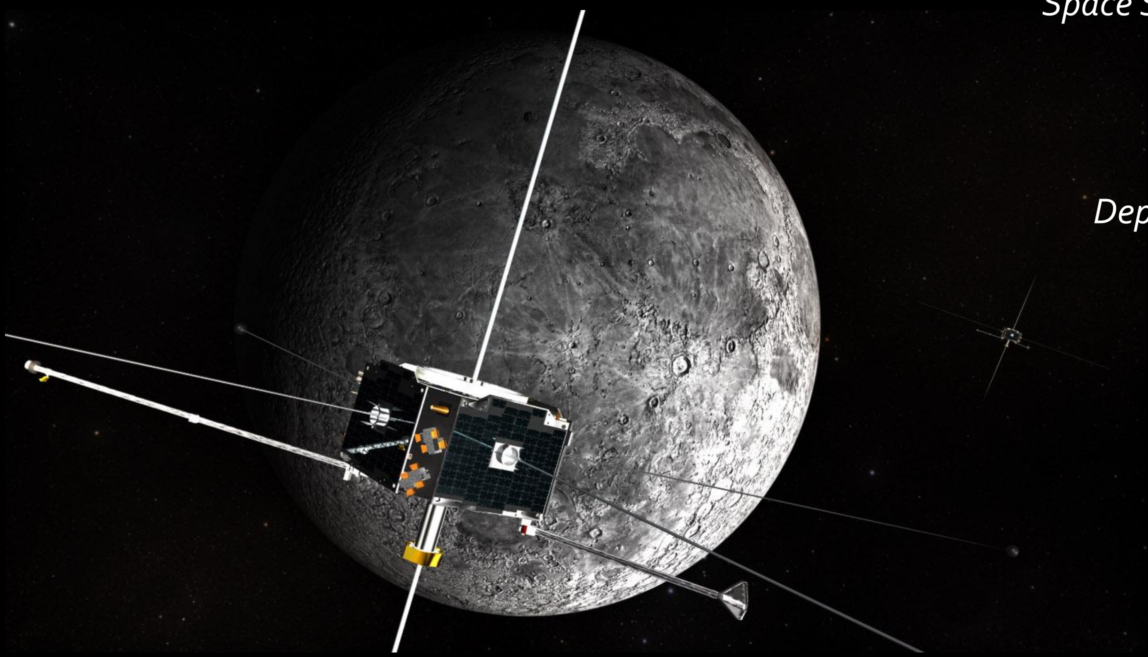
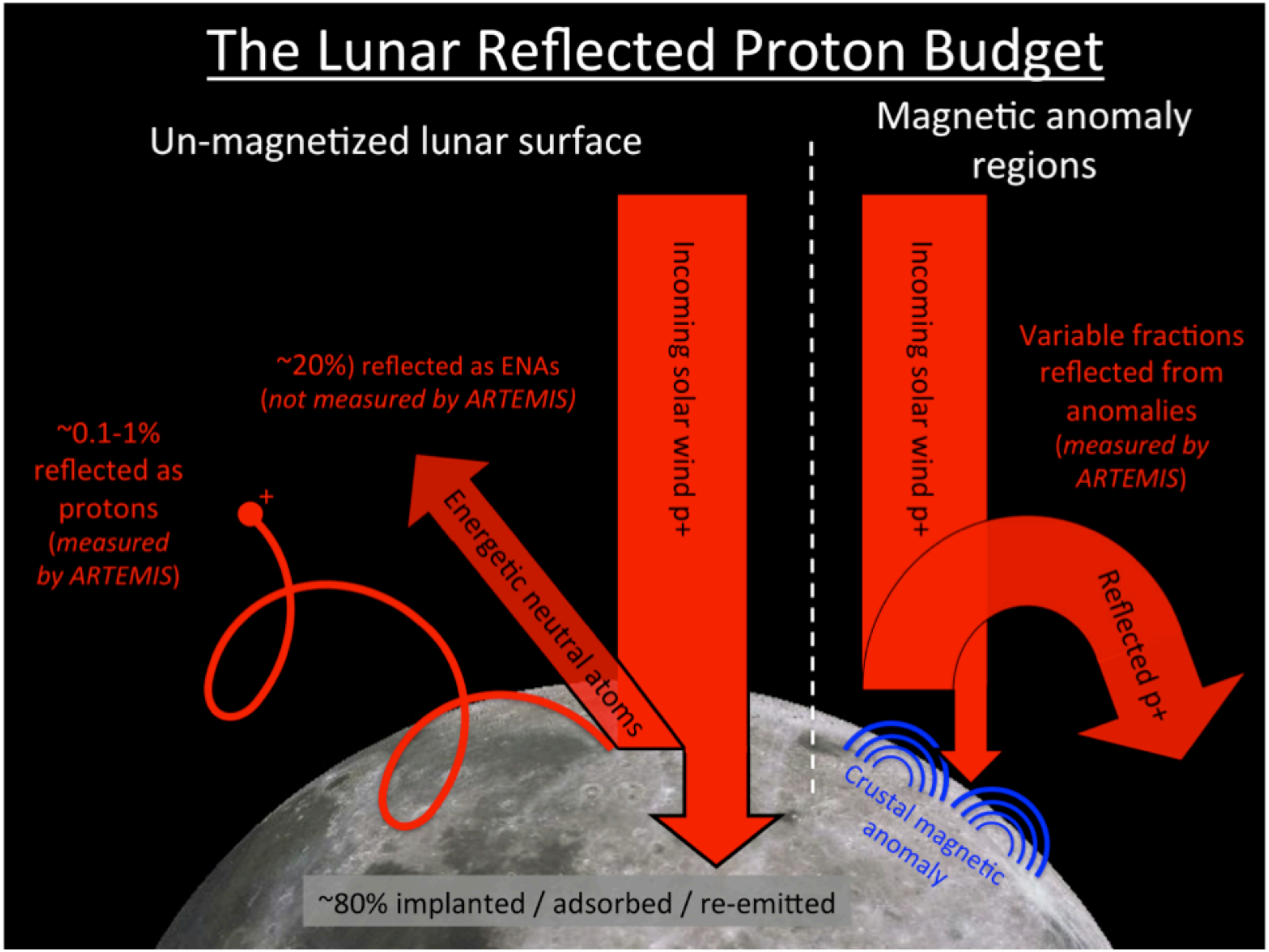
ARTEMIS mapping of lunar crustal magnetic reflection of solar wind protons



A. R. Poppe [*poppe@ssl.berkeley.edu*]
S. Fatemi
Space Sciences Lab., Univ. of California at Berkeley

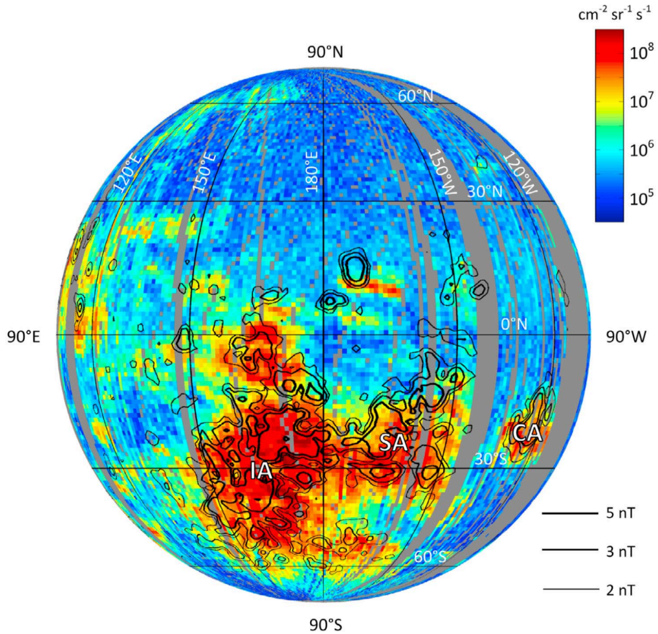
J. S. Halekas, C. Lue
Dept. of Physics & Astronomy, Univ. of Iowa

January 11, 2017
DAP-2017
LASP, Boulder, CO

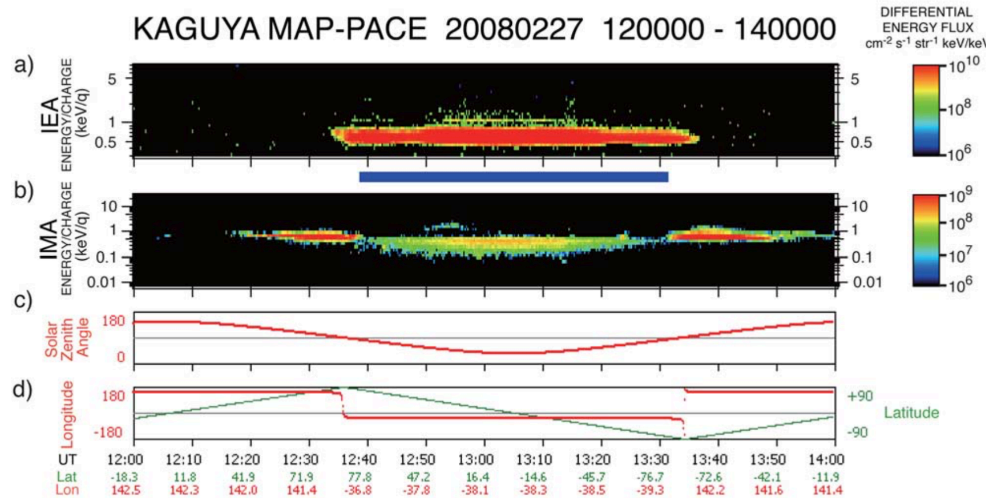


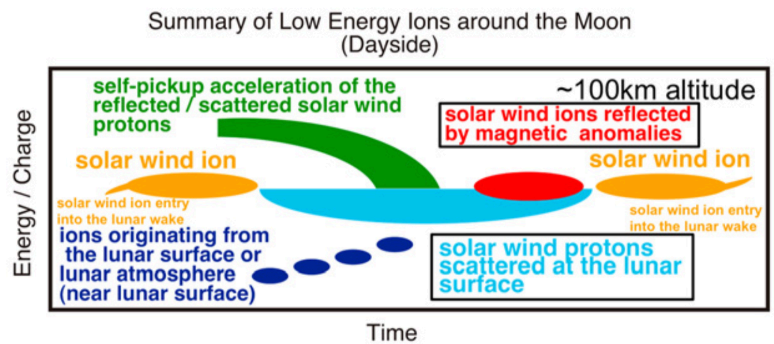
Protons are known to reflect from the un-magnetized regolith [*Saito et al. 2008*] and crustal magnetic anomalies [*Lue et al., 2011*]

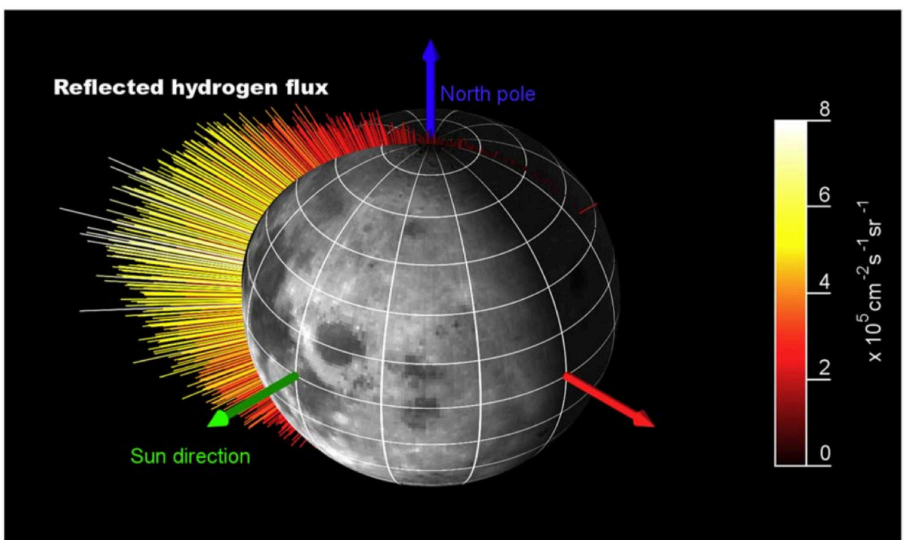
<u>Introduction and Motivation:</u> *Previous Observations*



Chandrayaan-1

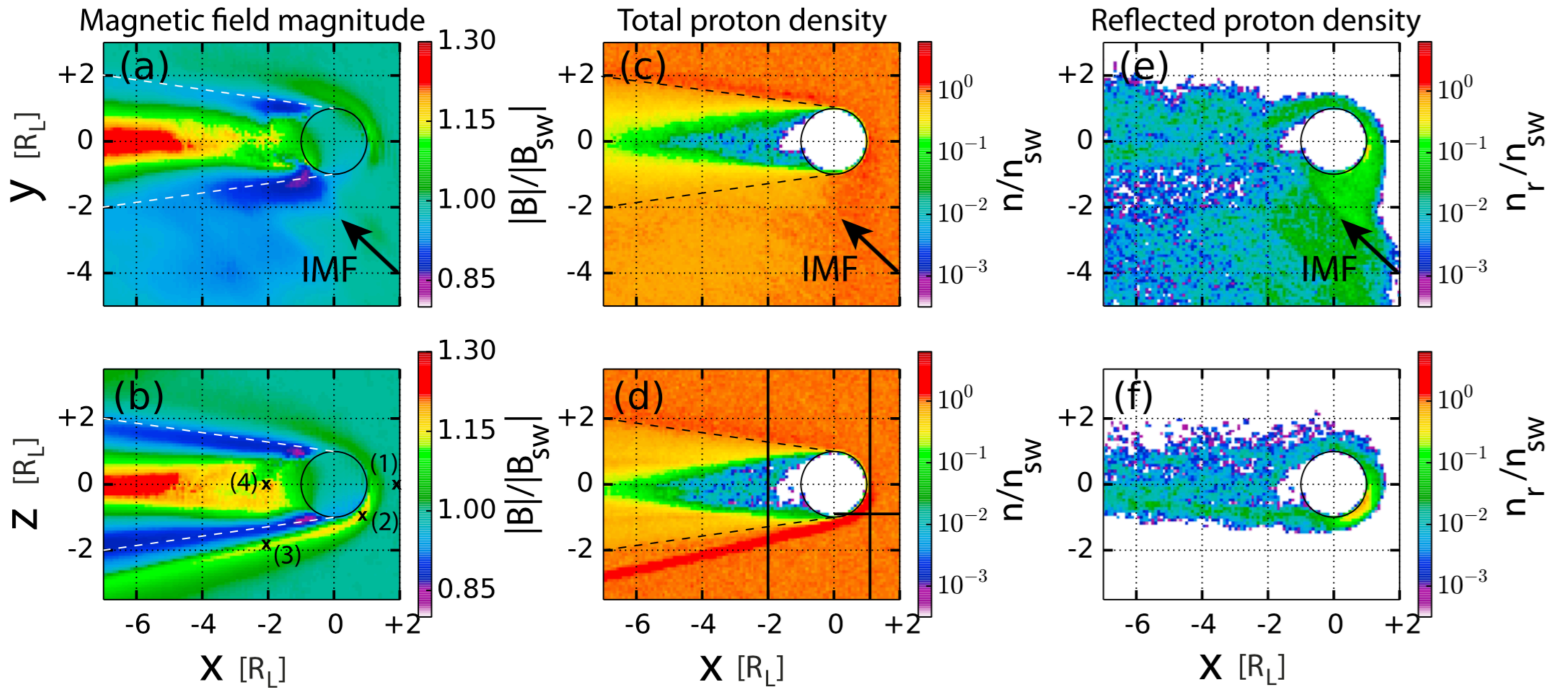


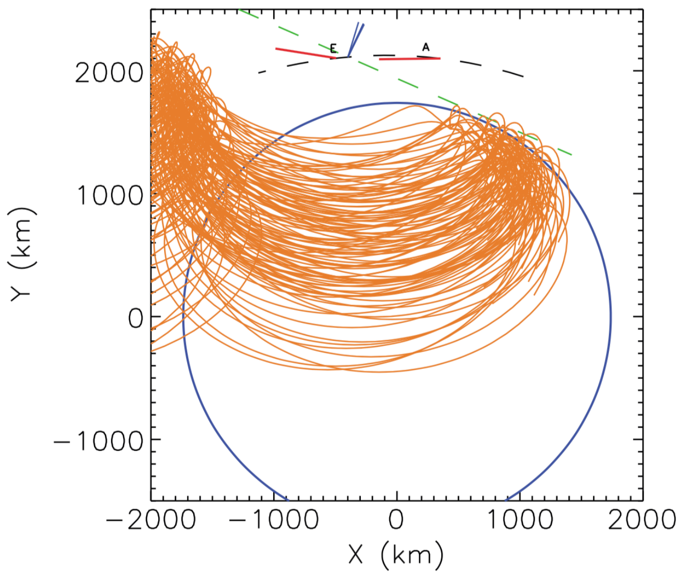




Multiple spacecraft have observed solar wind reflection in both charged [*Saito et al., 2008*; *Lue et al., 2011]* and energetic neutral form [e.g., *Wieser et al., 2009*; *Rodriguez et al., 2012*]

Introduction and Motivation: *Implications*

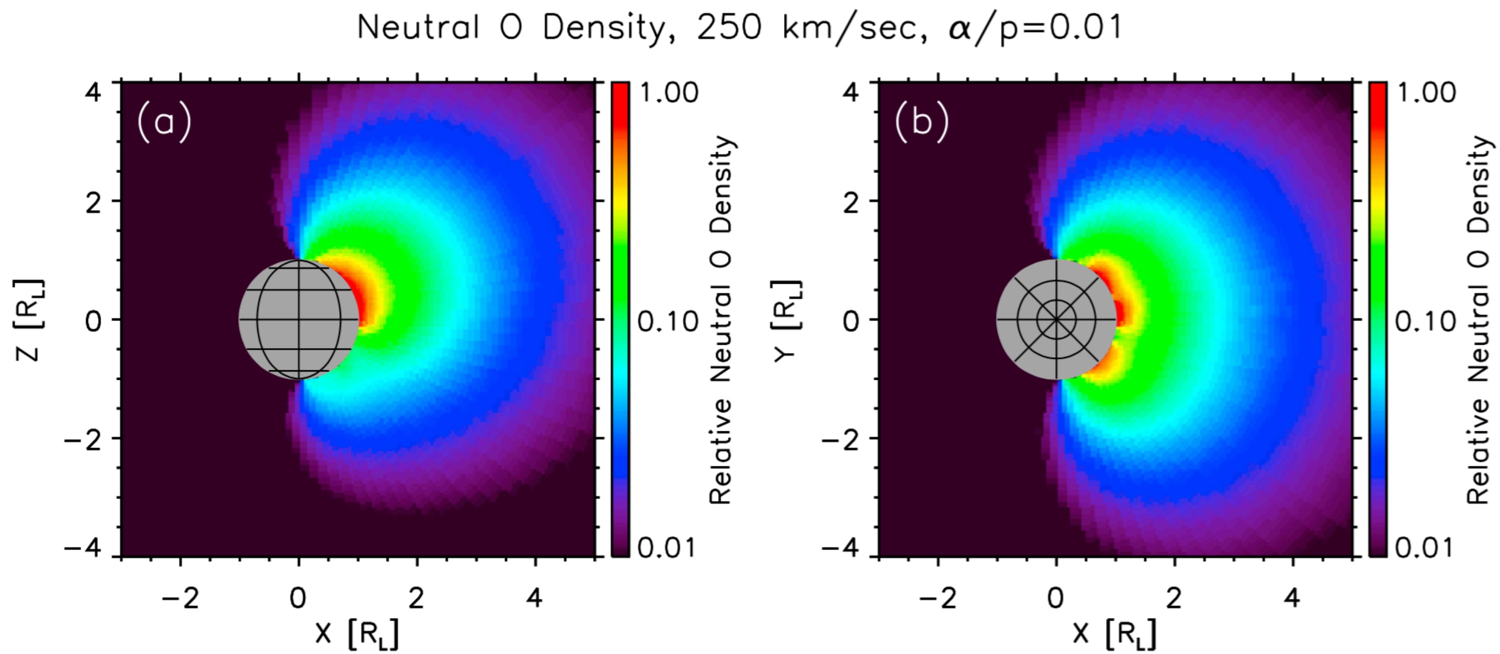




Reflected protons can affect the global-scale solar wind-lunar interaction

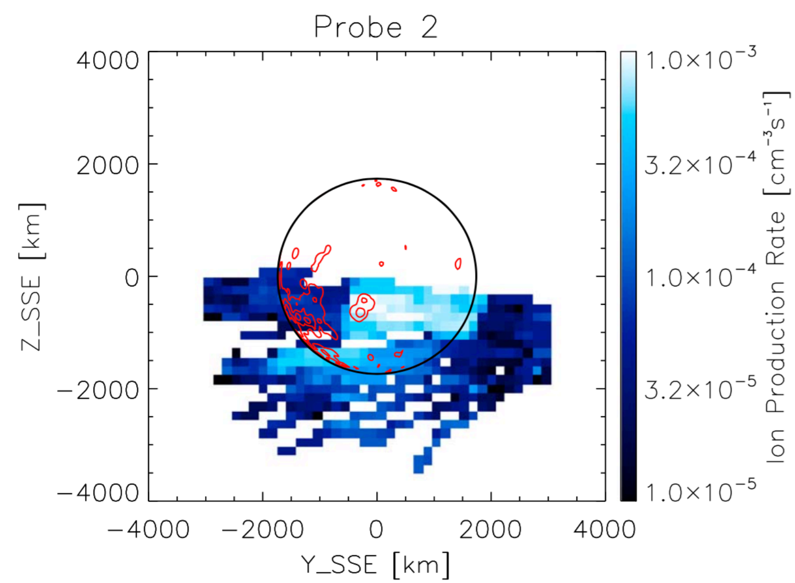
Solar wind compressions seen in hybrid simulations above [*Fatemi et al., 2014*] and "shock-lets" seen in ARTEMIS data left [*Halekas et al., 2014*]

Introduction and Motivation: *Implications*

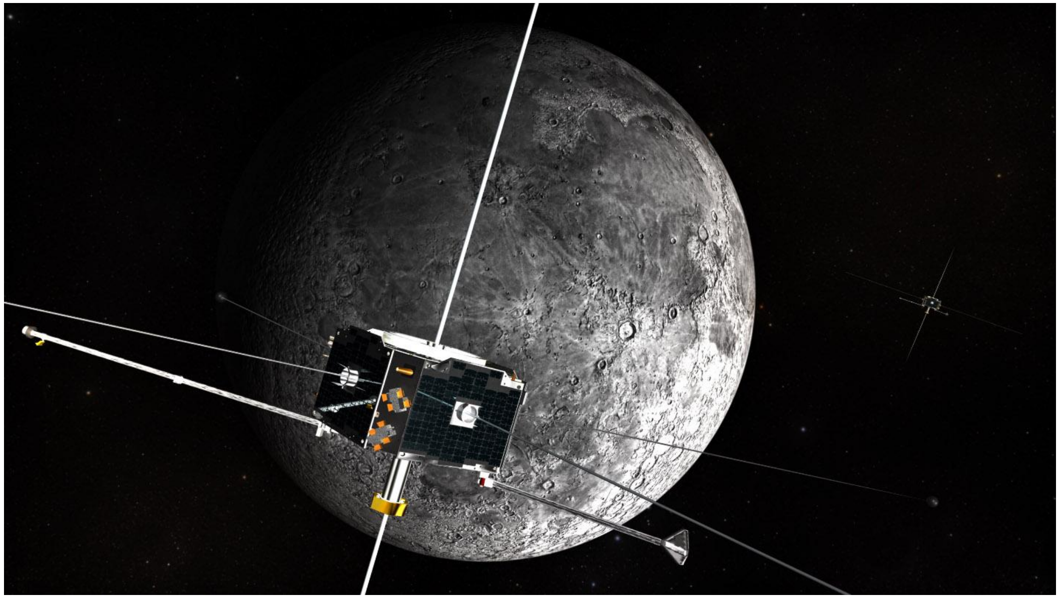


Reflected protons indicate areas of local surface shielding, resulting in reduced solar wind sputtering of neutral species into the exosphere

Resulting neutral distributions have been modeled above [*Poppe et al., 2014*] and potentially seen in ARTEMIS pickup ion observations, right [*Halekas et al., 2016*]



ARTEMIS Mapping of Reflected Protons



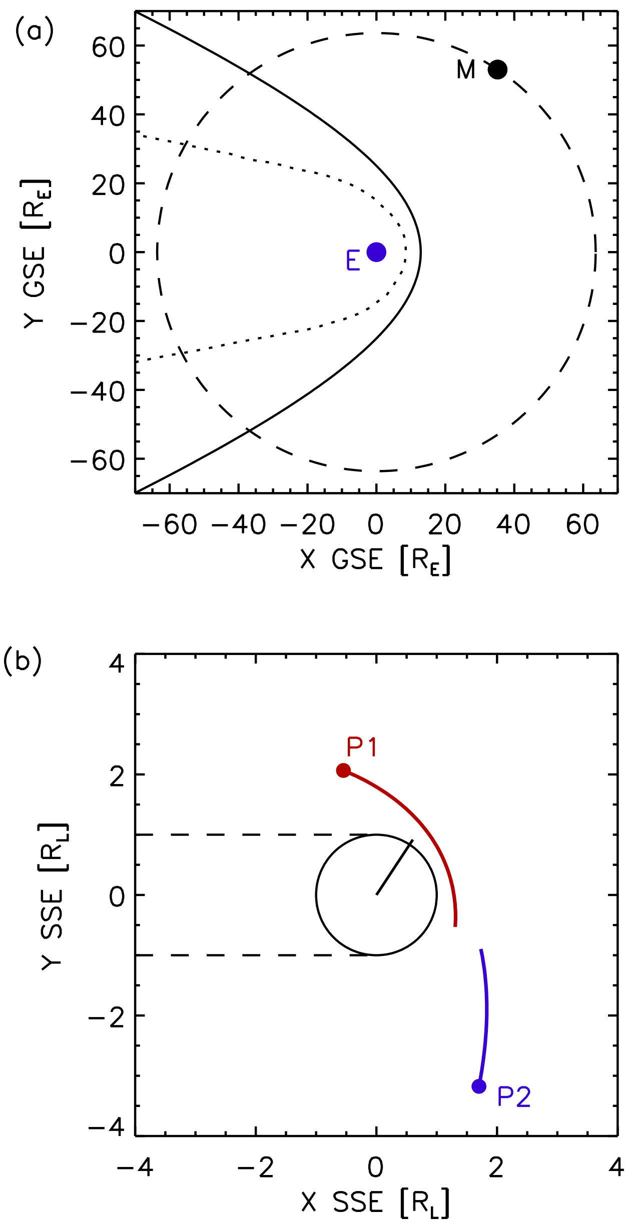
GOAL: Use observations by ARTEMIS of reflected proton populations near the Moon to:

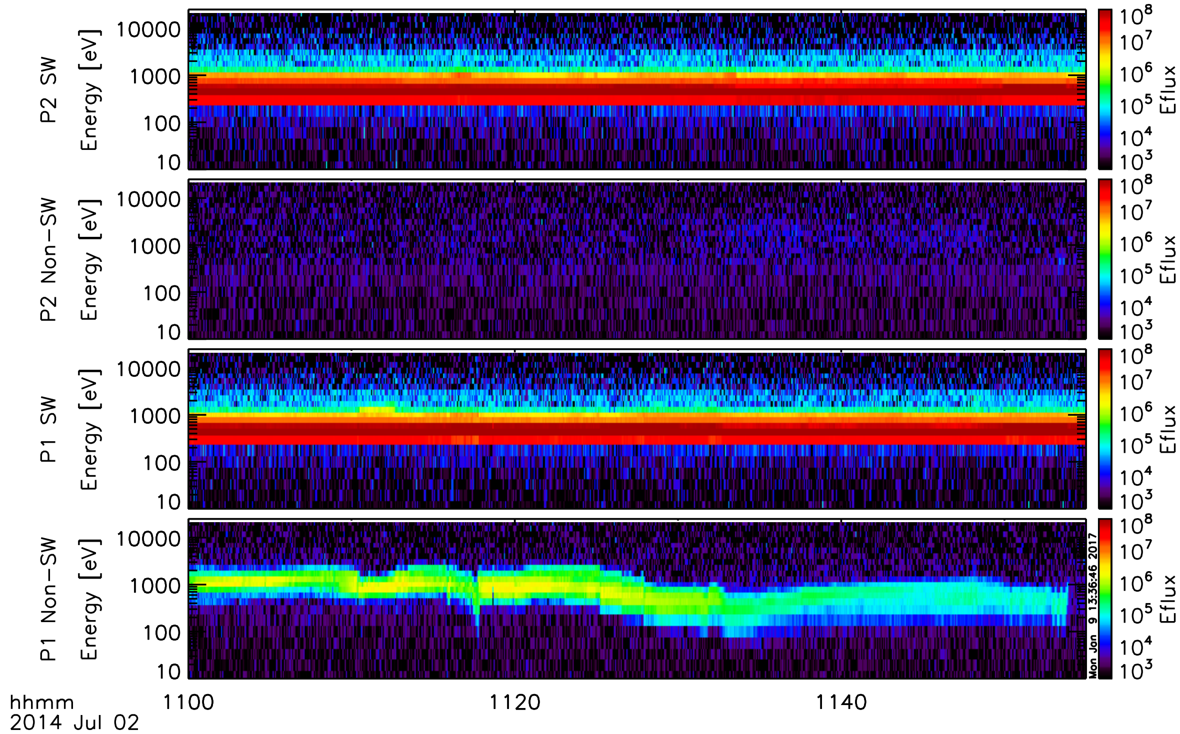
- (1) construct a reflection map and compare to previous observations and
- (2) investigate the behavior and mechanism(s) of proton reflection

ARTEMIS provides:

- Identical, dual probe measurements of low energy (1 – 25,000 eV) ions
- High-time resolution vector magnetic field measurements (which, along with ion data provides convection electric field data)
- Periselene passes between 10 – 1,000 km altitude approximately every 24 hours over wide range of selenographic locations and SZAs
- ~5.5 years of continuous operation for both probes

ARTEMIS P1 Observation – July 02, 2014





ARTEMIS P2 observes only the solar wind and no reflected ions

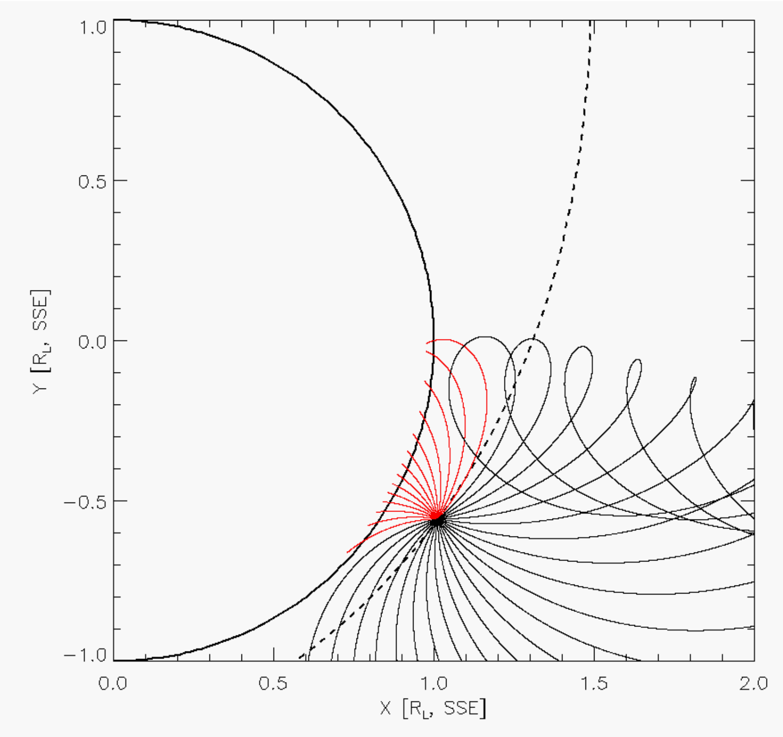
ARTEMIS P1 observes both the solar wind and a population of non-solar wind ions near periselene

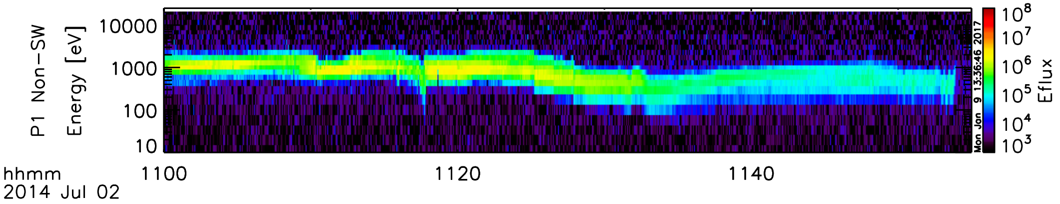
ARTEMIS P1 flies over the SPA anomaly region

ARTEMIS Mapping of Reflected Protons

METHODOLOGY:

- (1) Trace individual measurements of proton distribution function, *df*, back in time using local E, B fields
- (2) Liouville's Theorem holds that phase space density is conserved along trajectories
- (3) Construct reflection distribution function by averaging over all ARTEMIS observations and integrating to get moments



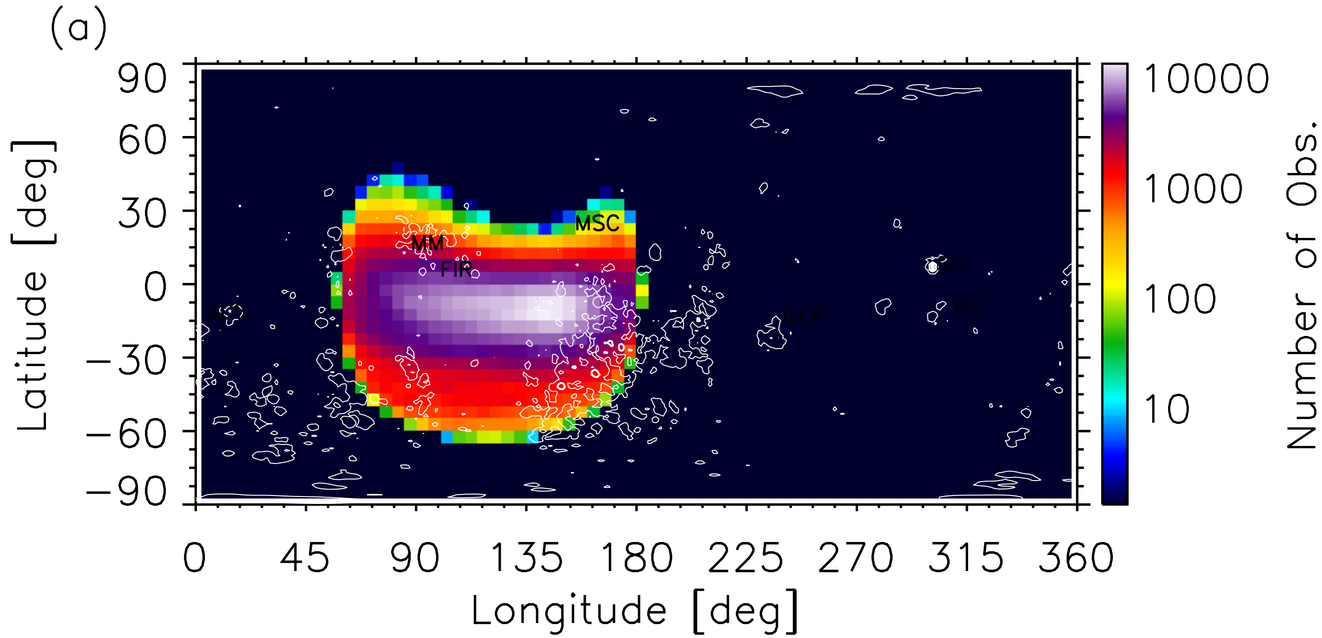


ABOVE: Reflected proton energy flux measured at ARTEMIS

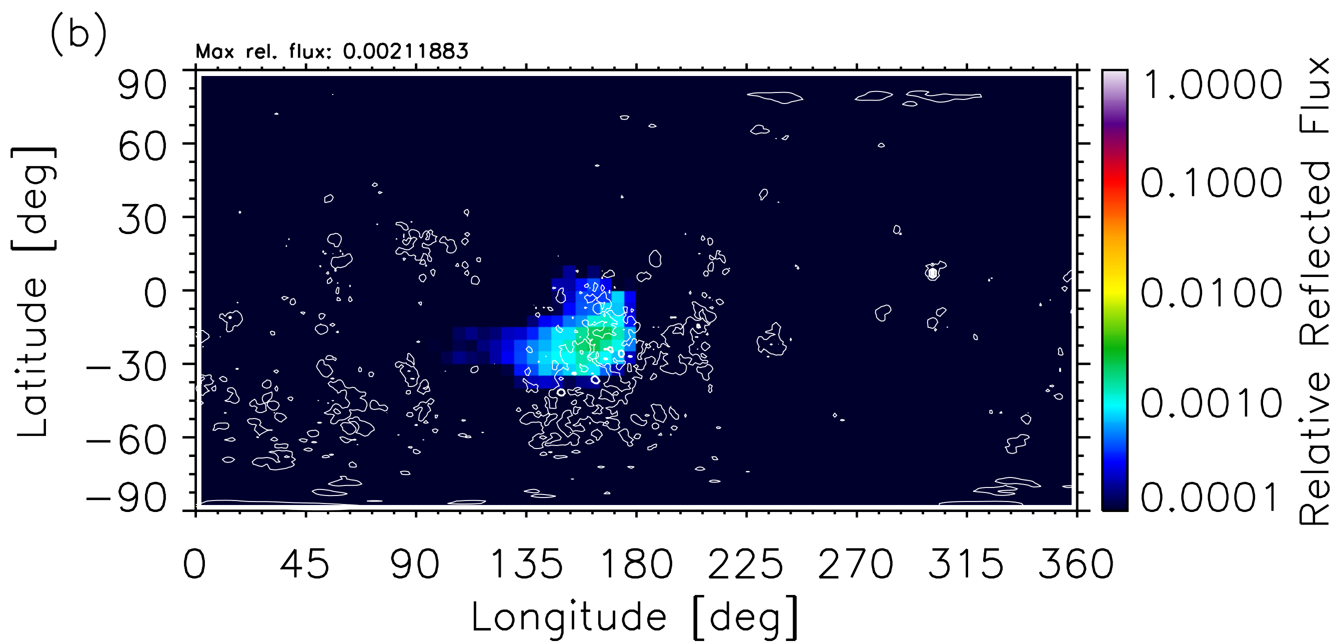
LEFT: Example trajectories traced from ARTEMIS at one time interval, for one energy (2 keV), for 5° phi angles

ARTEMIS P1 Observations – July 02, 2014

Where ARTEMIS trajectories traced back to:



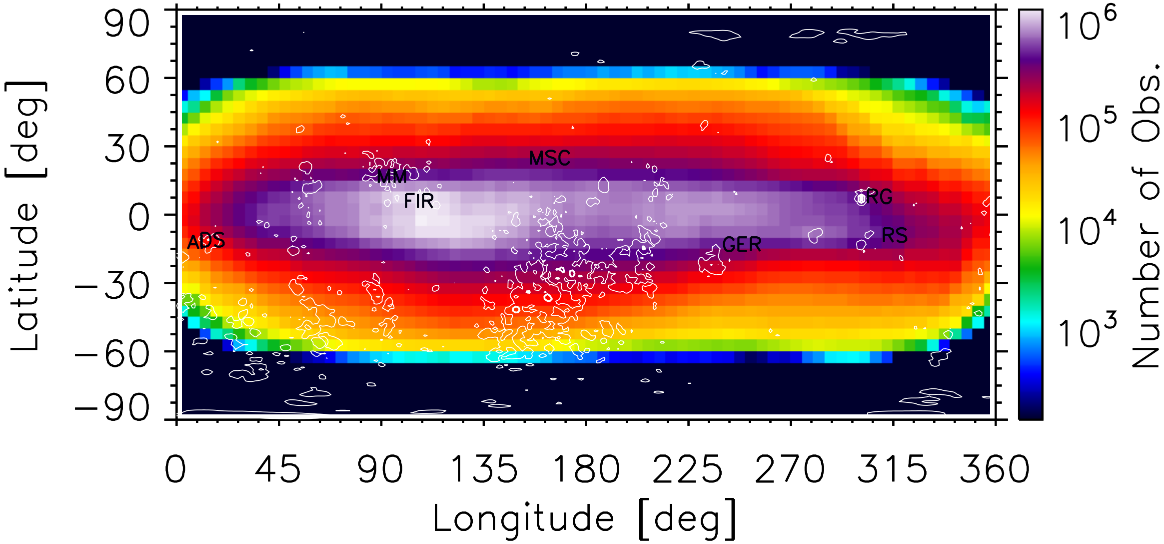
Where reflected flux originated from:



ARTEMIS Spatial Reflection Map

Currently processed ~50% of all ARTEMIS data

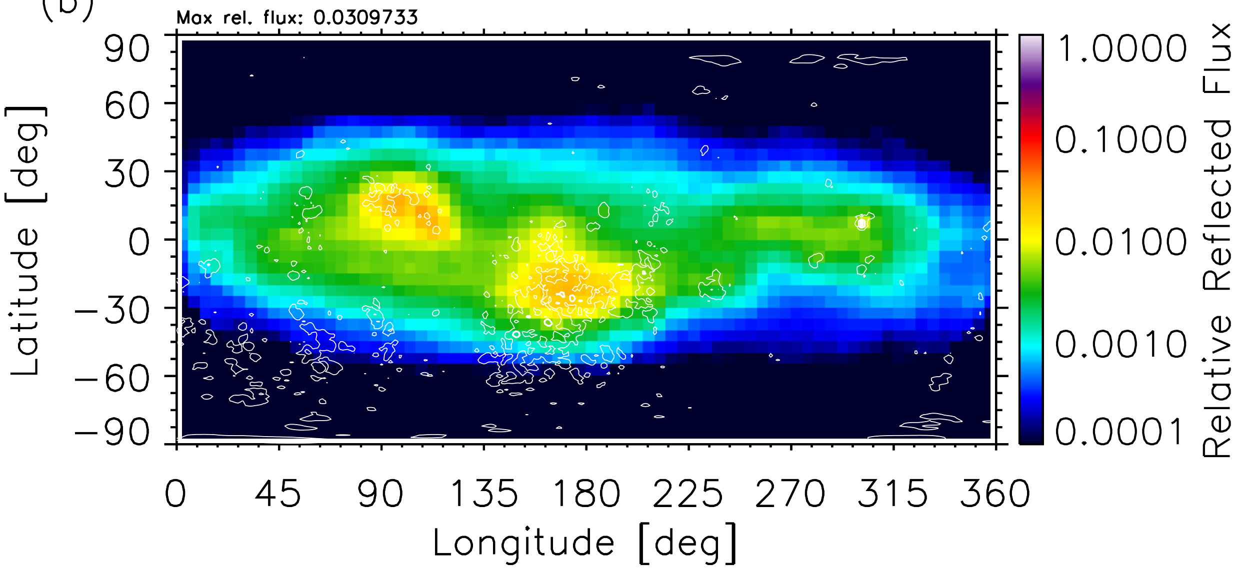
(a)



Filtered by:

- *Dayside only, out to 2.0 R_M*
- *350 < v < 425 km/sec*
- *1 < n < 10 cm^{-3}*
- *SZA < 60 degrees*

(b)



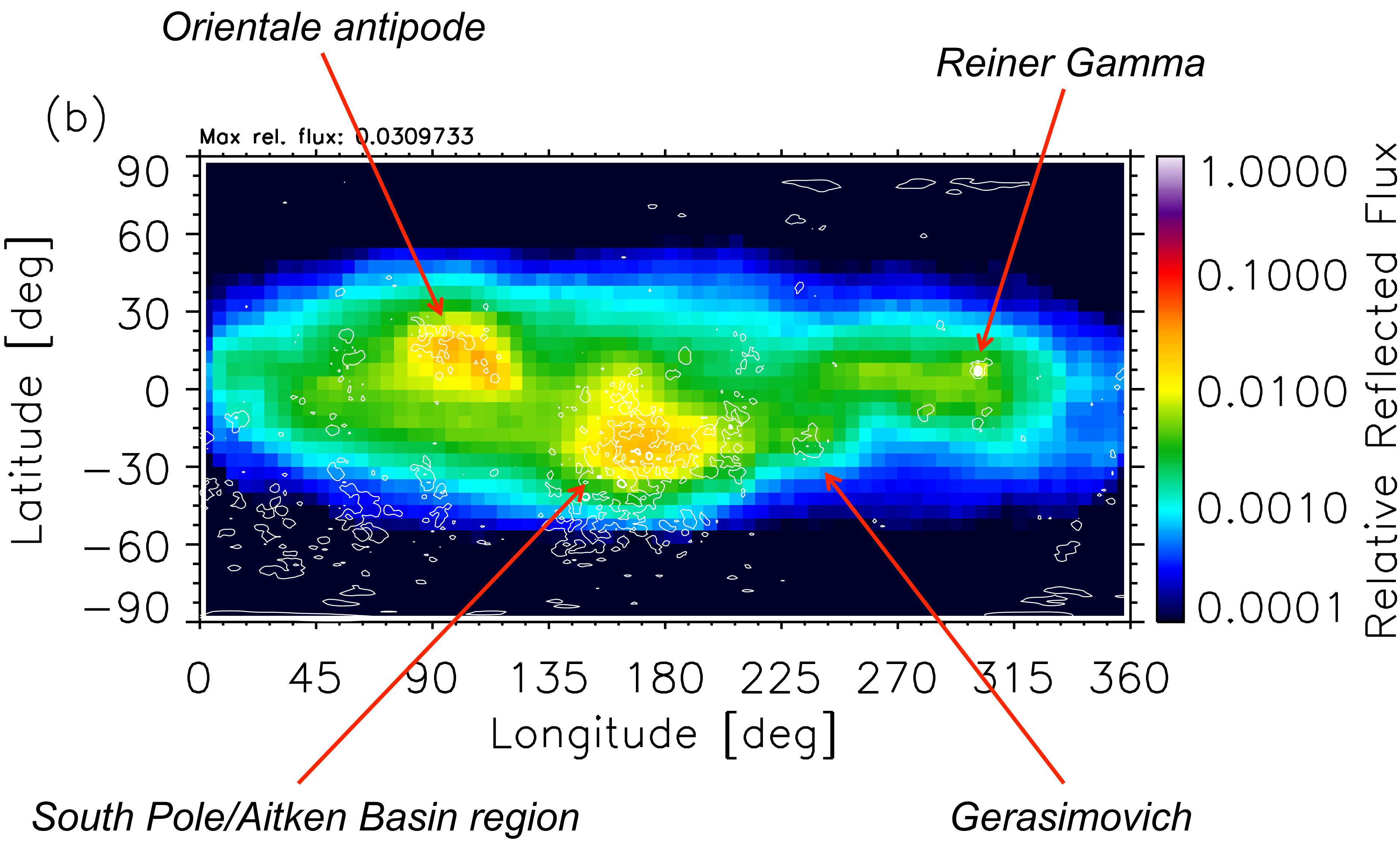
Unmagnetized average:

- 0.5 %

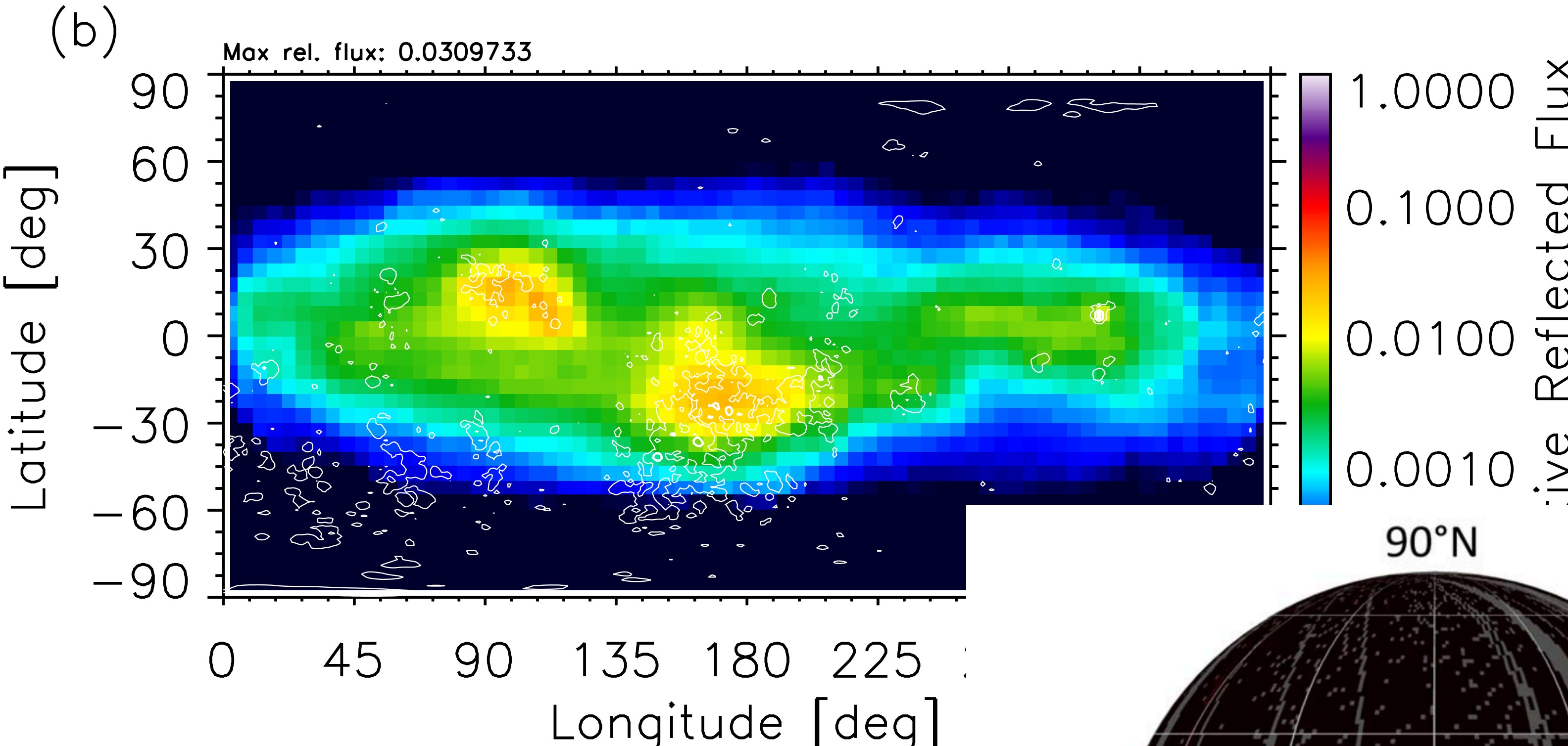
Magnetized regions, averaged over 5x5°:

- ~3%

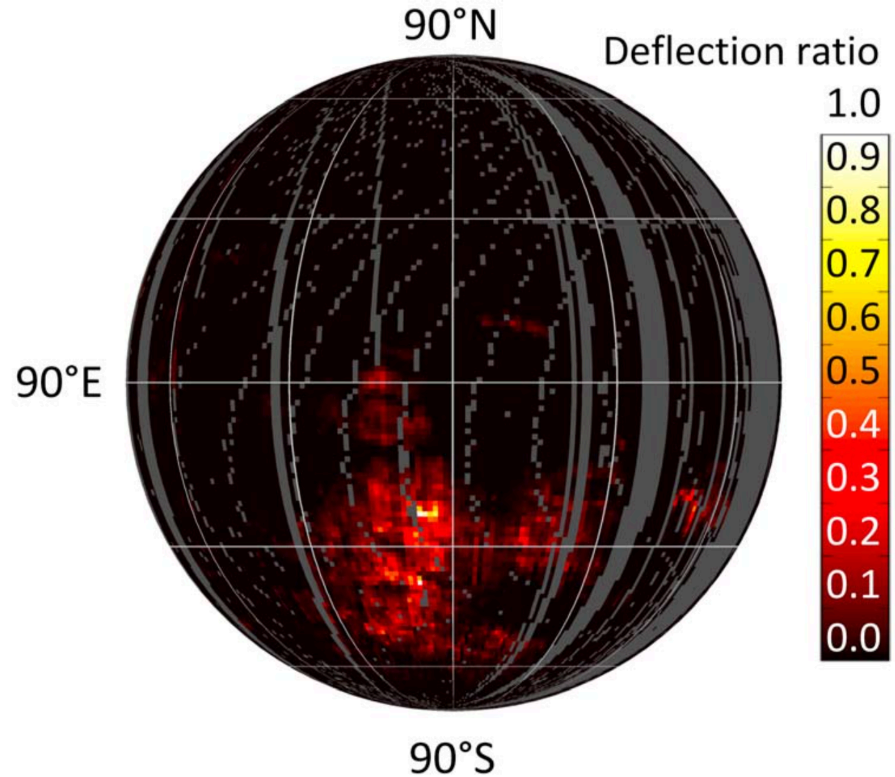
ARTEMIS Spatial Reflection Map



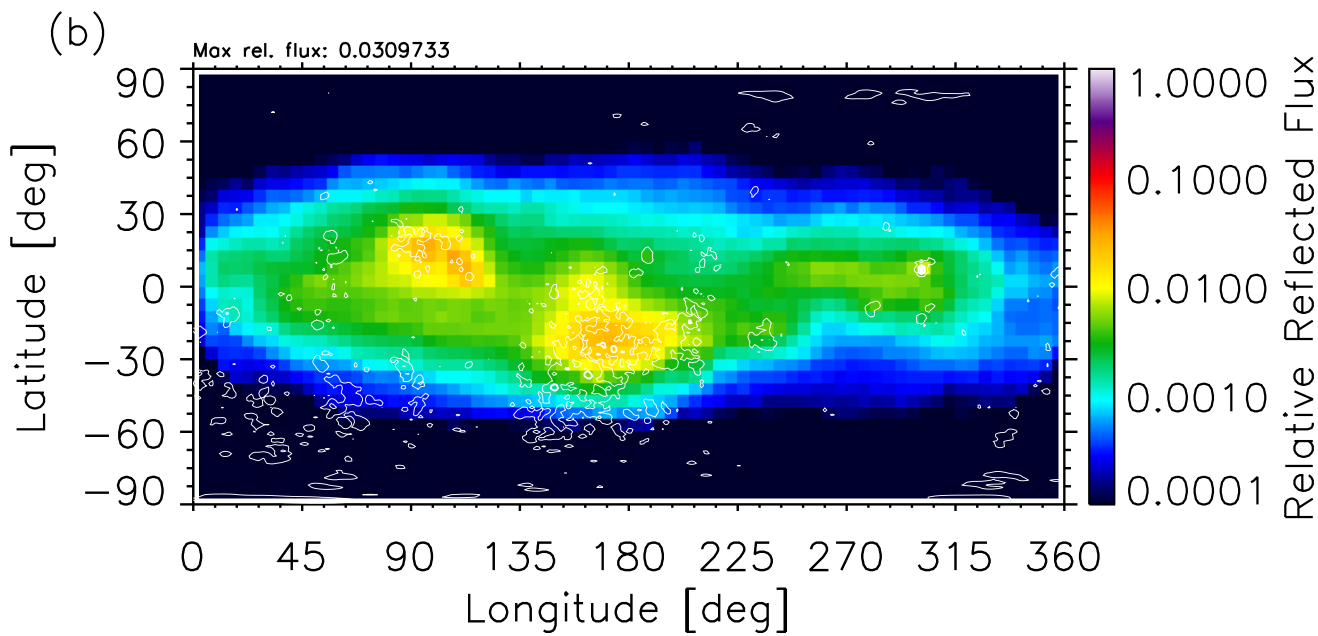
ARTEMIS Spatial Reflection Map

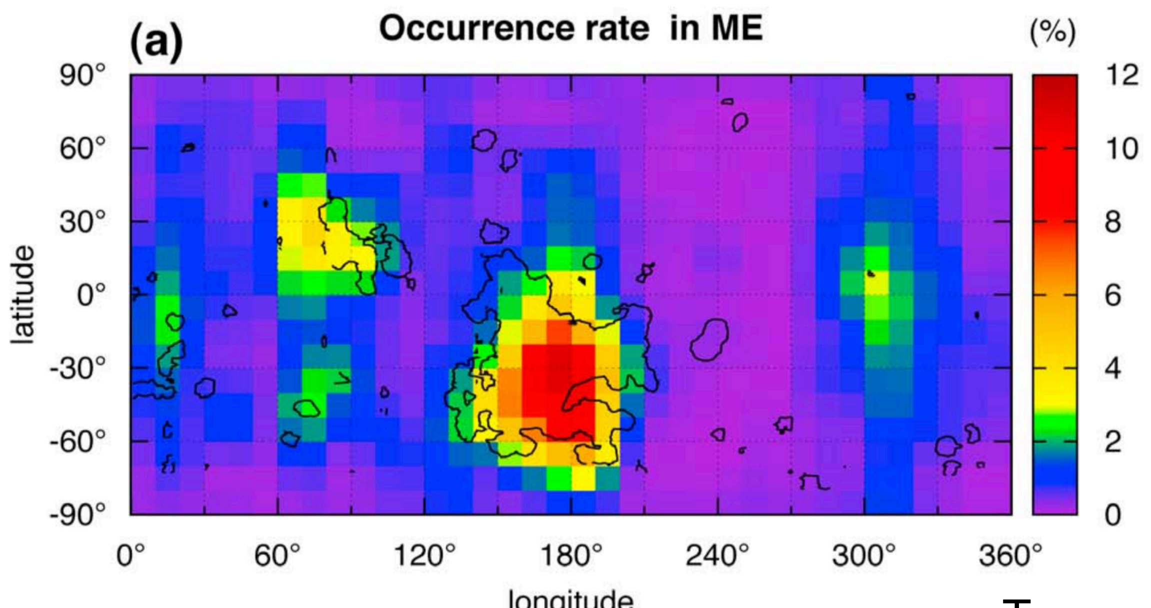


Comparison to Chandrayaan reflected proton mapping [*Lue et al., 2011*, right]



ARTEMIS Spatial Reflection Map



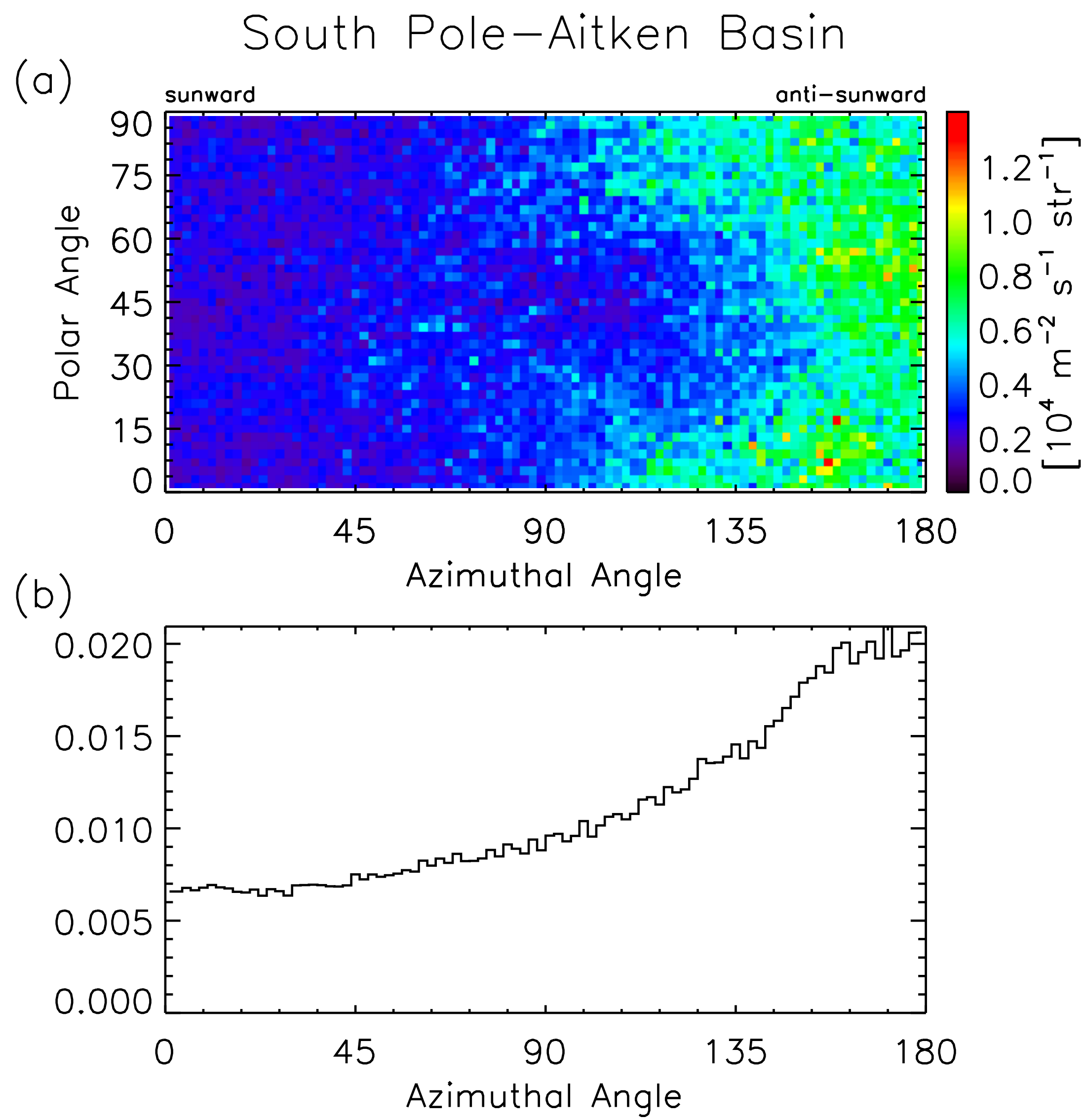


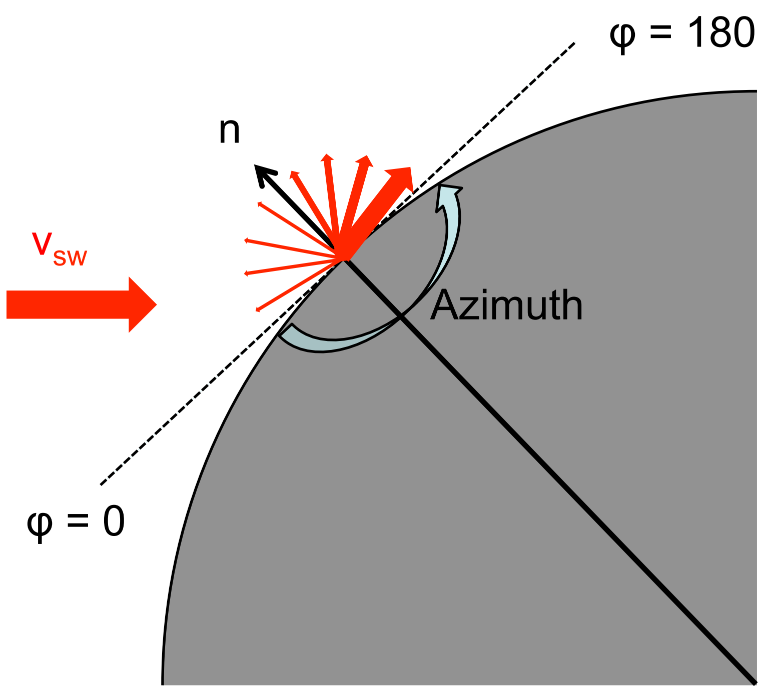
Tsugawa et al., 2012

Scattering Function in SPA Anomaly

Aggregation of reconstructed proton trajectories yields the average scattering function

Anomalies are mainly forward-scattering with ~33% diffuse scattering at all angles





Conclusions

ARTEMIS routinely observes reflected protons in the lunar environment

Back-tracking of proton trajectories and application of Liouville's Theorem yields the reflected distribution function at each selenographic location

Unmagnetized surface reflects ~0.5% of the solar wind flux, in agreement with previous observations (Chandrayaan, Kaguya)

Magnetized surface reflects *at minimum* ~2-5%

Future Work

Finish processing the other ~70% of ARTEMIS observations

Look for correlations of reflected flux with upstream parameters, i.e., solar wind density, pressure, IMF strength

Comparison to hybrid and particle-in-cell modeling of solar wind/anomaly interactions

Backup Slides

ARTEMIS P1 Observation – July 02, 2014