The solar wind interaction with the Moon

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Nagoya University, Aichi, Japan
Aalto Univ., Aalto, Finland

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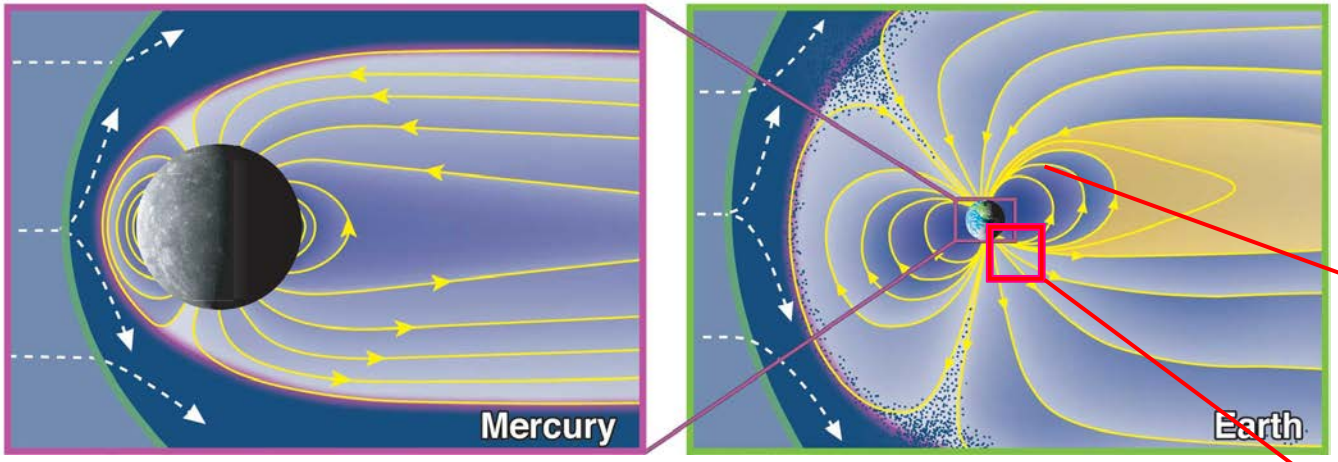
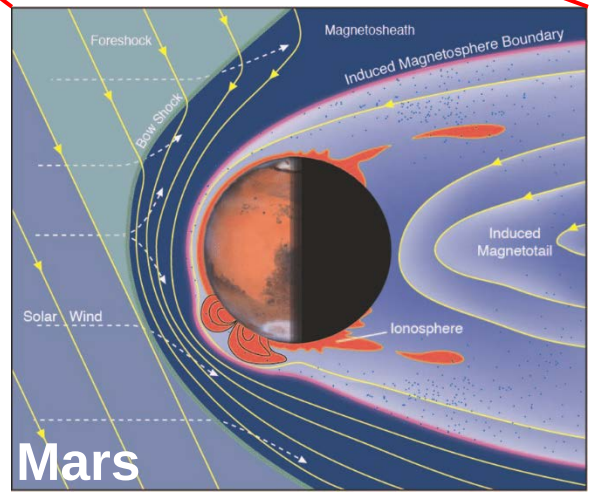
Solar wind interaction with terrestrial bodies

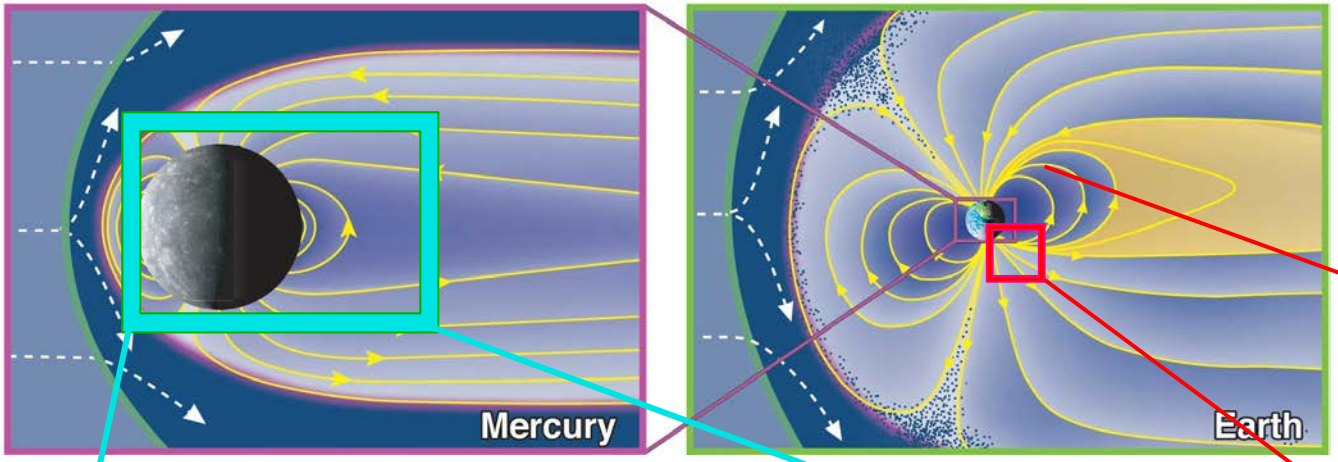


Courtesy of C. Arridge, F. Bagenal and S. Bartlett.



[Brain et al., 2015]

Solar wind interaction with terrestrial bodies



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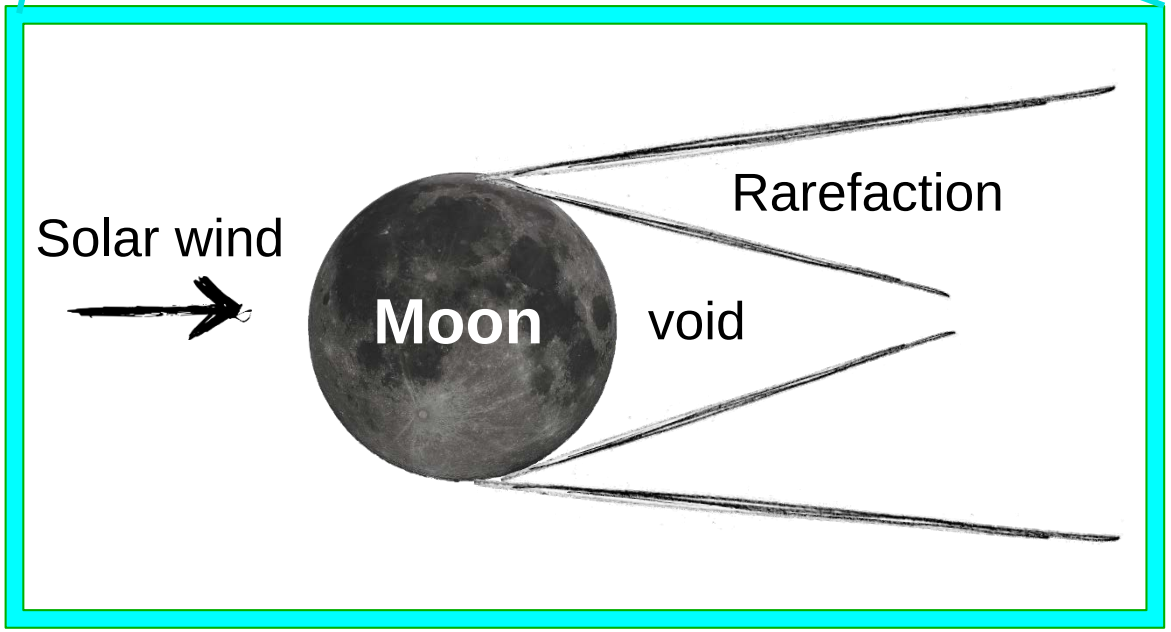
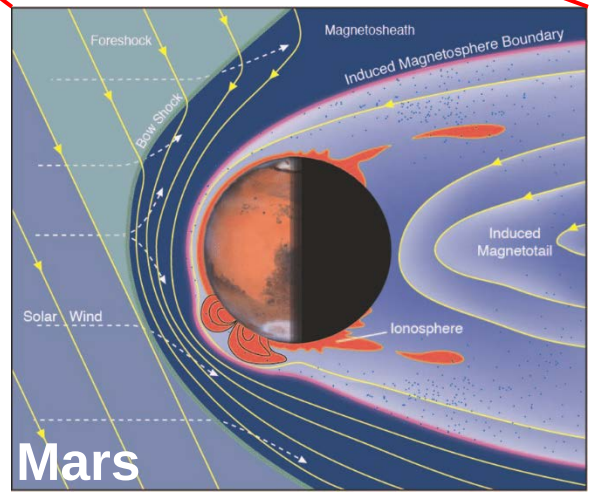


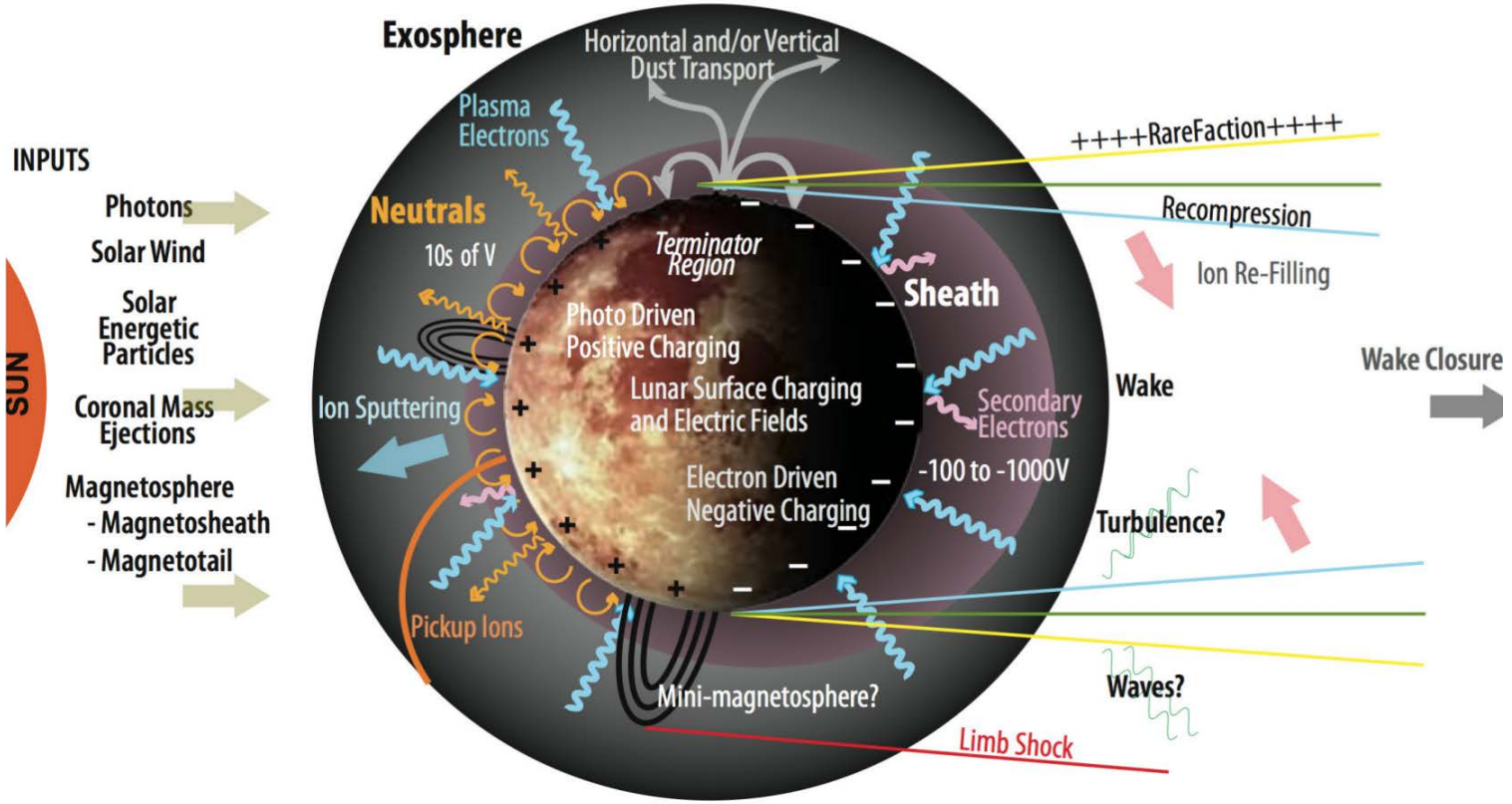


[Brain et al., 2015]

Interaction with the Moon (updated view!)

- Renewed interest in lunar exploration in the last two decades

~70-80% of the incident solar wind plasma is absorbed by the Moon:
10-20% are reflected as Energetic Neutral Atoms (ENAs)
20% are reflected in charged form from the surface and crustal fields



[Credit: NASA/SSERVI/DREAM2]

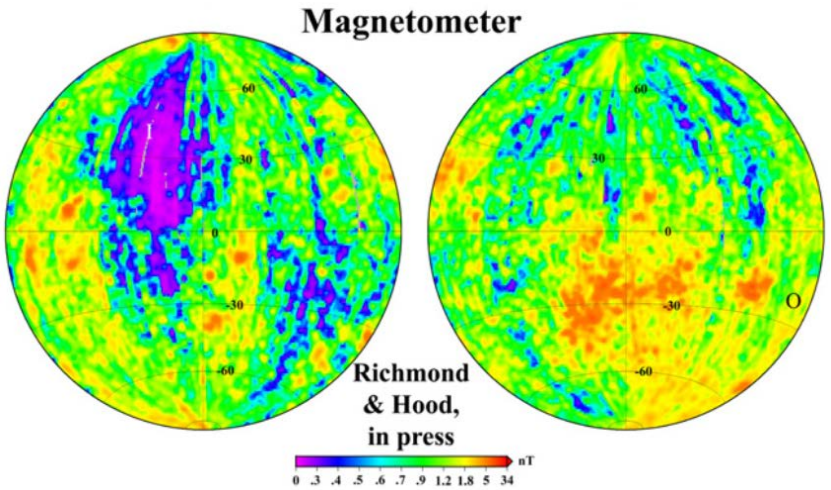
Lunar crustal magnetic fields

Different methods used to observe/estimate structure of crustal fields:

- Direct measurements (MAG):

* ~30 km above the surface

(Hood et al., 1979, 2001, Richmond et al., 2008)



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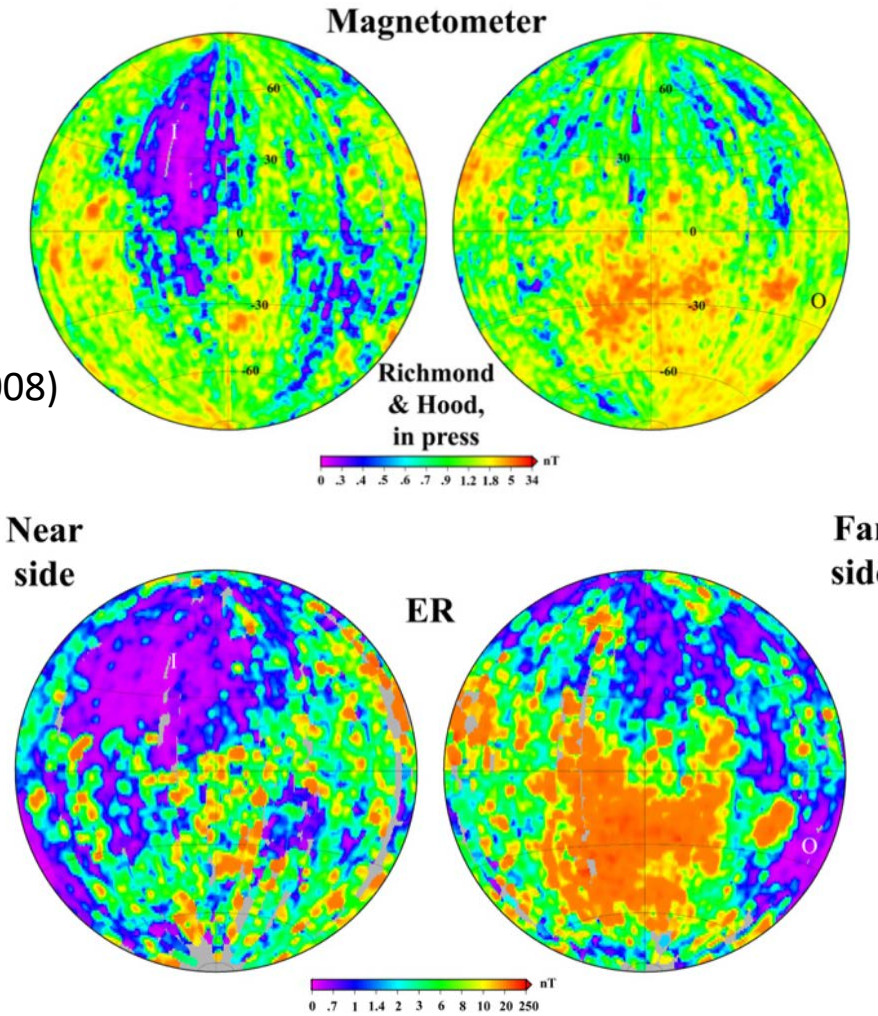
- Electron Reflectometery (ER)

*magnetic mirror; uniform fields

(Binder, 1998; Halekas et al., 2001; Mitchell et al., 2008)



[Purucker, 2008]

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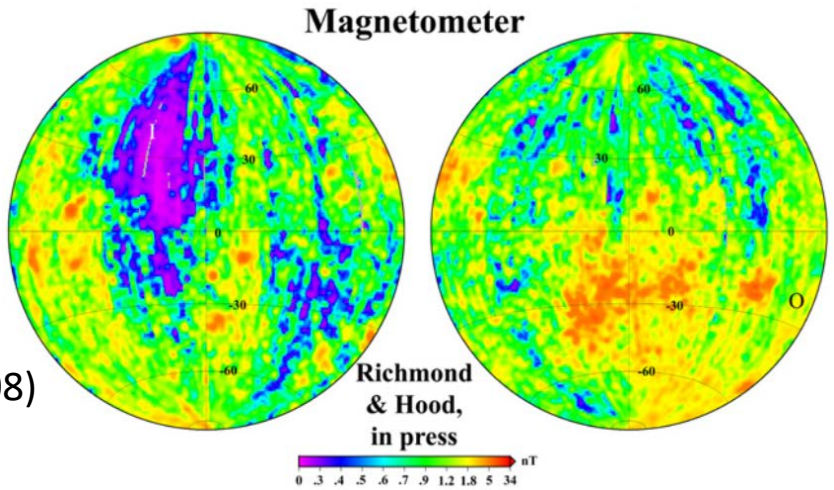


- Electron Reflectometery (ER)

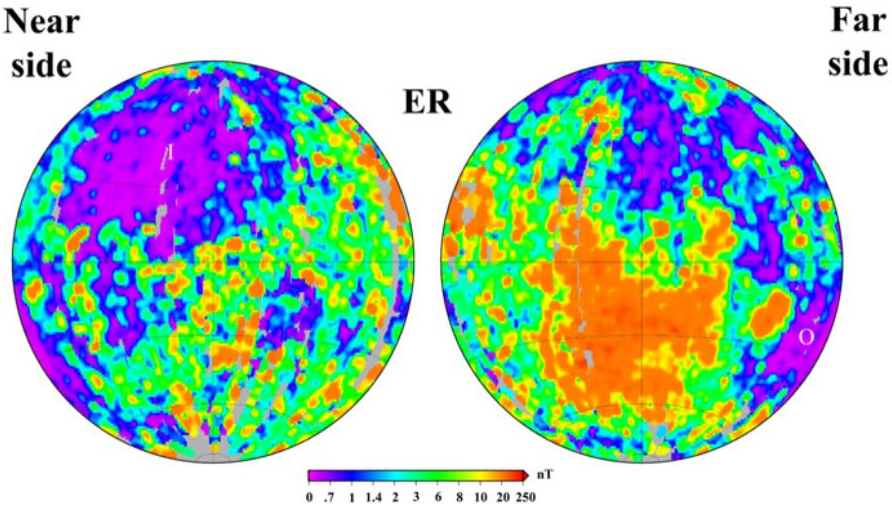
*magnetic mirror; uniform fields

(Binder, 1998; Halekas et al., 2001; Mitchell et al., 2008)

- Empirical (Spherical harmonics)

* extrapolated to the surface

(Purucker et al., 2008, 2010;
Tsunakawa et al., 2010, 2015)



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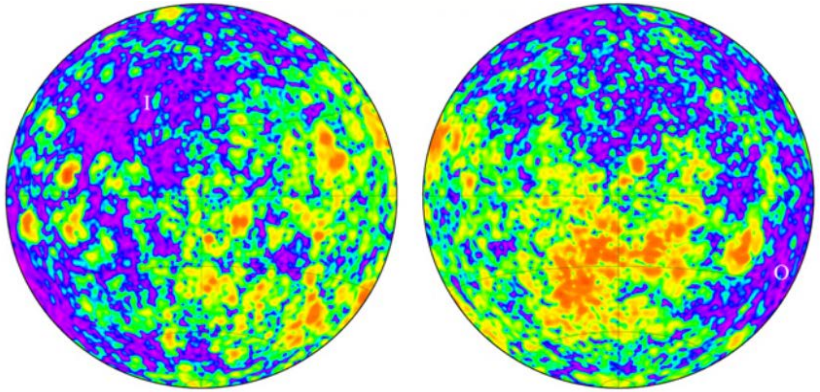
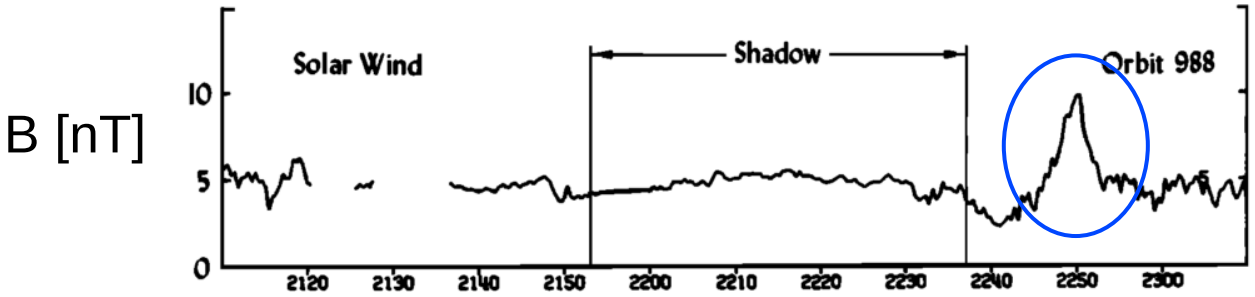


Solar wind interaction with crustal fields

Apollo 15 & 16 observation of **limb compression** [Russell and Lichtenstein, 1975]



- Limb compression outside the lunar wake

- Effects of lunar crustal magnetic fields

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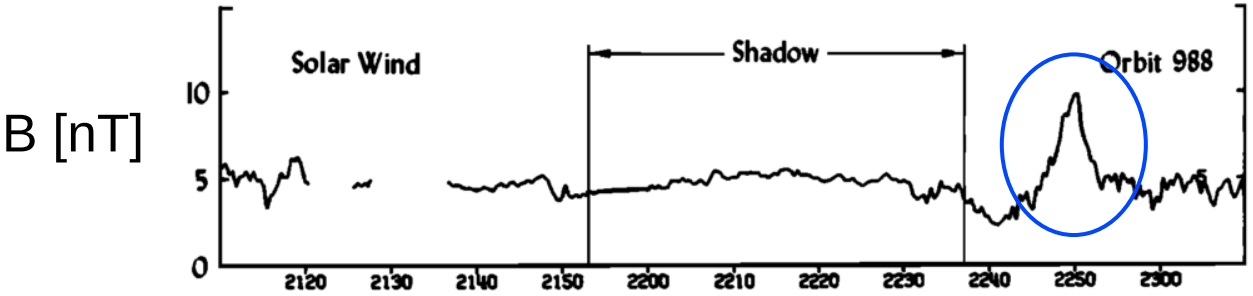
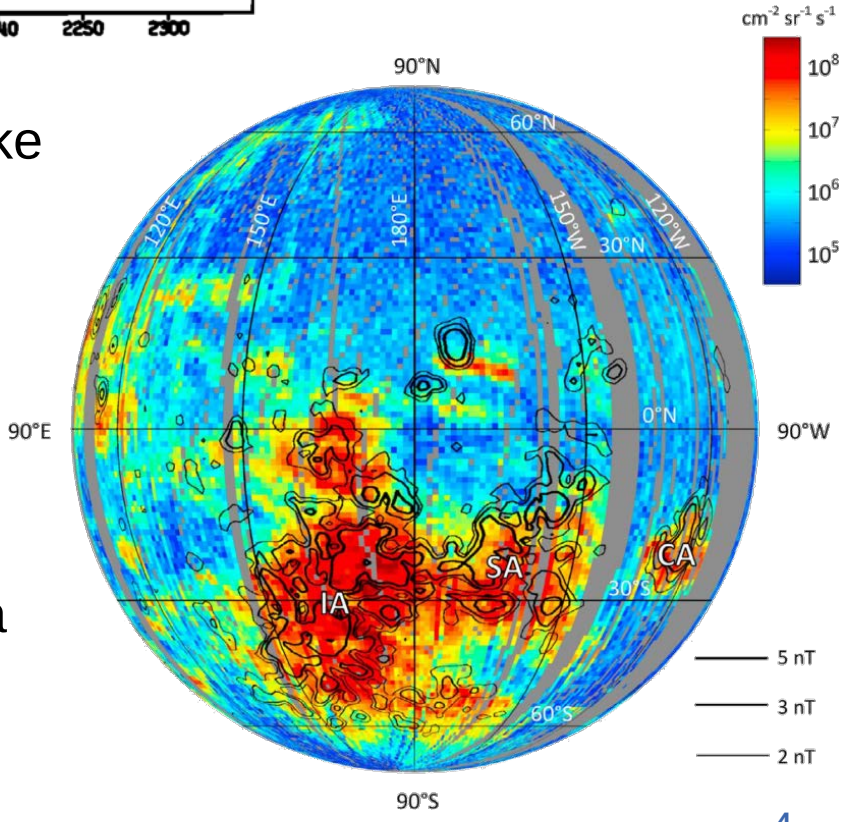


- Limb compression outside the lunar wake

- Effects of lunar crustal magnetic fields

- Solar wind reflection from crustal fields
[e.g., Saito et al., 2010, 2012; Lue et al., 2011; Harada and Halekas, 2016]

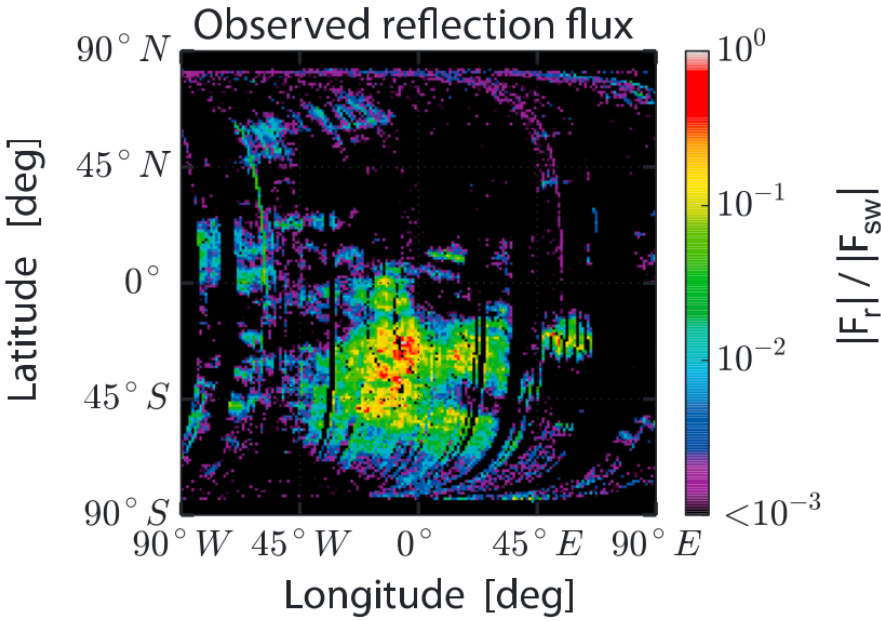
- Is there any correlation between plasma reflection and limb compression?



[Lue et al., 2011]

Solar wind reflection from crustal fields

- We applied proton reflection map into our hybrid model.



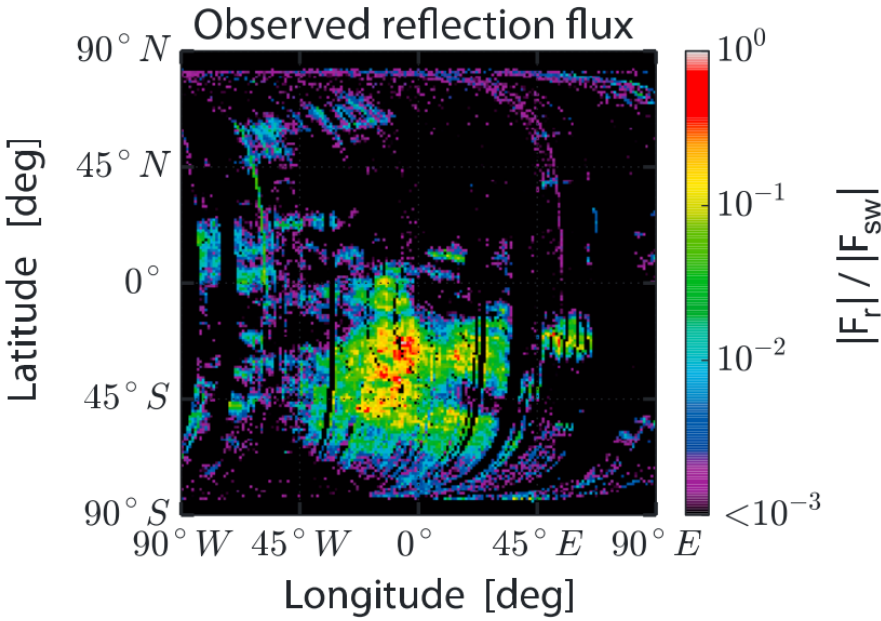
[Fatemi et al., 2014]

Solar wind reflection from crustal fields

- We applied proton reflection map into our hybrid model.

- Limb compression outside the wake is associated with proton reflection

- Is there any shock?
(e.g., Russell and Lichtenstein, 1975; Lin et al., 1998)



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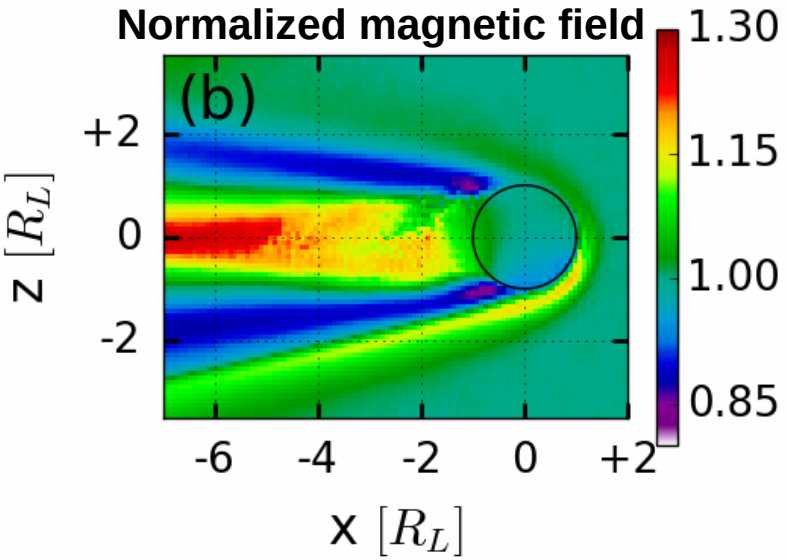
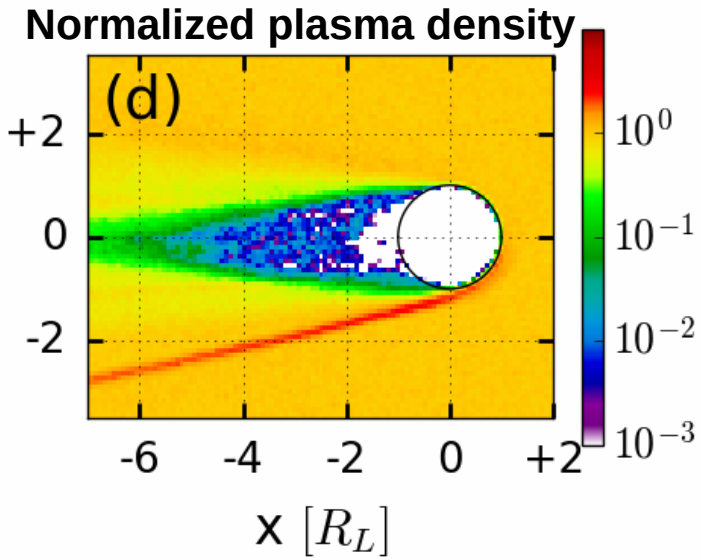




Small-scale collisionless shock

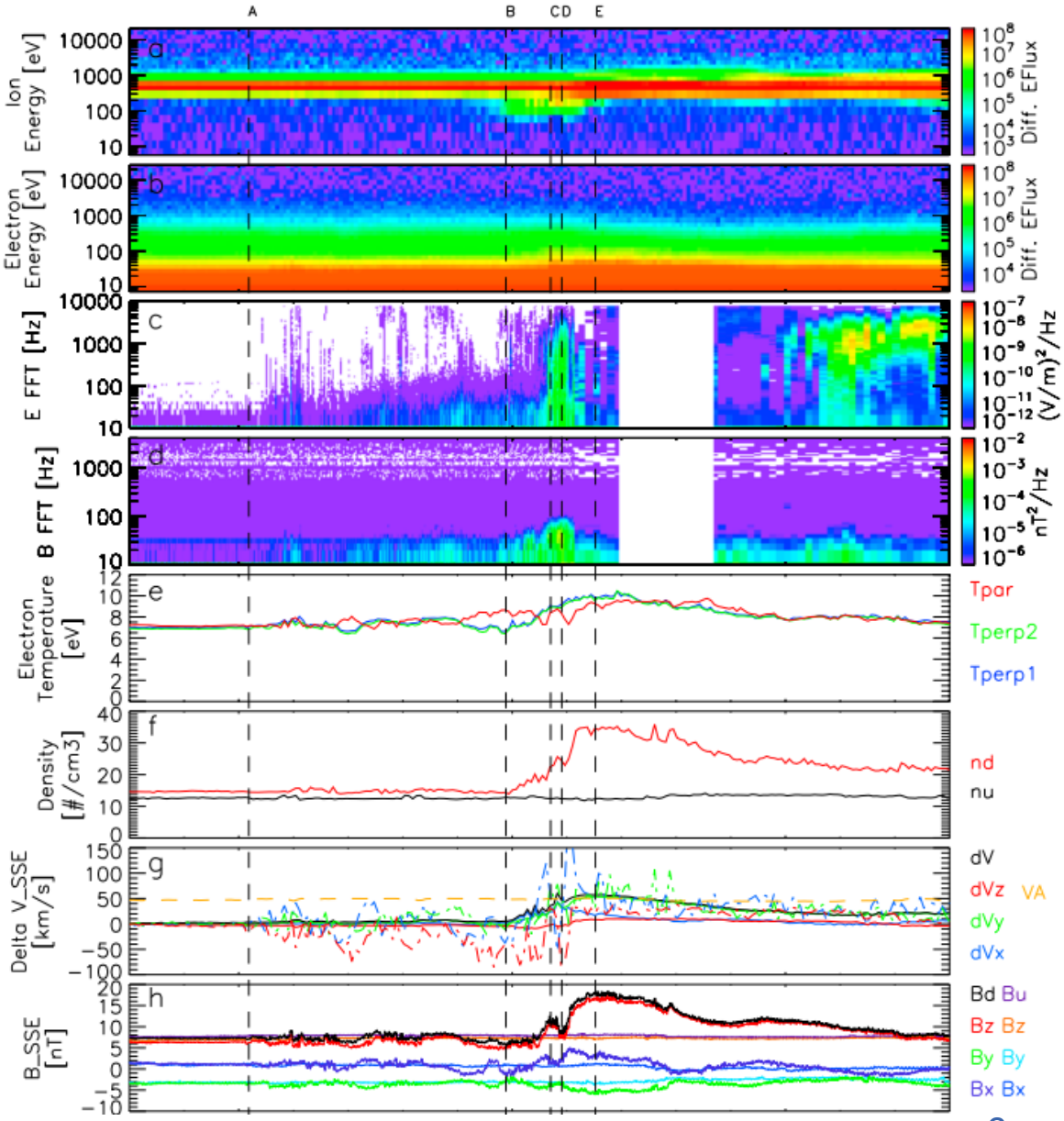
A discontinuity with
- magnetic field and plasma density compression

- velocity deflection
- mass flux and heating across the boundary
- Related to crustal fields
- The smallest shock

- Also suggested by models

[e.g., Harnett and Winglee 2000; Fatemi et al., 2014; Xie et al., 2015; Bamford et al., 2016]

What is the mechanism?

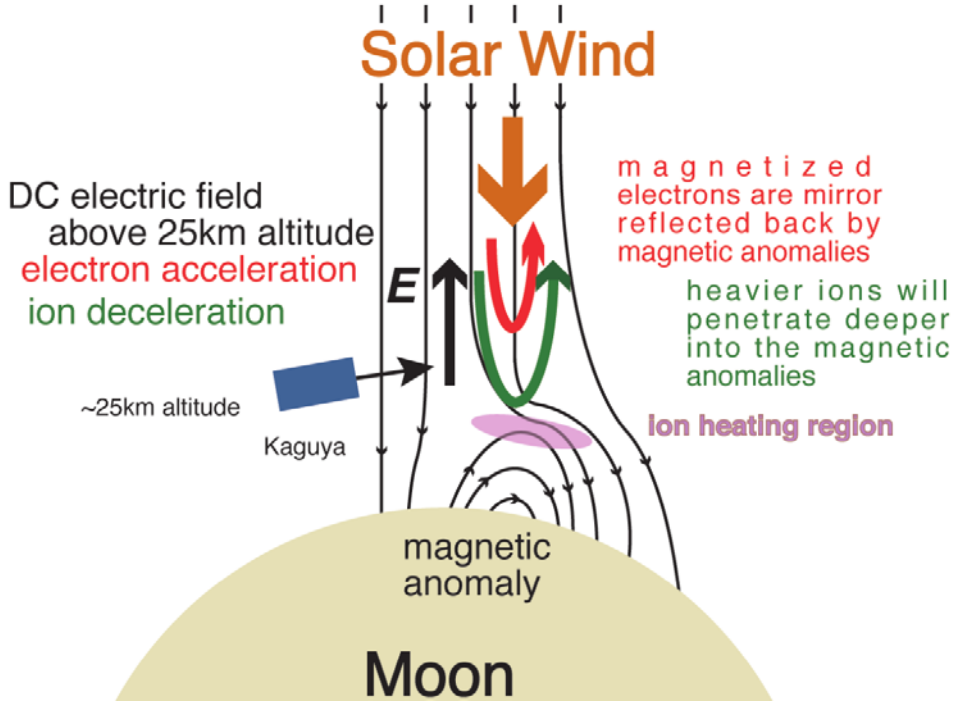


[Halekas et al., 2014]

Particle reflection from crustal fields

Contribution of electric field

Observed by multiple spacecrafts
[e.g., Saito et al., 2010, 2012; Lue et al., 2011]



[Saito et al., 2012]

Particle reflection from crustal fields

Contribution of electric field

Observed by multiple spacecrafts
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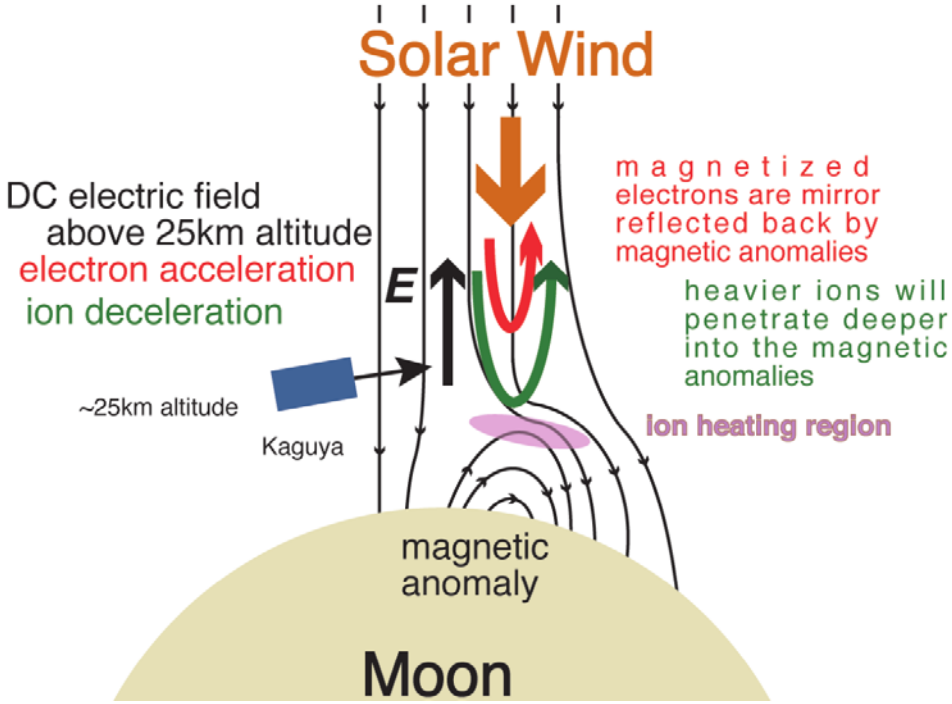
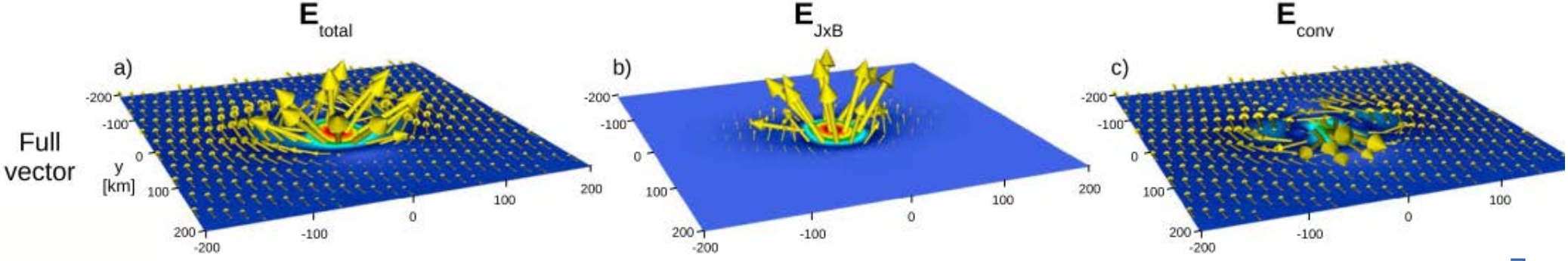
Examined by simulations
[e.g., Bamford et al., 2012; Jarvinen et al., 2014;
Fatemi et al., 2014, 2015a; Deca et al., 2015, 2016]

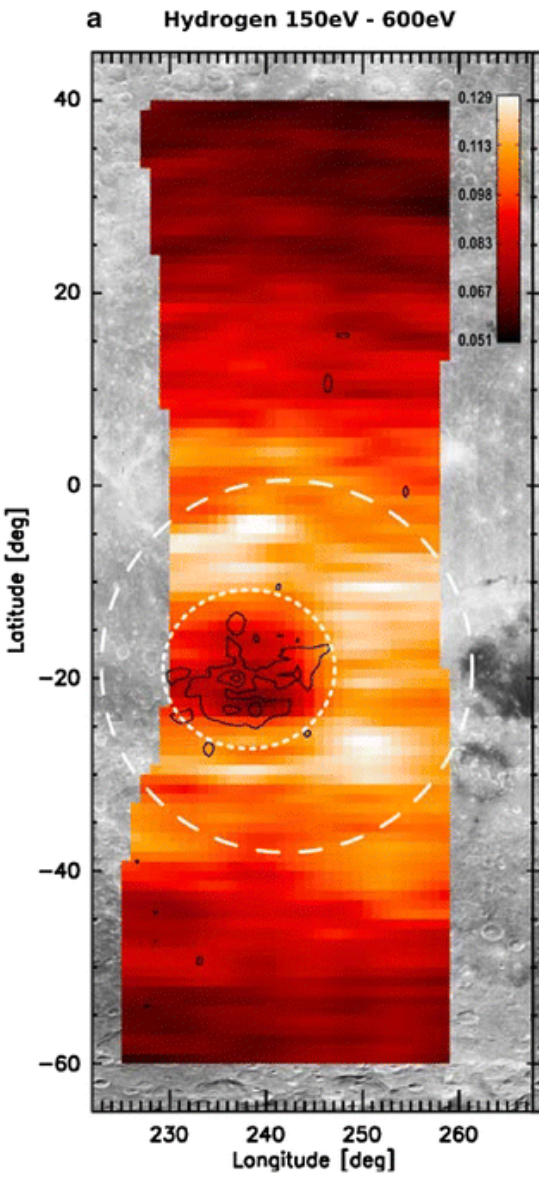


[Saito et al., 2012]



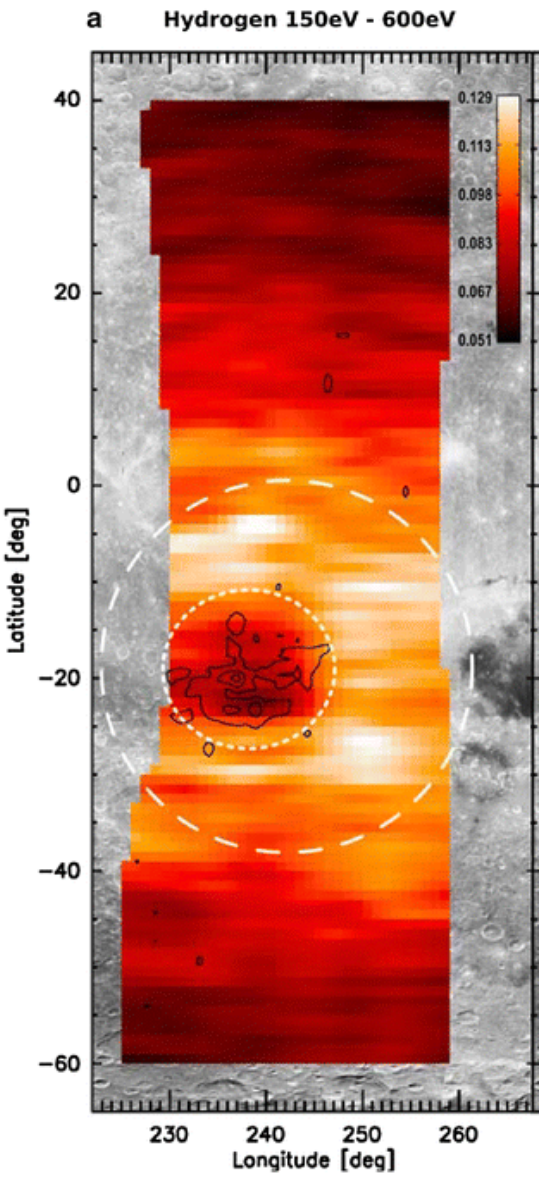
[Jarvinen et al., 2014]

ENA observation & indication of crustal fields



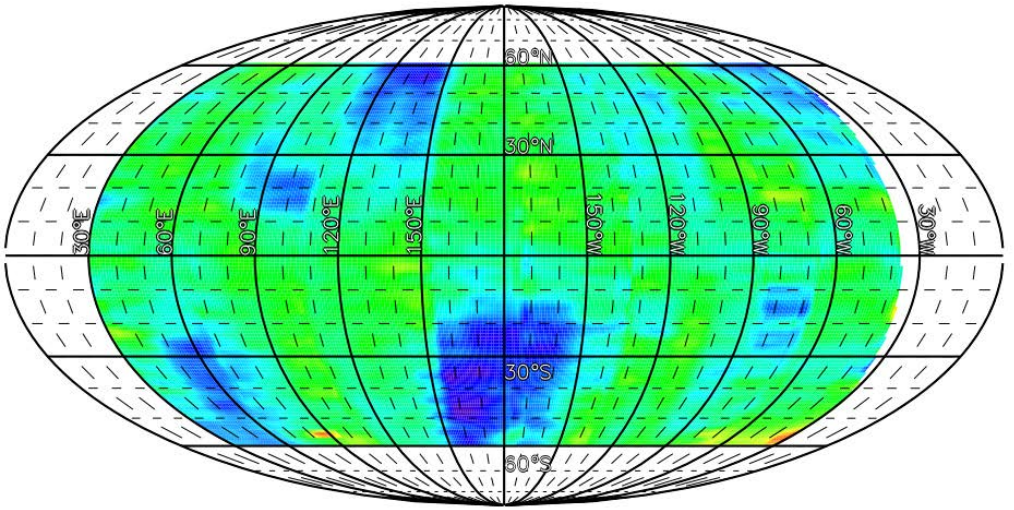
[Wieser et al., 2010]

ENA observation & indication of crustal fields

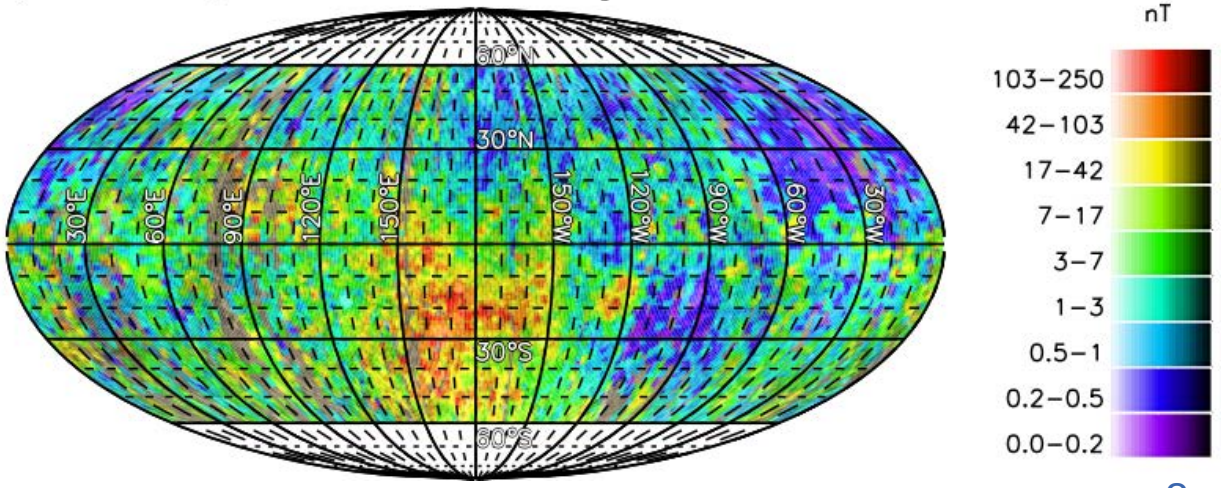


[Wieser et al., 2010]

Global ENA reflection map



Global surface magnetic fields



[Vorburger et al., 2013]

Lunar swirls

- Lunar surface albedo marking on the lunar regolith (swirls)

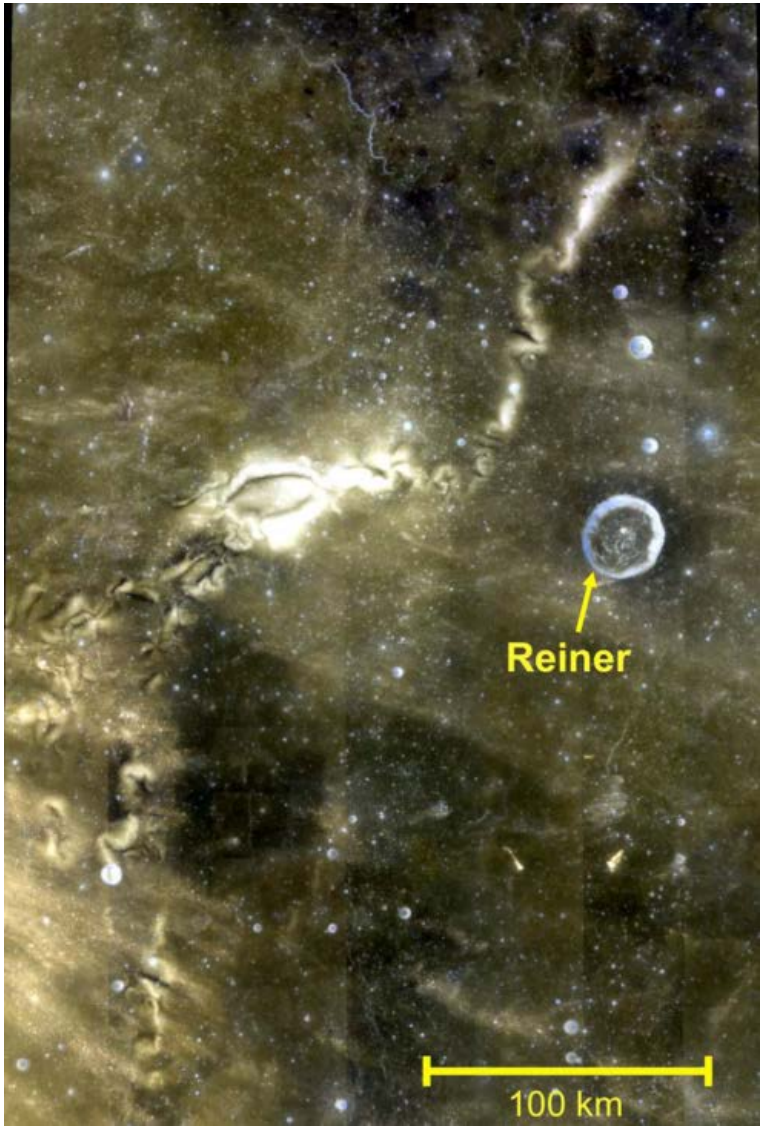
- Optically immature

- Seemingly unique in the Solar System

- Correlation with lunar crustal fields
(e.g., Hood & Williams 1989;
Fatemi et al., 2015a; Deca et al., 2016, 2018;
Poppe et al., 2016)

- Effects of space weathering

- Formation is not fully understood!

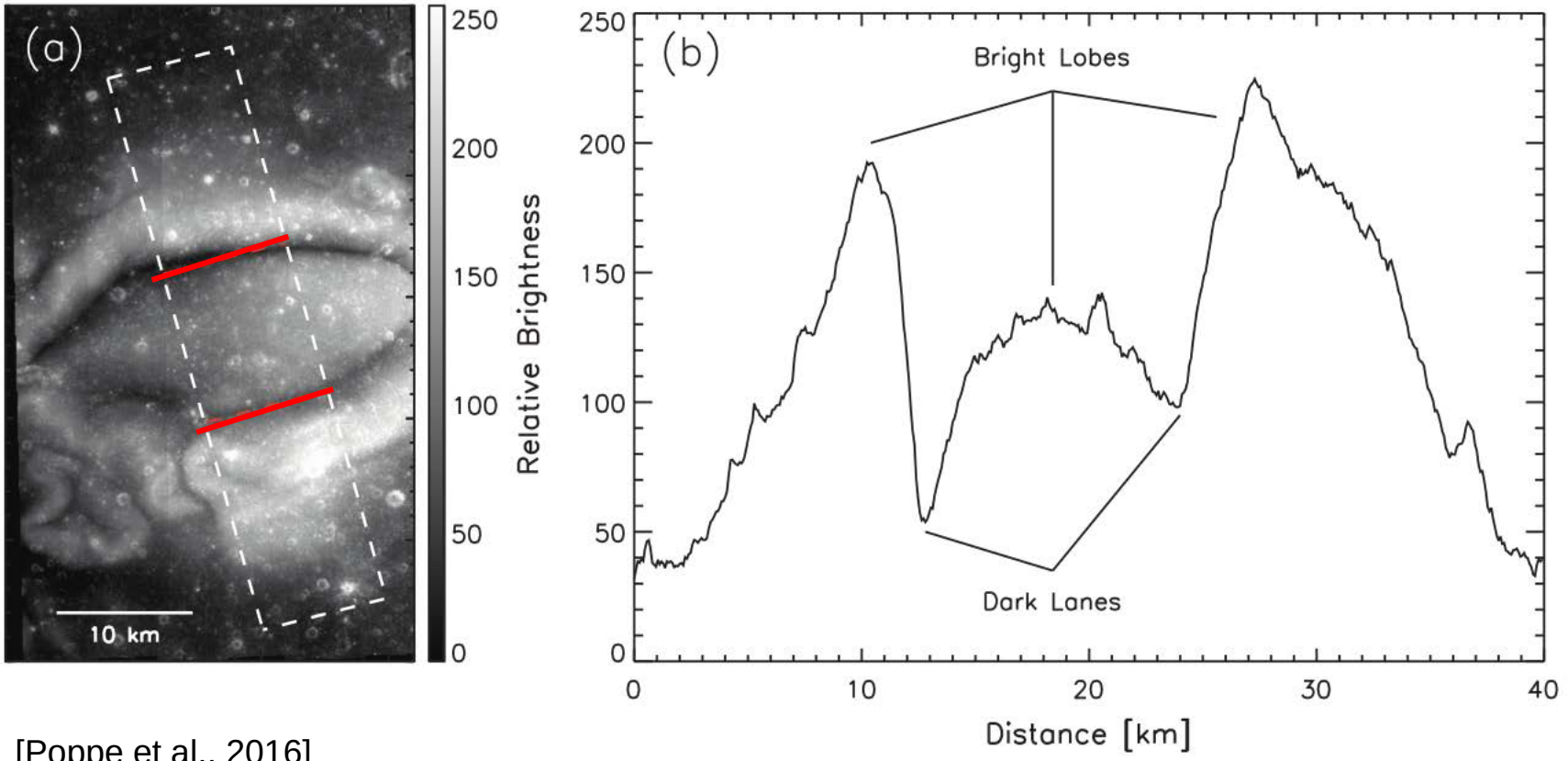


[Blewett et al., 2011]

Crustal magnetization & surface brightness

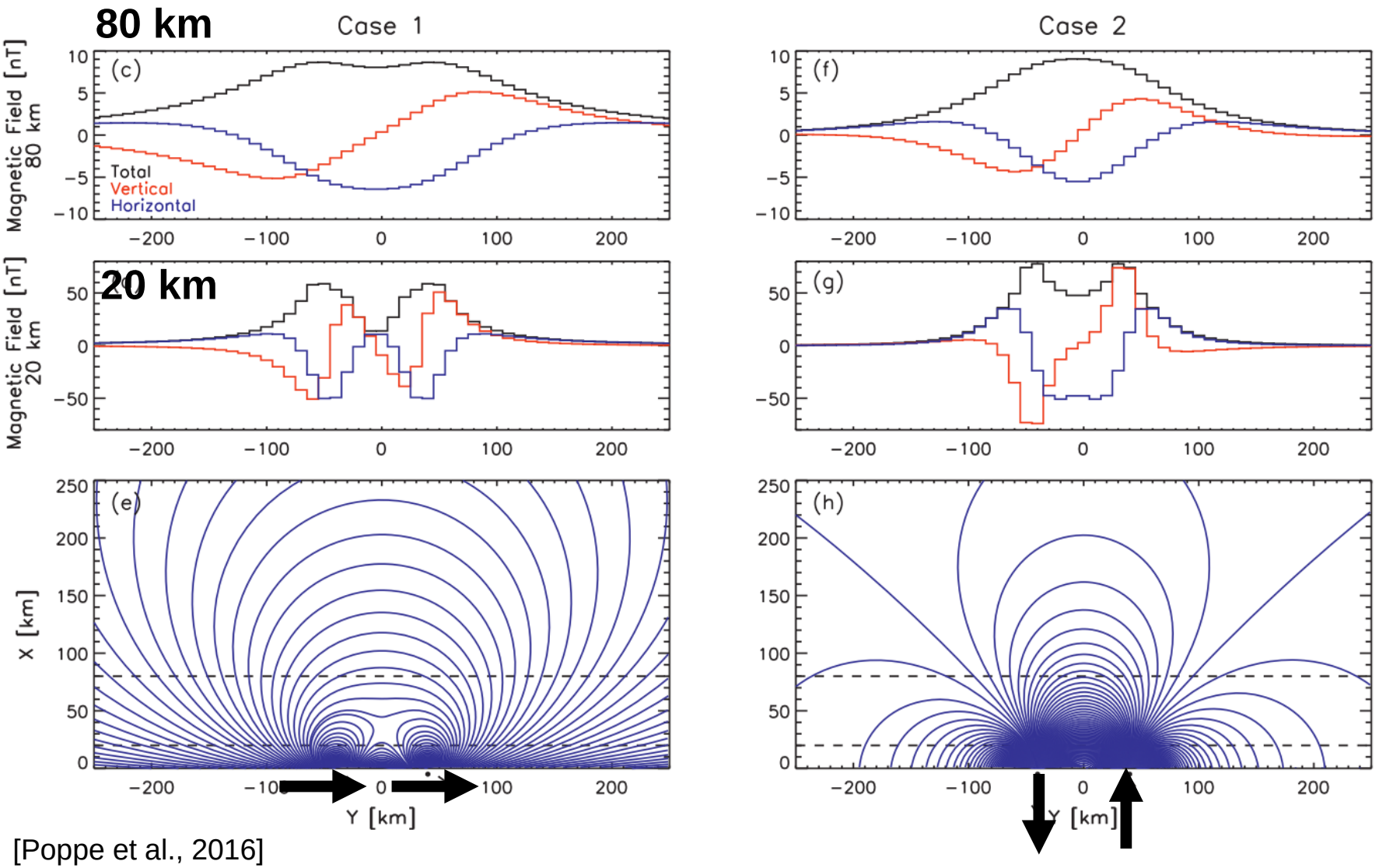
Reiner Gamma

(On the lunar near side)



[Poppe et al., 2016]

Crustal magnetization



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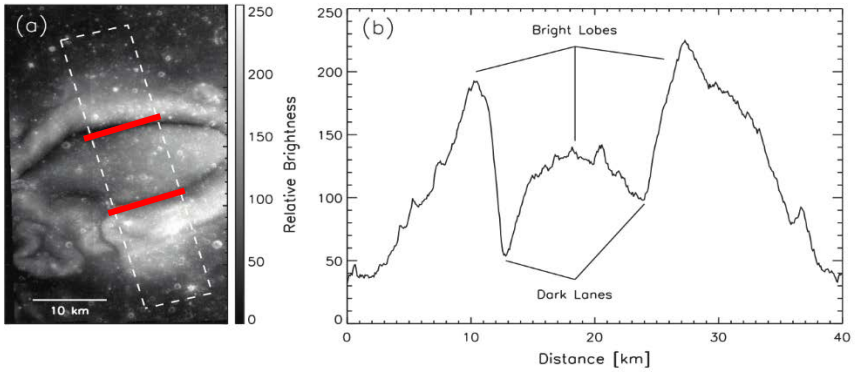
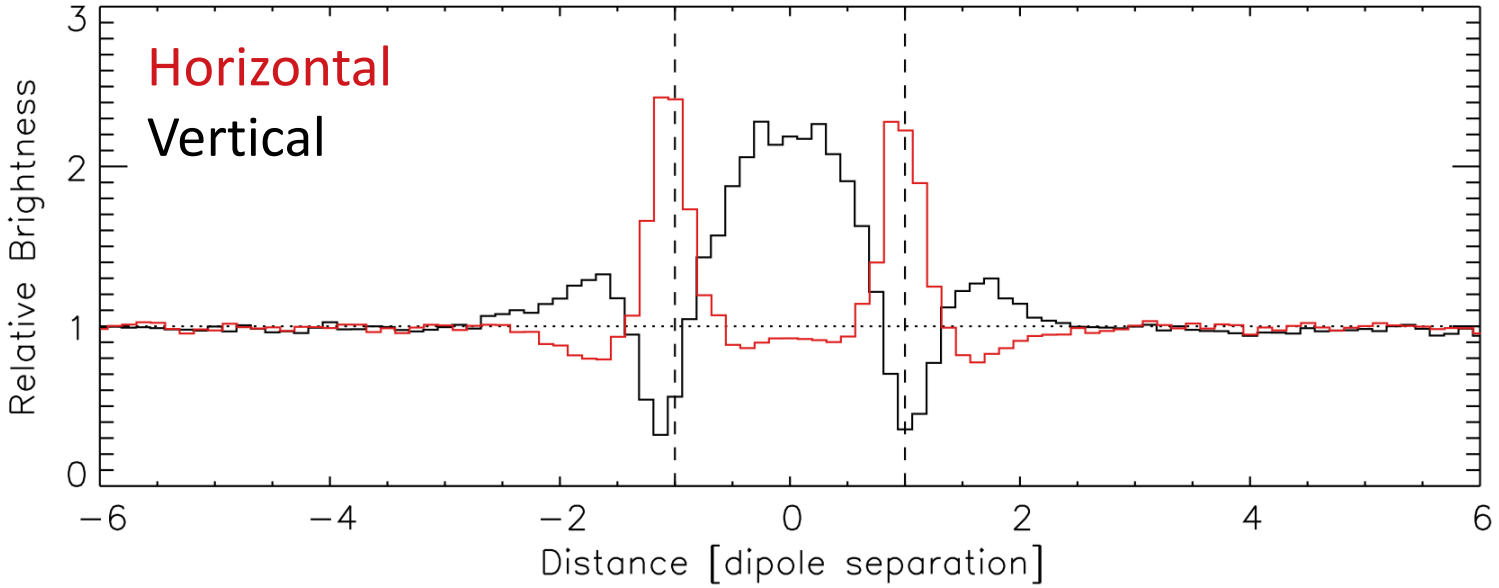
Surface brightness & surface magnetization





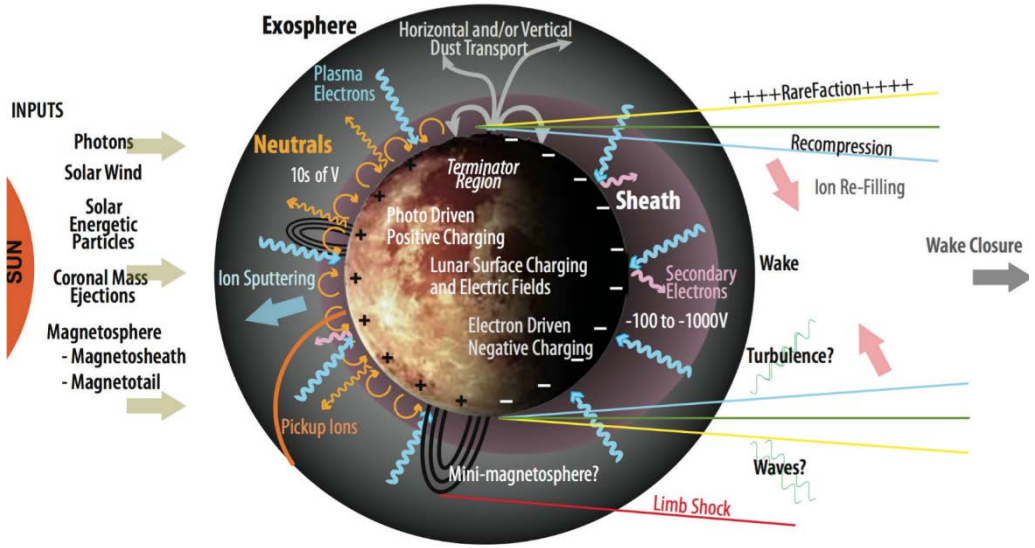
Modeling plasma interaction can examine different source magnetization!

Summary

- Similar to other terrestrial bodies, solar wind interaction with the Moon is complex and is not fully understood.

- The solar wind interaction is not only about the plasma, but also provides detailed understanding about several processes occurring in the surrounding lunar environment and on the lunar surface.

- A renewed interest in lunar exploration in the last two decades and an increasing probability of returning to the Moon with manned missions demand deep understanding on the plasma environment around this object.

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