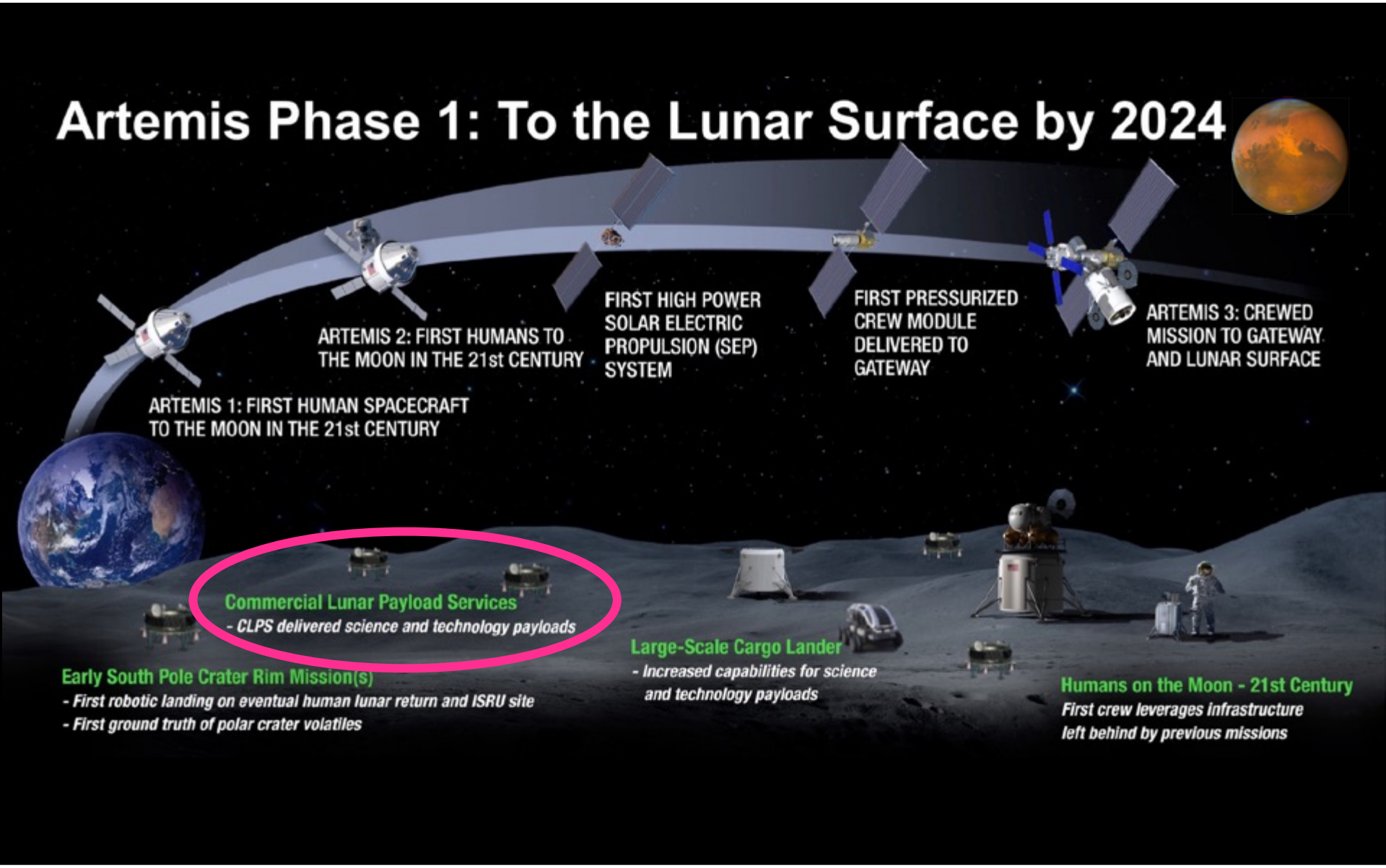
Fuqua Haviland et al. 2019, ASR

Conclusion & Future Work

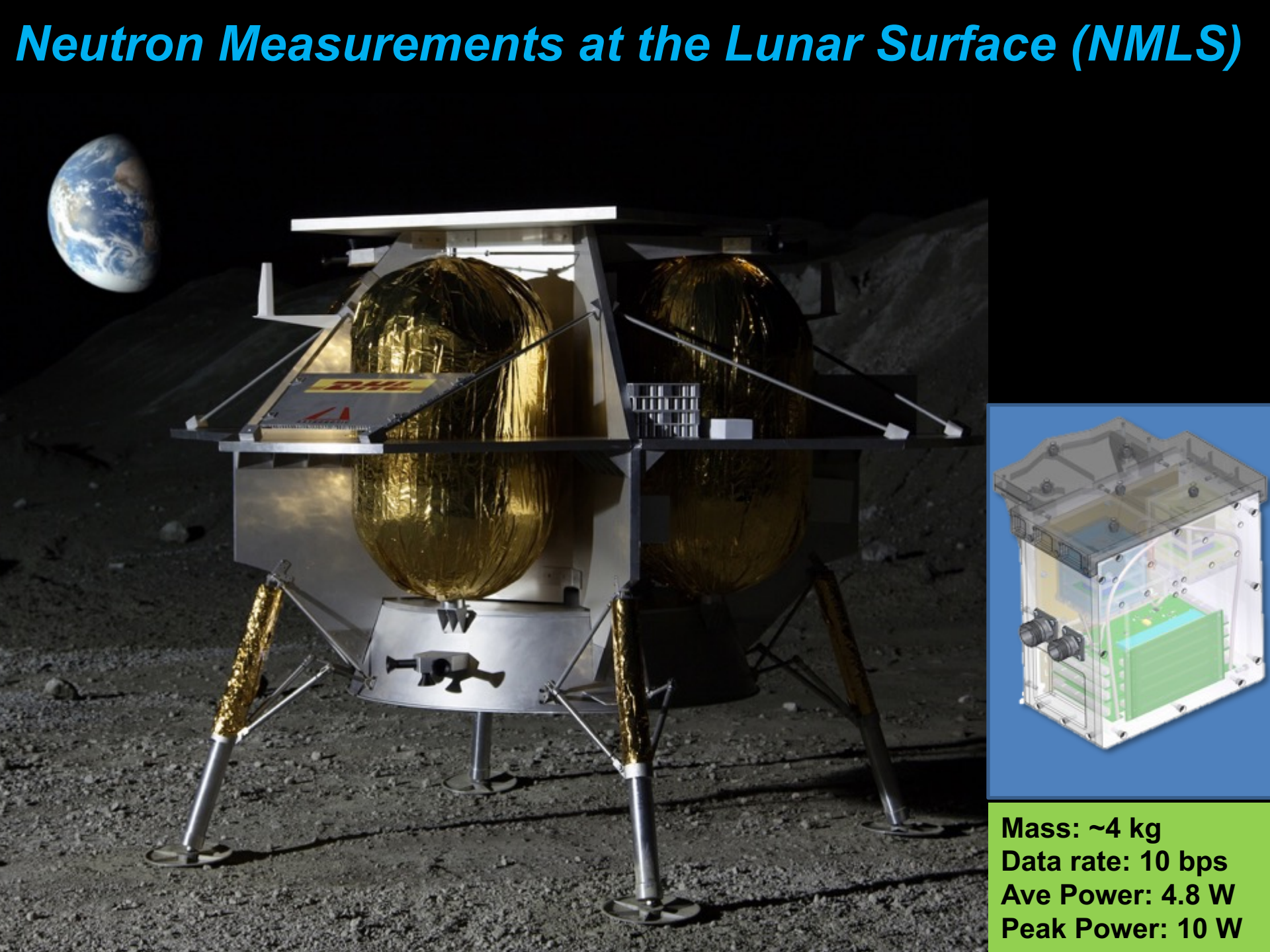
- Vacuum theory alone is not able to fully characterize nightside induced fields.
- Plasma hybrid model is able to characterize plasma currents which vary depending on solar wind conditions
- For the first time, we see wake and induced field coupling in models. Redefining Apollo era assumption about wake field confining induced field within cavity.
- Additional work is needed to isolate induction with magnetometer observations (Apollo, LP, Kaguya, ARTEMIS).

Future Lunar and planetary geophysical instrument and missions

CLPS Supports the Artemis Program



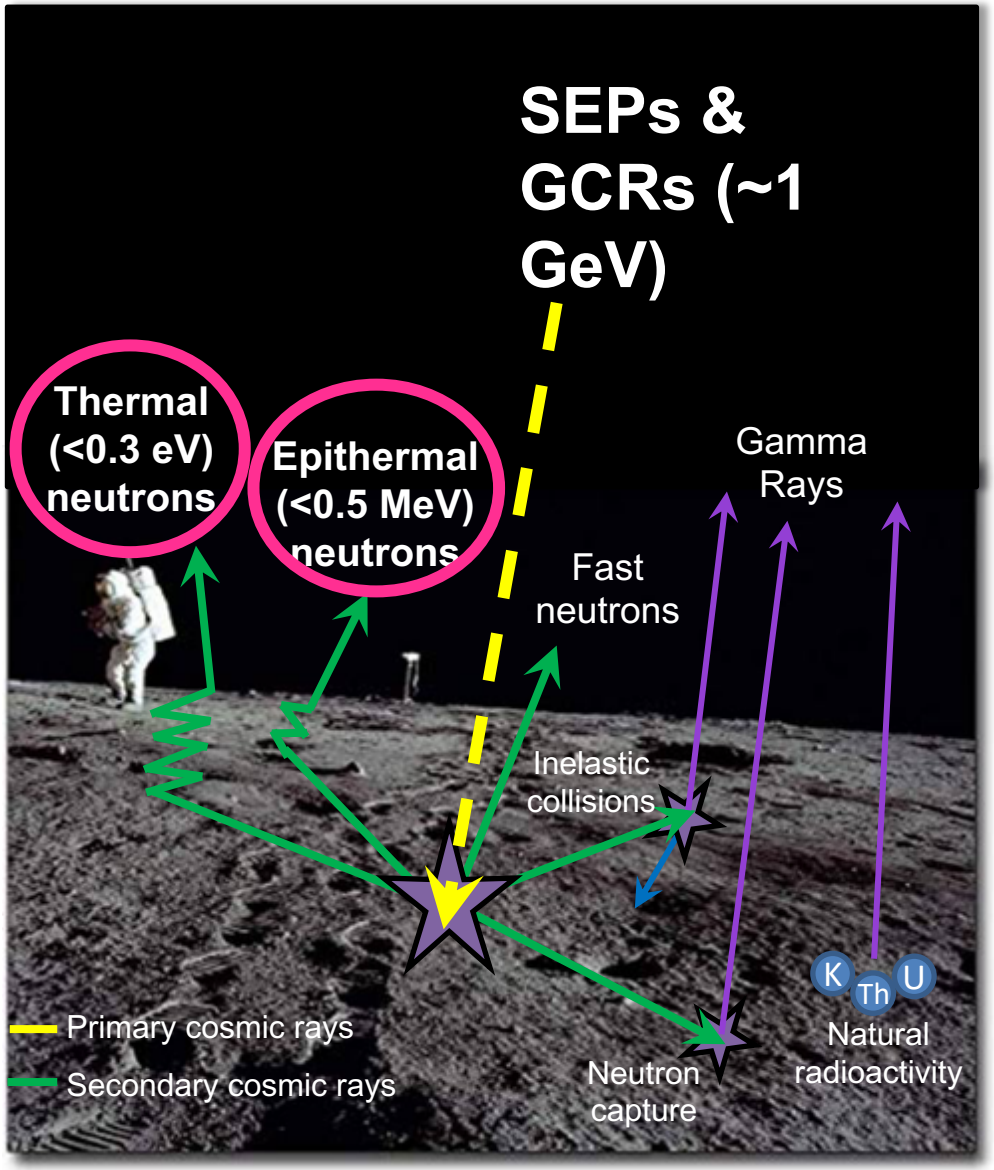
Neutron Measurements at the Lunar Surface (NMLS)



Mass: ~4 kg
Data rate: 10 bps
Ave Power: 4.8 W
Peak Power: 10 W

Neutron Spectroscopy

After Curran [2017]



- "**Epithermal neutrons**"
  - medium energy
  - ~constant for most lunar compositions (except H).
- "**Thermal neutrons**"
  - low energy
  - absorption cross section increases by nuclei
  - is highly composition dependent (flux is large for Fe, Ti)
  - Flux is greater in mafic materials (mare basalts, Mg or Fe-rich, of igneous/volcanic origin, dark in color, olivine, pyroxene)
  - Flux is smaller in the Fe-poor highlands (farside).
- MSFC scintillator technology effectively discriminates between pulse shapes and distinguishes between neutron and gamma ray (as well as other false) triggers.

High value science opportunities exist for NMLS

Science at Astrobotic M1

75 km

WAC Color Ratio Composite
R:689/321 G:415 B:321/689

Why Return to the lunar surface?

- The Moon records 4.5 Ga of Inner Solar System History
- The Moon is key to understanding differentiated planetary processes & exospheres
- The Moon acts as a plasma physics lab for understanding key solar system processes
- Unknown phenomena: *swirls, crustal magnetization, shallow moonquakes, sub surface structure*, core, origin, … & LOTS more!
- The more we learn about the moon & our local space environment, the more we learn about ourselves

Questions?