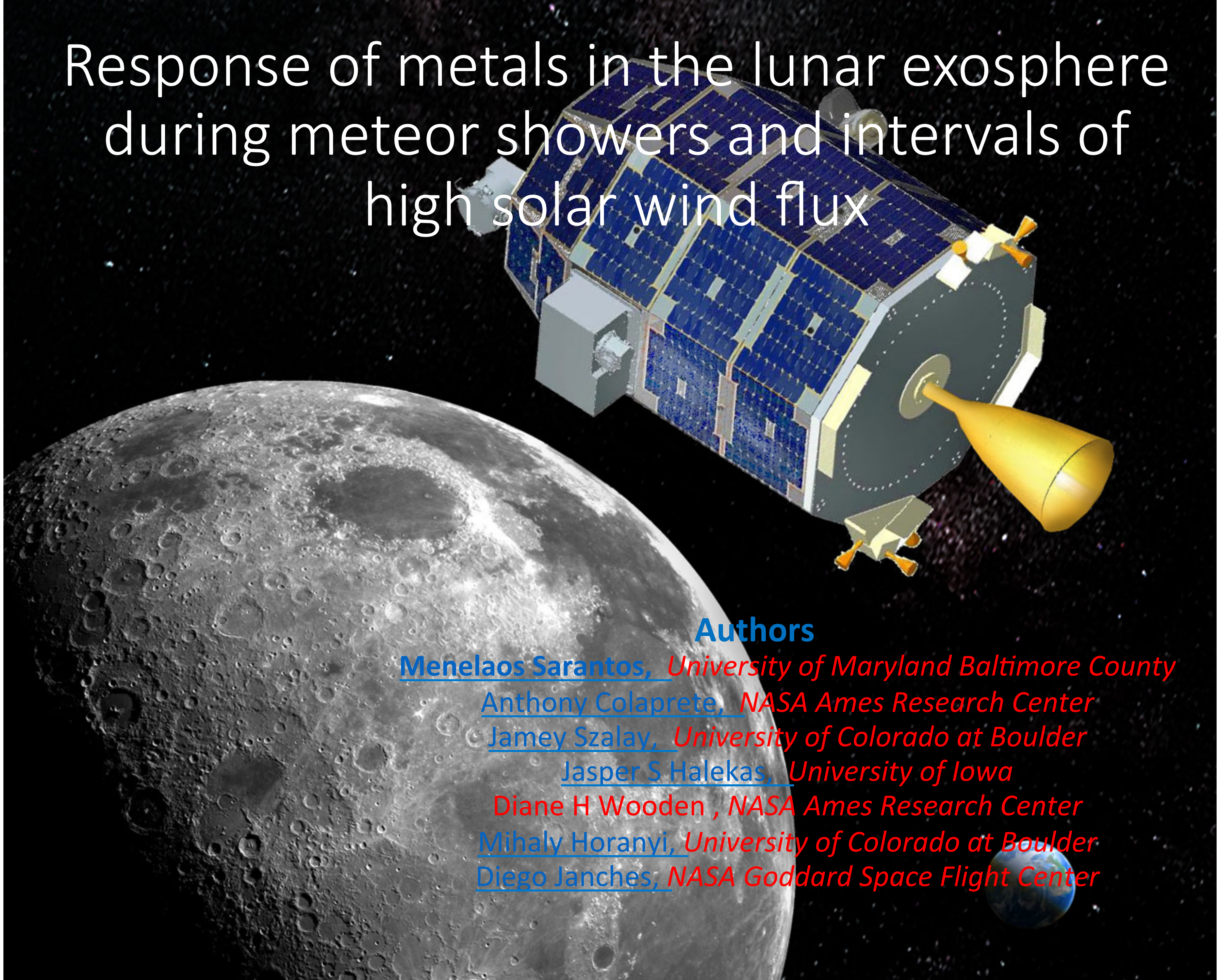
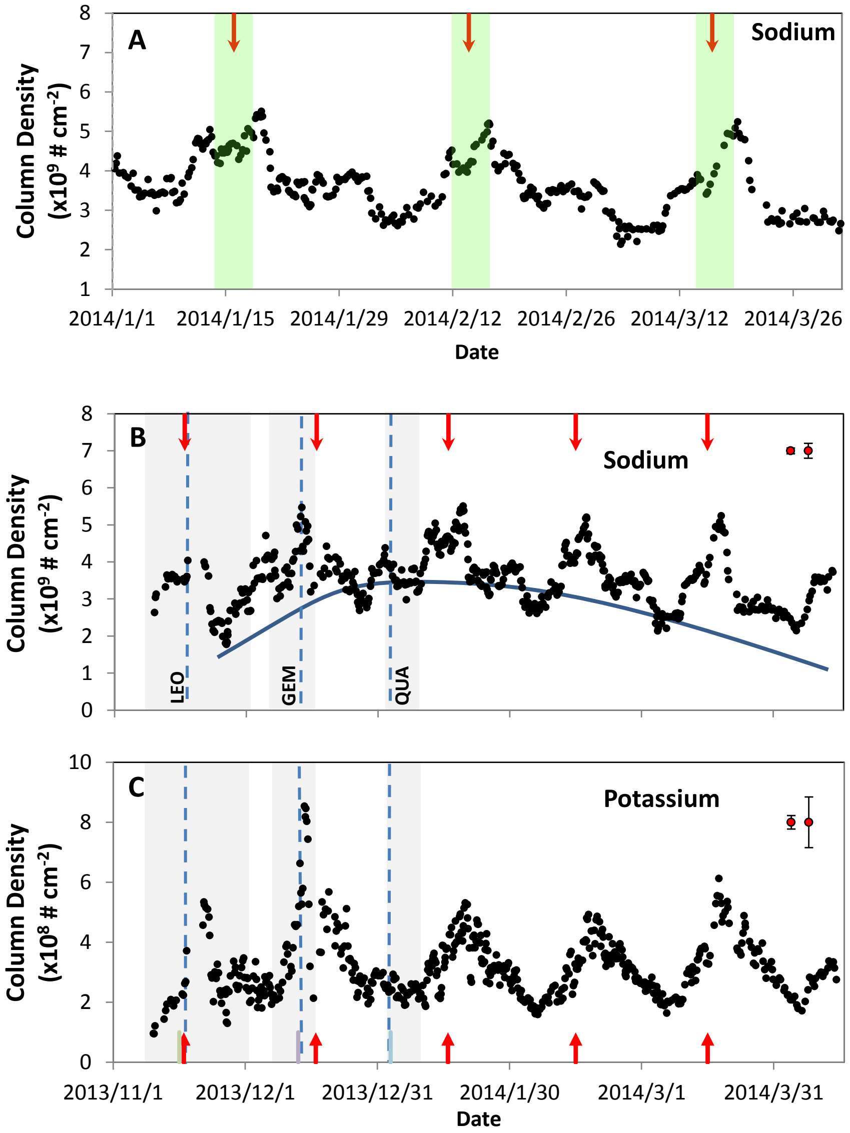


Response of metals in the lunar exosphere during meteor showers and intervals of high solar wind flux

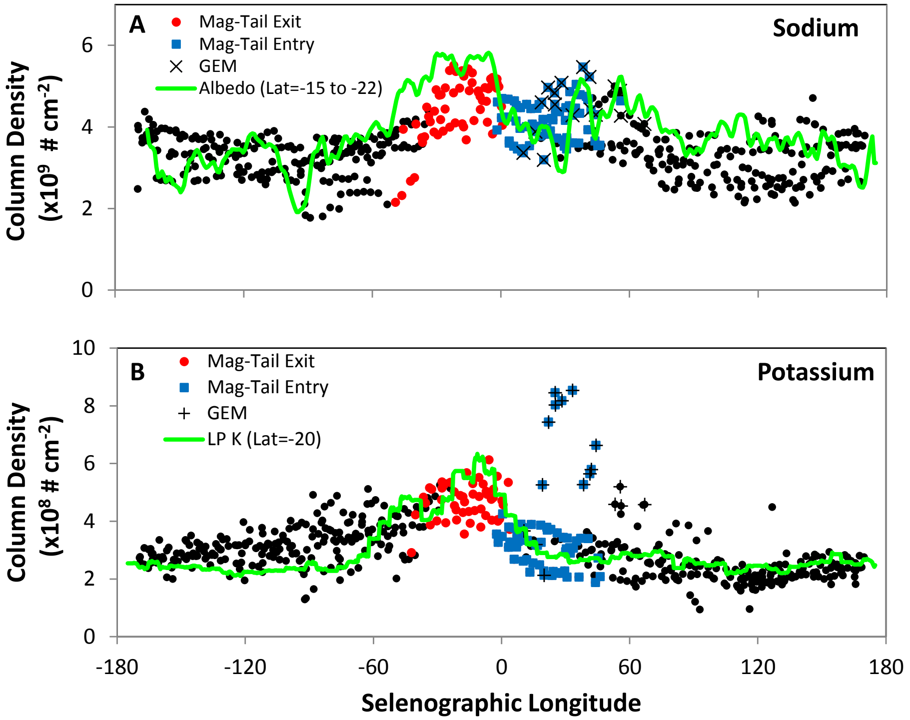
Authors

Menelaos Sarantos, *University of Maryland Baltimore County*
Anthony Colaprete, *NASA Ames Research Center*
Jamey Szalay, *University of Colorado at Boulder*
Jasper S Halekas, *University of Iowa*
Diane H Wooden , *NASA Ames Research Center*
Mihaly Horanyi, *University of Colorado at Boulder*
Diego Janches, *NASA Goddard Space Flight Center*

Sodium and Potassium Variation from LADEE UVS

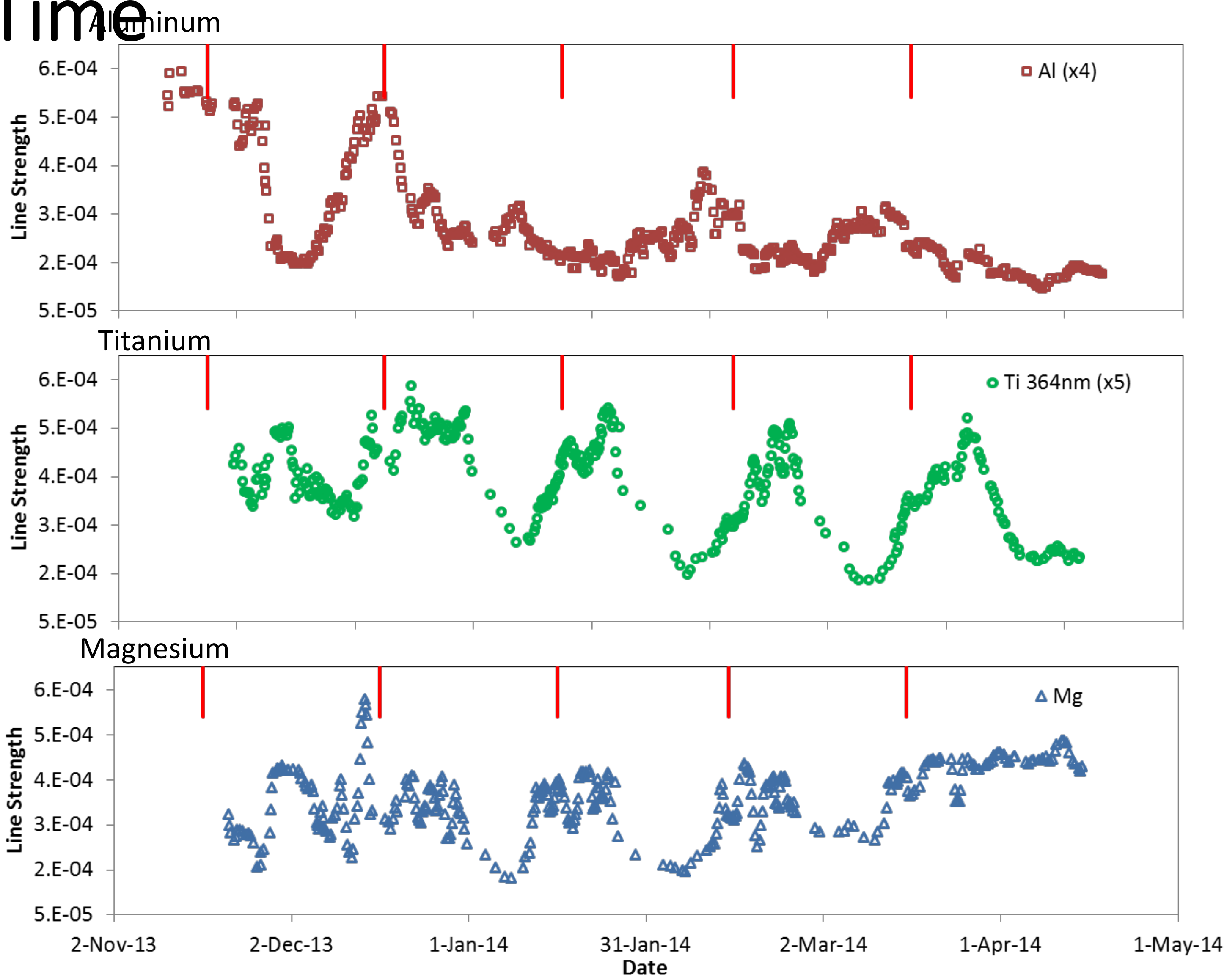


Sodium and potassium observation from Noon activities showed monthly variation, response to magnetotail (Na), and meteoroid showers (K)



Colaprete et al., Science, 2016

Line Strengths for other metals vs Time



Colaprete et al., LPSC, 2016

Motivating Questions

- What do LADEE measurements tell us about the relative importance of sources for the lunar exosphere (e.g., micrometeoroid impacts, sputtering)?

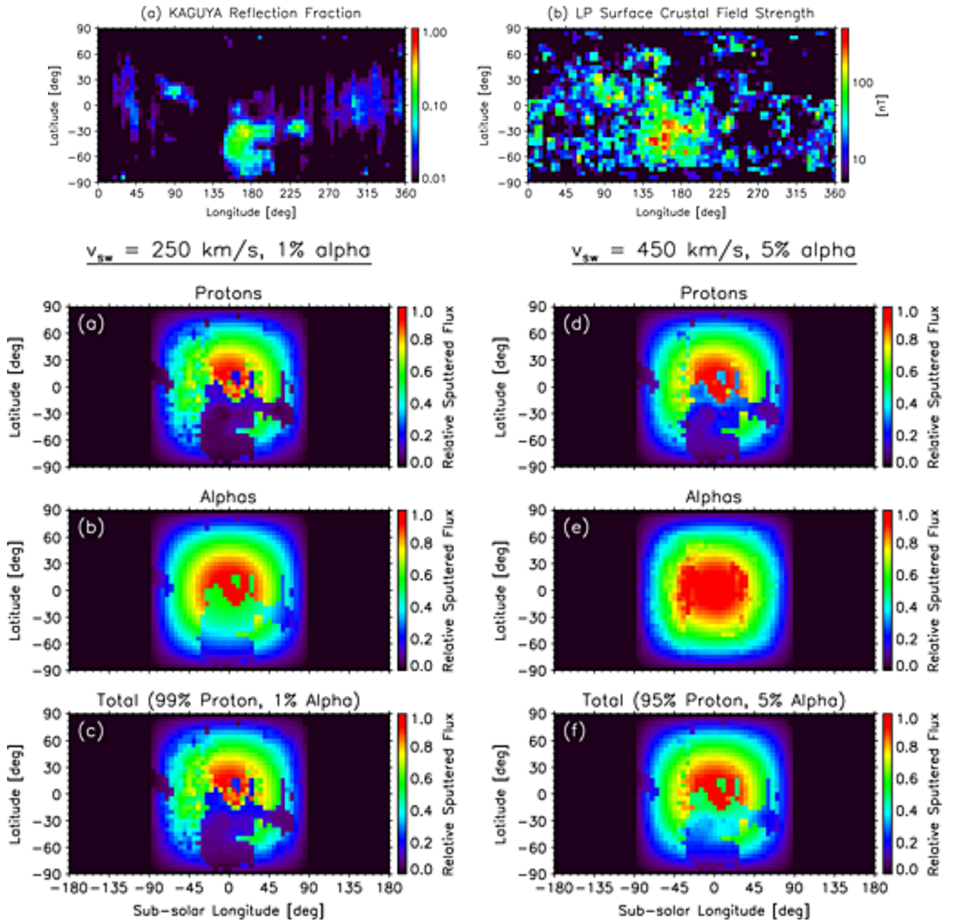
  - ❑ Pre-flight calculations suggested that impacts and sputtering should each provide half the exospheric content for metallic species (Sarantos el al., 2012)
  - ❑ For alkalis, Na and K, indirect effects of the solar wind such as ion-enhanced diffusion have been considered to enhance the photodesorption rate (e.g., Potter et al., 2000)

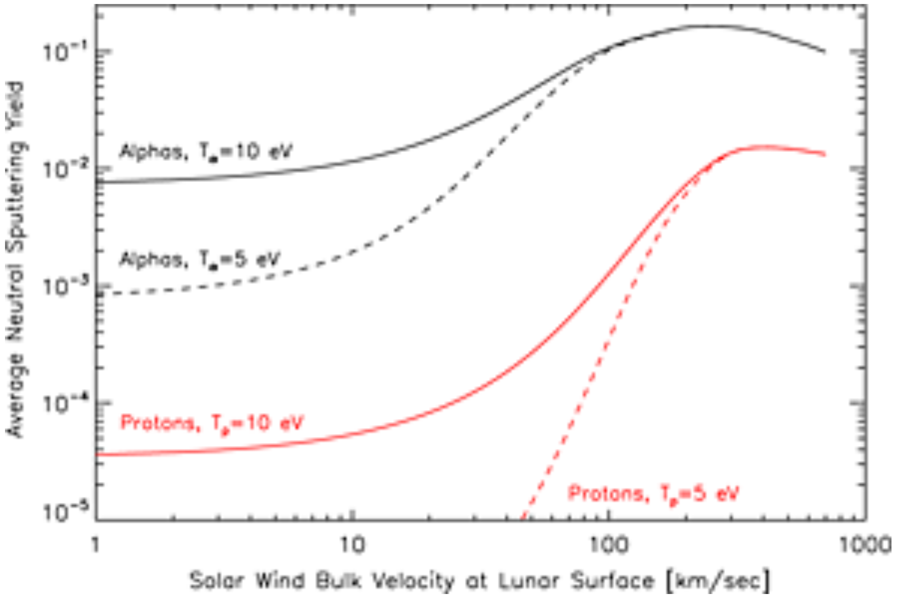
Methods

Combining LADEE UVS, LDEX and ARTEMIS data…

- We searched for evidence of solar wind effects on the K-Mg-Ti exospheres via:
    1. Correlation of brightness/abundance to proton flux;
    2. Correlation of alpha-to-proton ratio.
- We searched for evidence of the relative importance of each mechanism during the 2013 Geminids, when both drivers peaked about 12 hrs apart.
- And finally, we searched for evidence of the main source mechanism by modeling the lunar phase dependence (the repeated monthly variability for these species) with a Monte Carlo model.

Anisotropic solar wind sputtering of the lunar surface induced by crustal magnetic anomalies

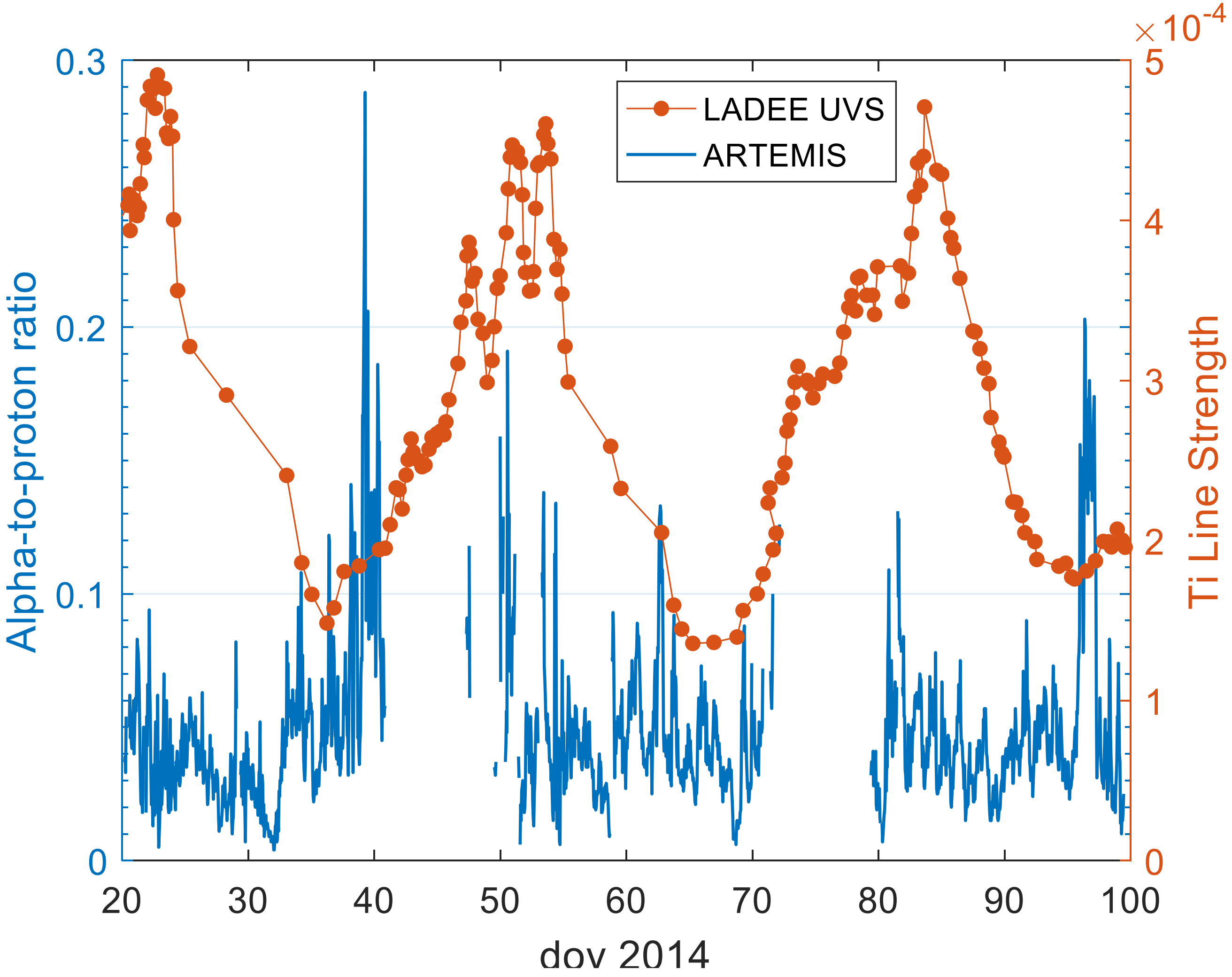


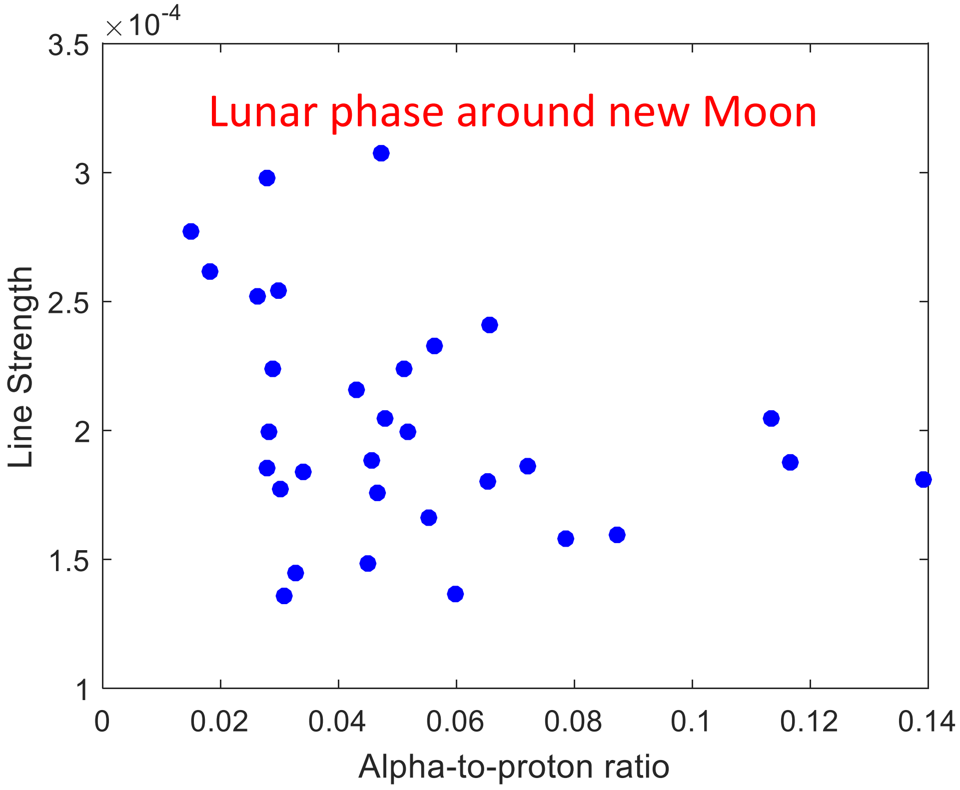


Q: Do we see this in LADEE data?

Poppe et al., Geophysical Research Letters
Volume 41, Issue 14, pages 4865-4872, 22 JUL 2014 DOI: 10.1002/2014GL060523
http://onlinelibrary.wiley.com/doi/10.1002/2014GL060523/full#grl51896-fig-0002

Comparison of Ti emission with solar wind alpha-to-proton ratio

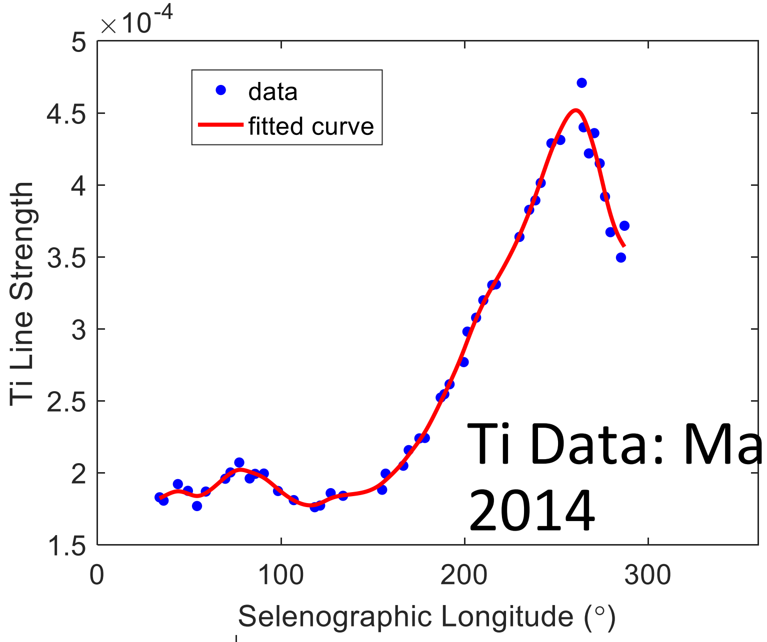




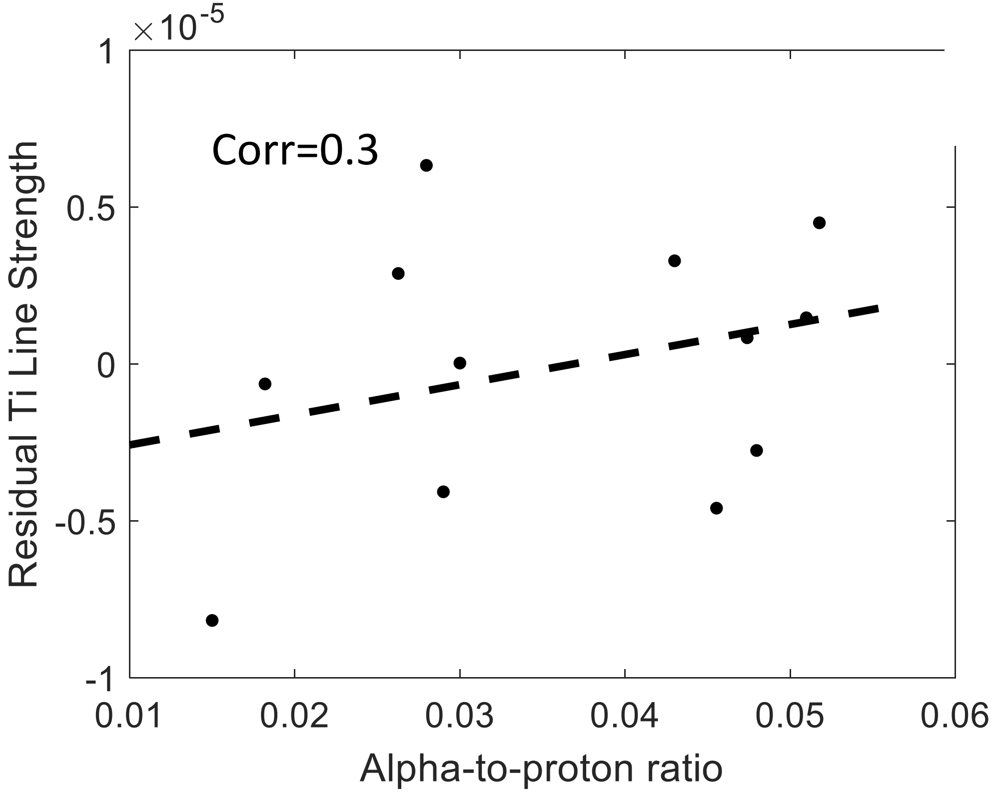
- No apparent correlation of data binned in a small window of lunar phases (especially around magnetic anomalies over South Pole- Aitken, when the effect of alphas should become pronounced)

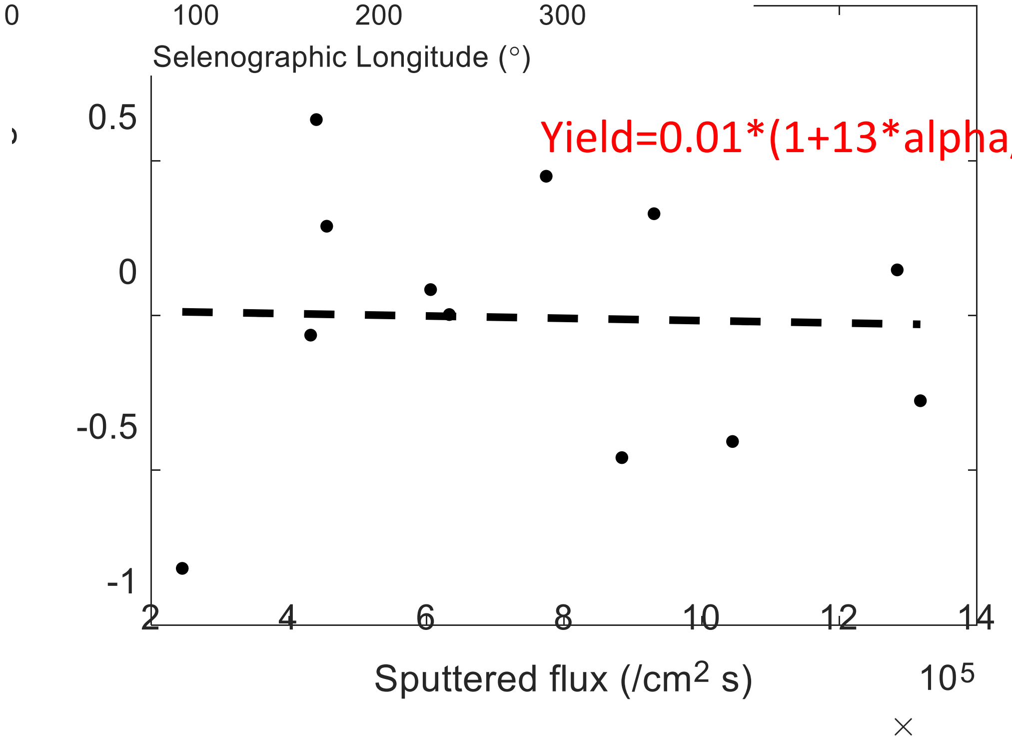
2nd attempt: Detrending for lunar phase dependence did not help things!

150<Sel_lon<210 deg
(New Moon)

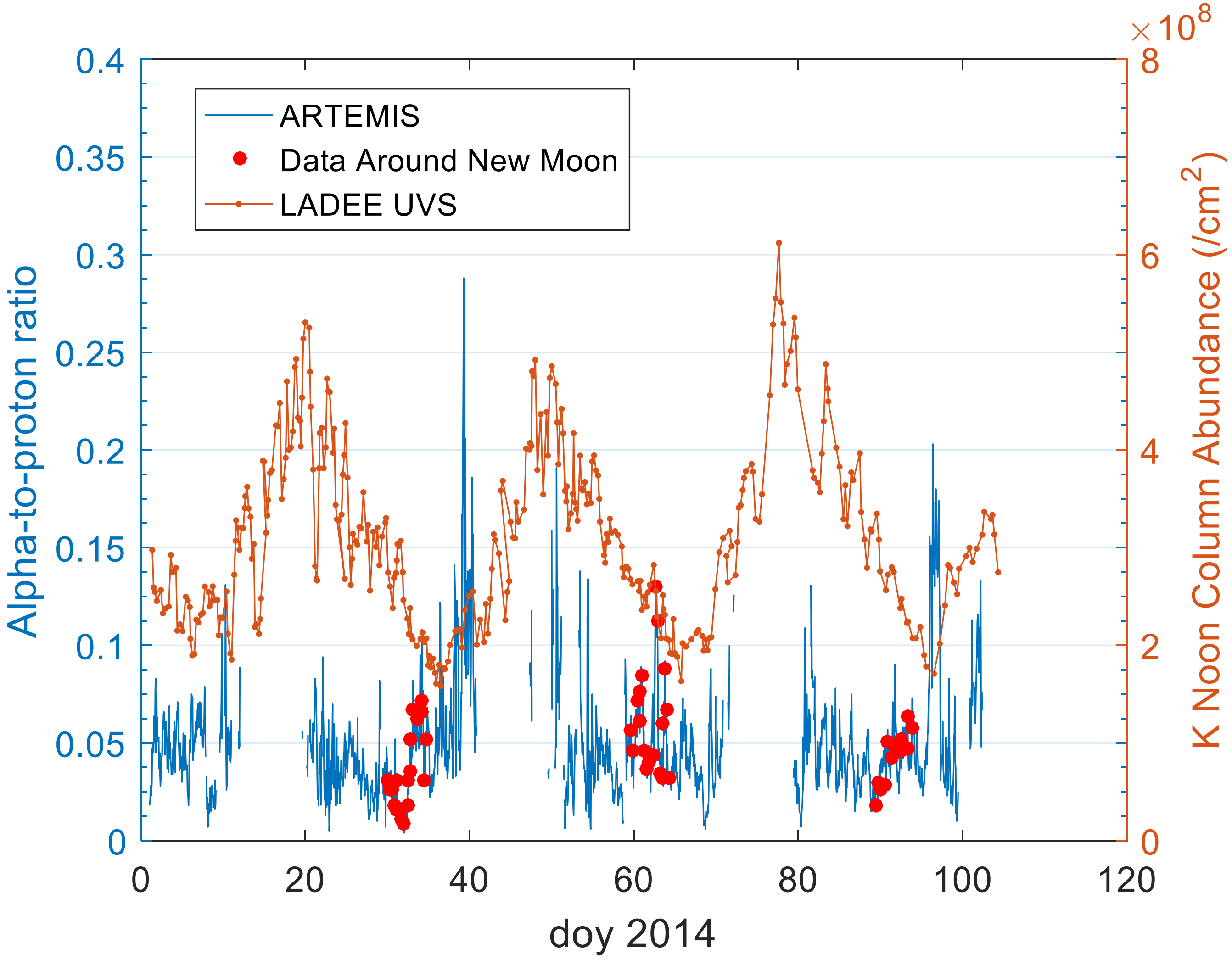


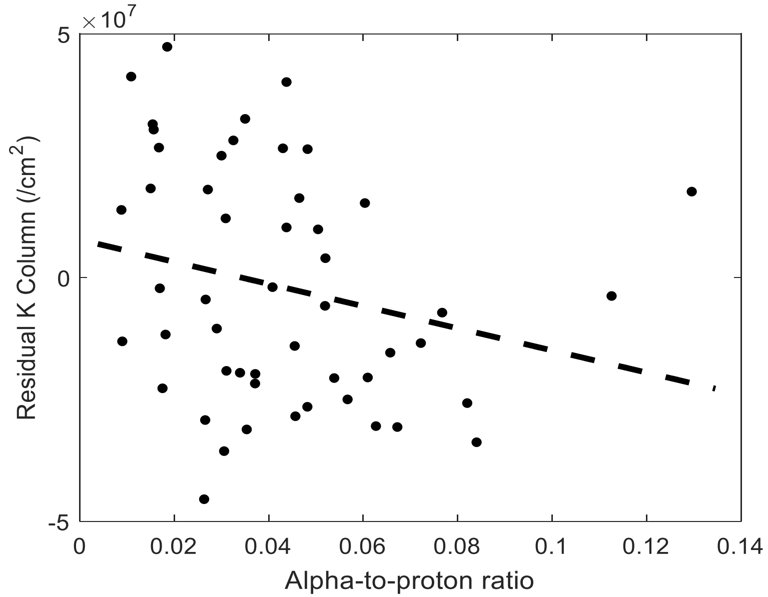
Non-parametric fit
For lunar phase

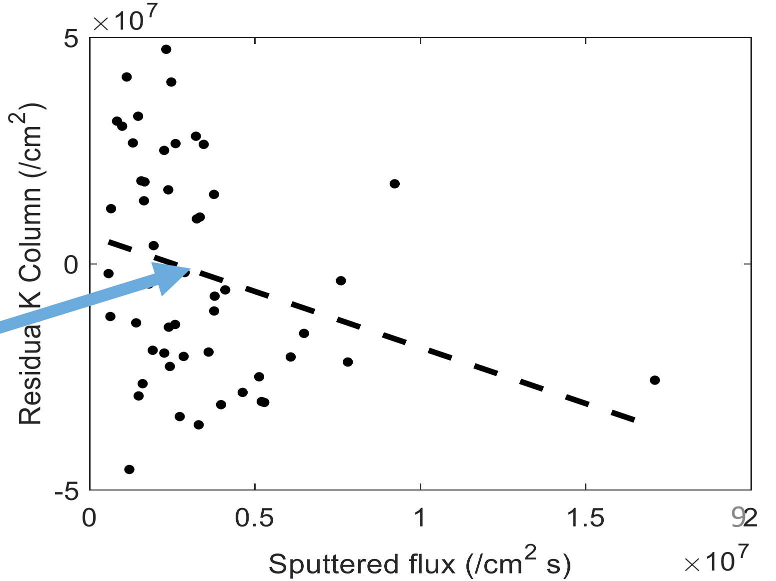




Comparison of K noon column abundance with solar wind alpha-to-proton ratio and proton flux

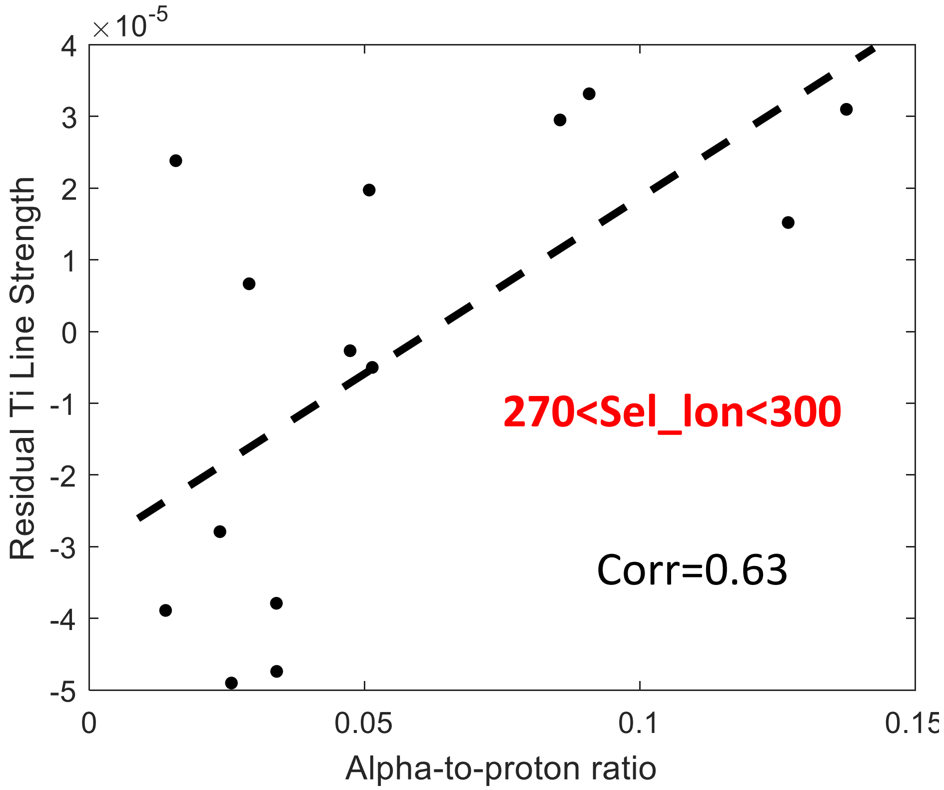


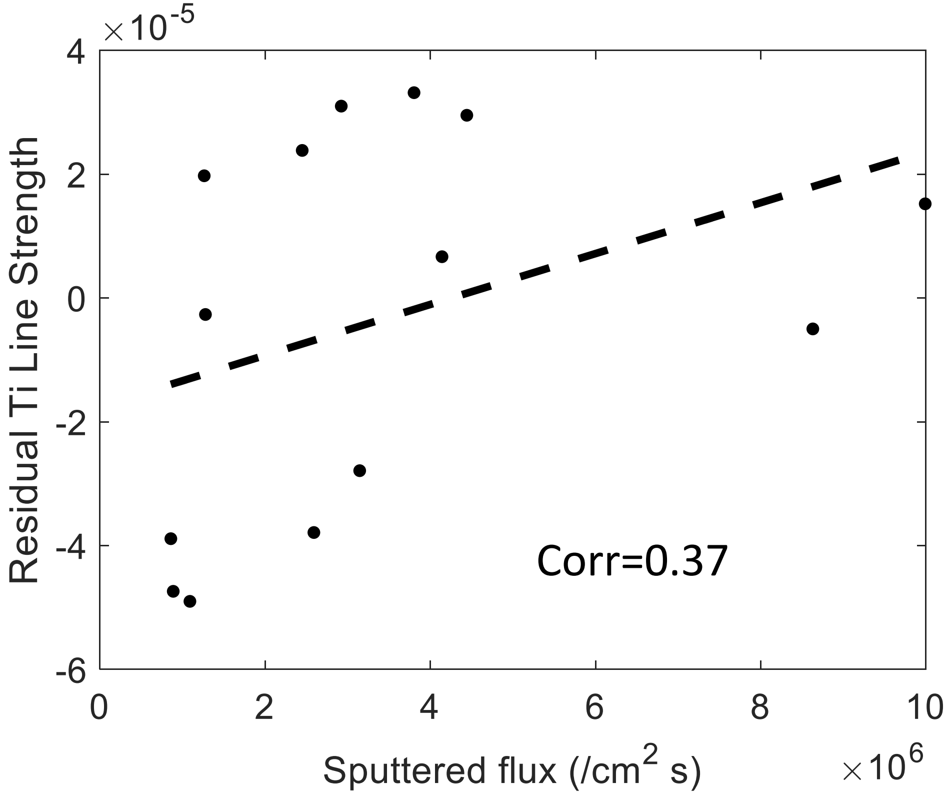




Anti-correlation to solar wind flux may indicate that the solar wind acts as a sink for adsorbates of this species, but lack of statistical significance implies that it is not the main sink.

Ti: improved correlation to solar wind upon exit from magnetosphere?

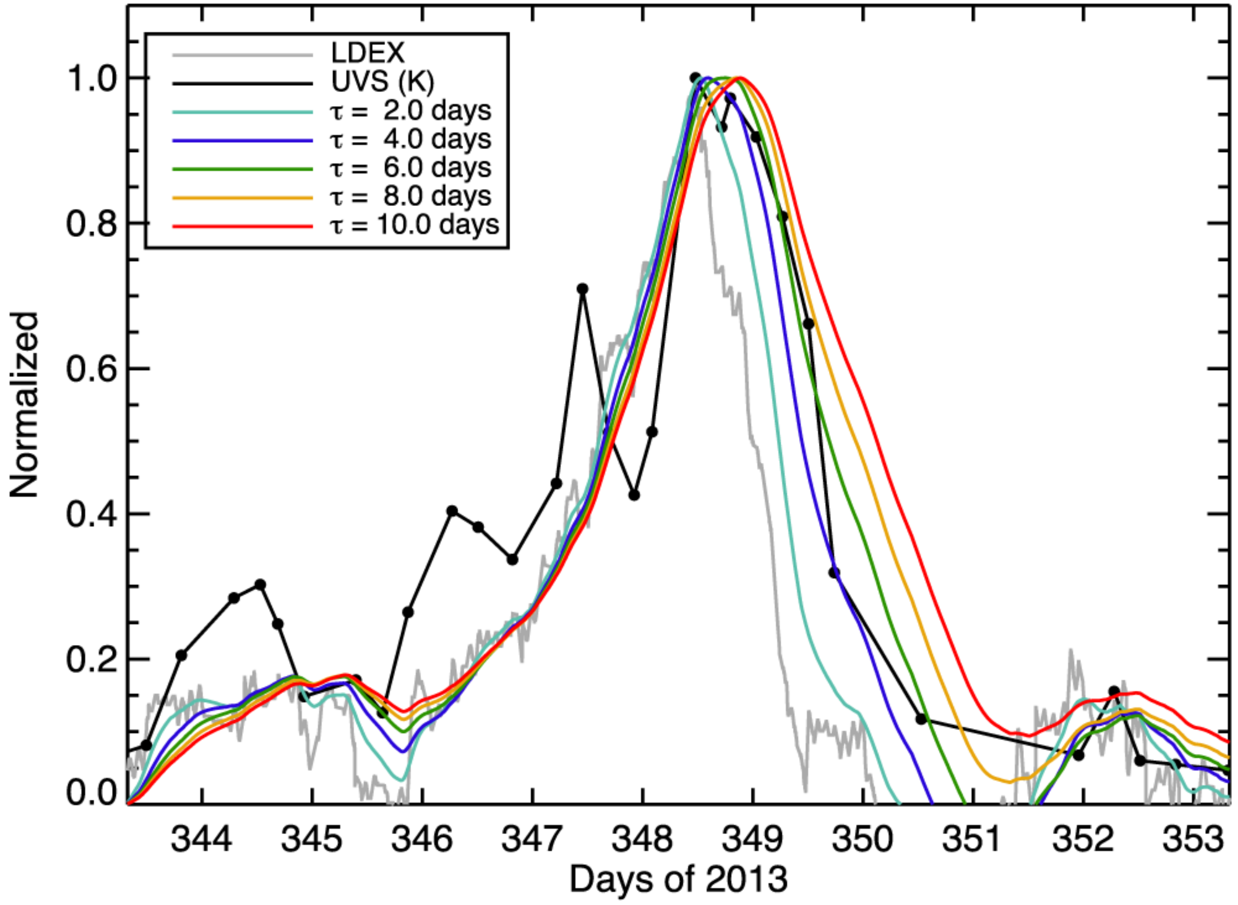




March 2014 data

…when contrasted to New Moon results,
Is this suggestive of higher sputtering yields for different soils?

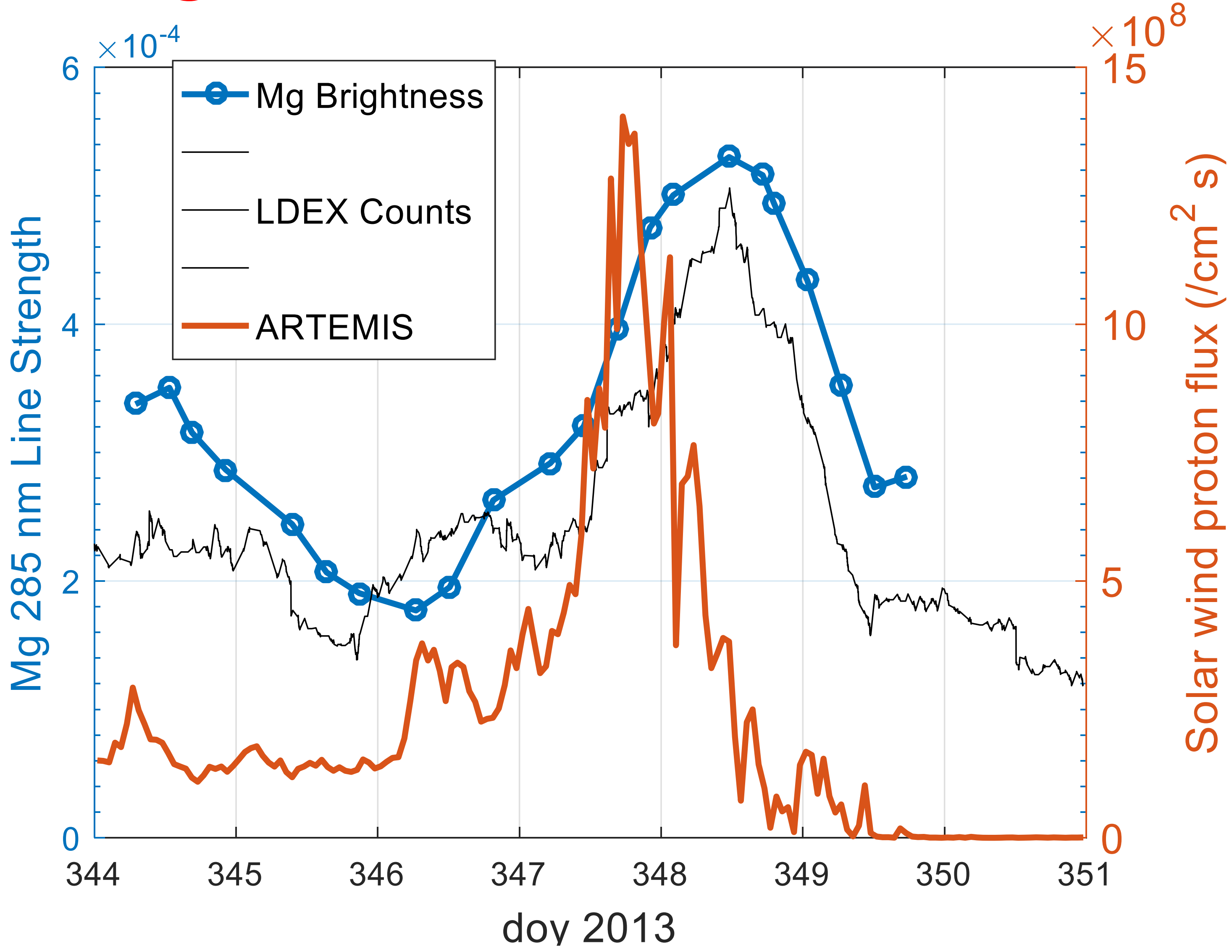
Geminids: a natural clock for sink rates!



Simple ODE model for exosphere response: dn/dt=dM/dt-n/tau

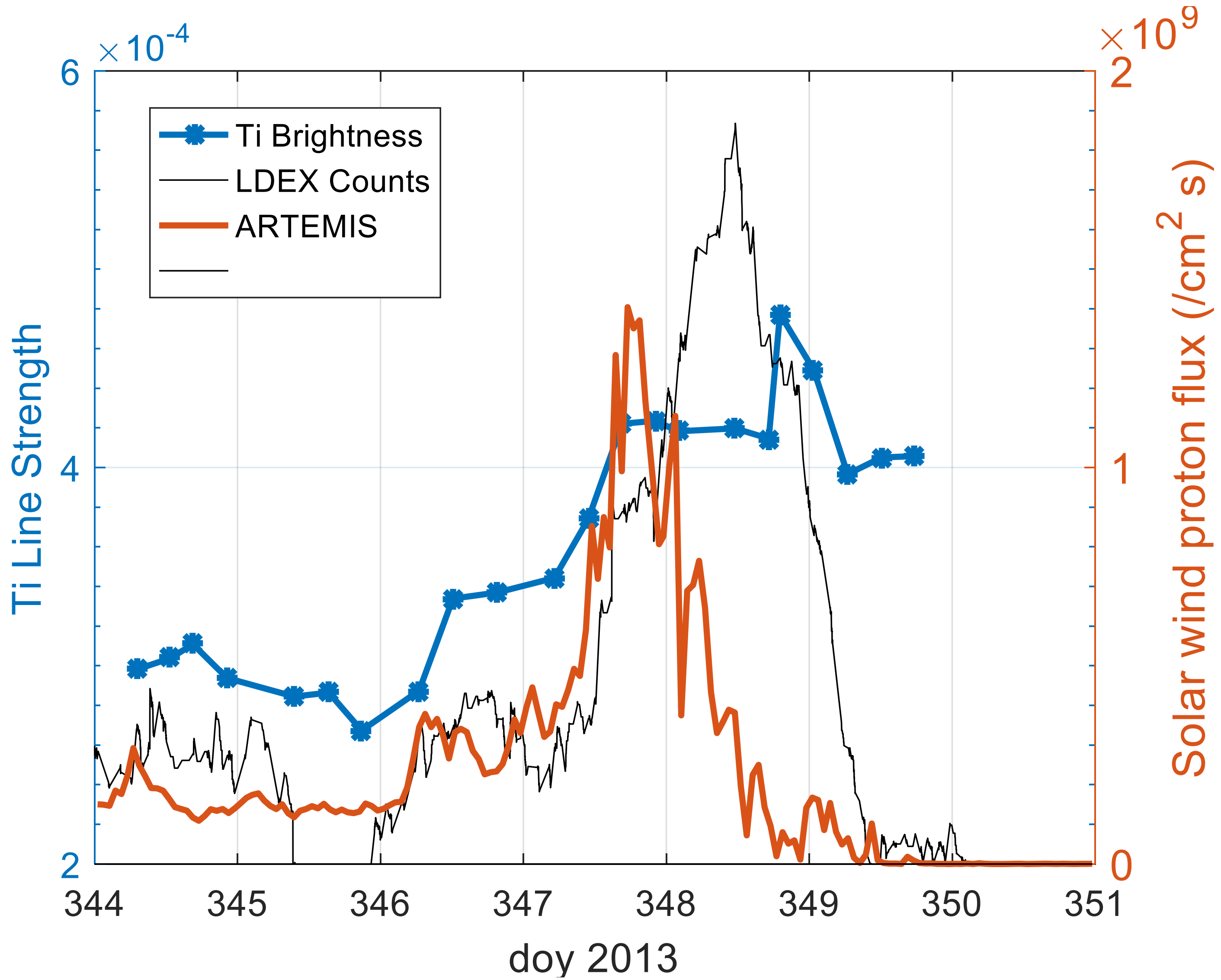
Szalay et al., GRL, 2016. “**Meteoritic influence on sodium and potassium abundance in the lunar exosphere measured by LADEE**“

Mg emission versus drivers around 2013 Geminids



- Mg brightness increased by x2.5 by the combined increase of solar wind flux and shower activity
- Timing of peak and overall magnitude of brightness variation for Mg correlated well to a smooth of dust counts detected by the Lunar Dust Experiment (LDEX) on LADEE
- **These finding are suggestive of impacts being the dominant source of Mg even outside of showers**

Ti emission versus drivers around 2013 Geminids

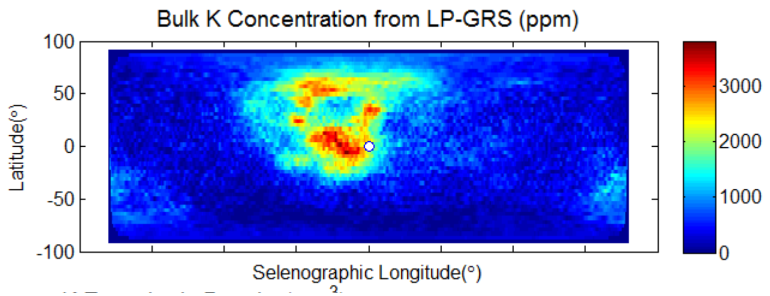


- Factor of six increase in solar wind flux caused only a ~x2 increase in exospheric brightness for this species, suggesting that sputtering is not the dominant source

- Overall change in brightness consistent with x2 variation in LDEX counts, but exospheric peak does not exactly coincide with the peak of the Geminids shower (possibly because the radiant is at 2 AM, and Ti is heavier than Mg)

What does the repeatable monthly variability tell us about sources?

Local time dependence of meteoroid influx



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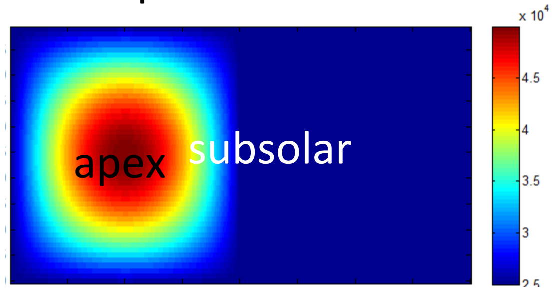
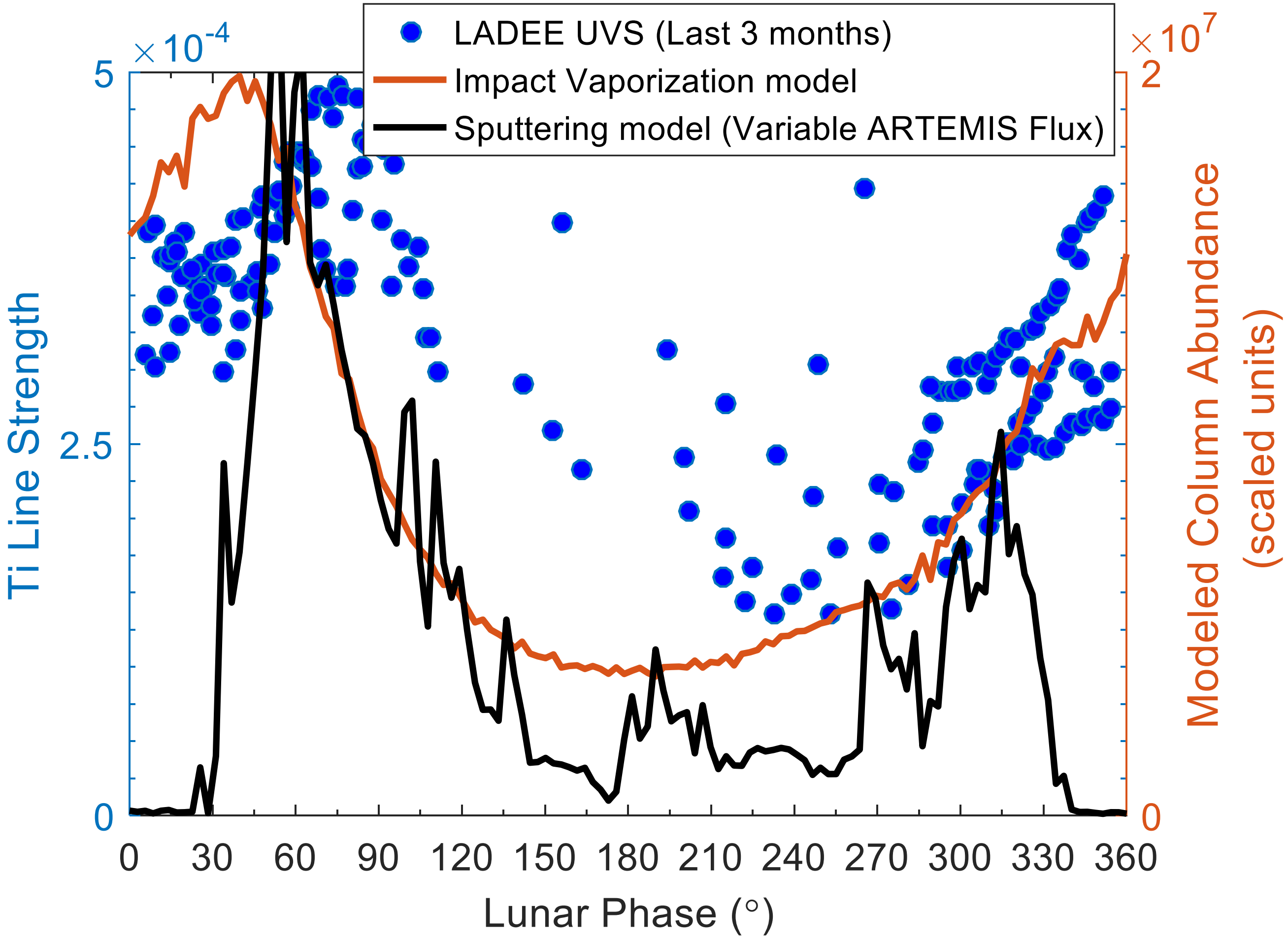


Periodic pumping in a month

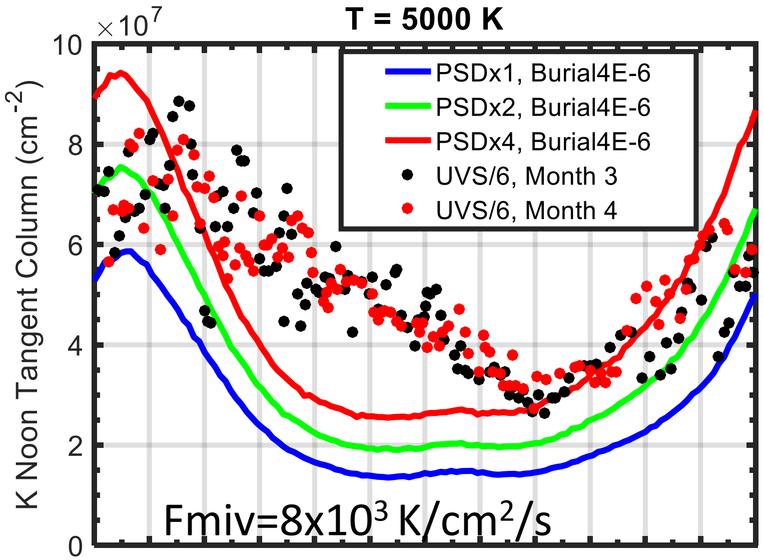
We can study in detail the convolution of surface composition with sources (apex-centered for impacts, subsolar-centered for sputtering) with a neutral particle Monte Carlo model

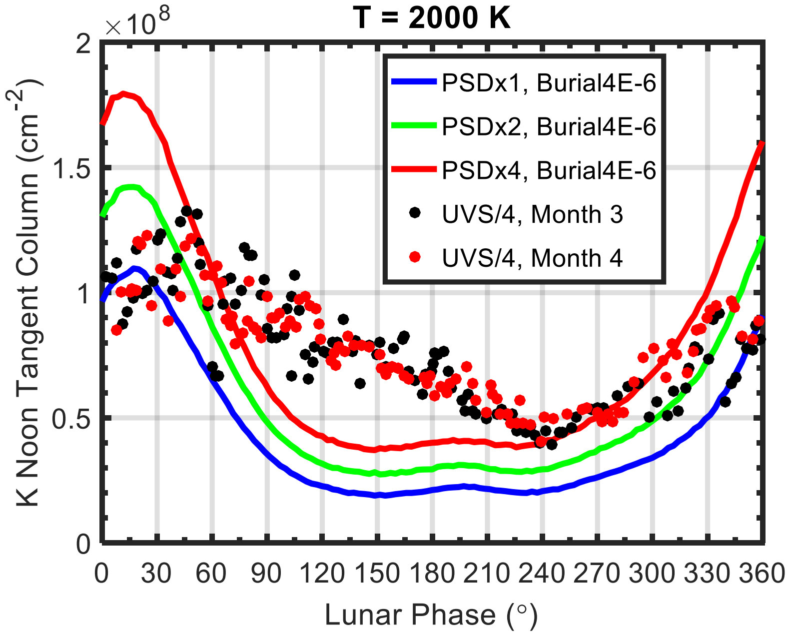
Ti variation with lunar phase vs model

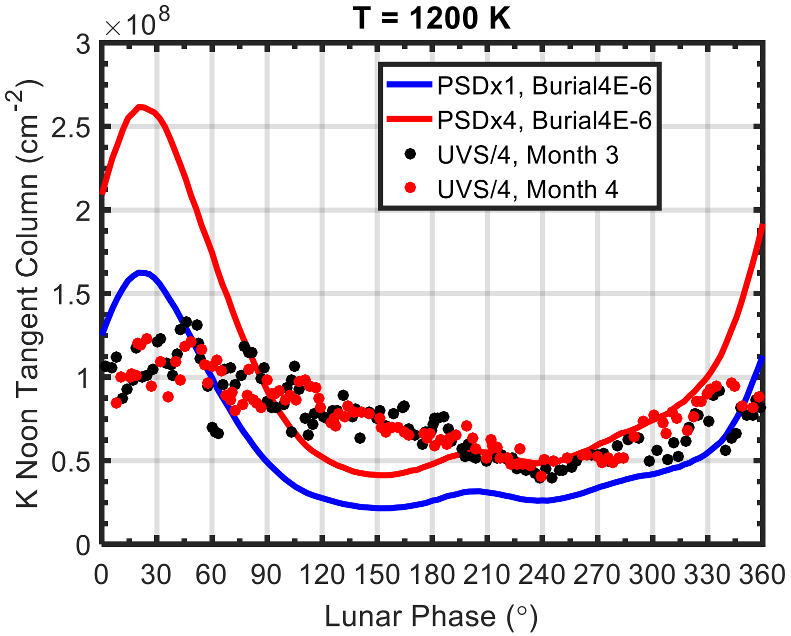


- A model of impacts focused at apex and adjusted for compositional inhomogeneity of Ti on the surface approximately reproduces the monthly trend and amplitude
- Suggestive of secondary role for sputtering
- Note: model and data in better agreement when earlier months are included. Suggests shifting of the lunar phase peak to later times coincides with decreasing relative importance for MIV, and increasing importance for sputtering

The K monthly amplitude tells us source temperature





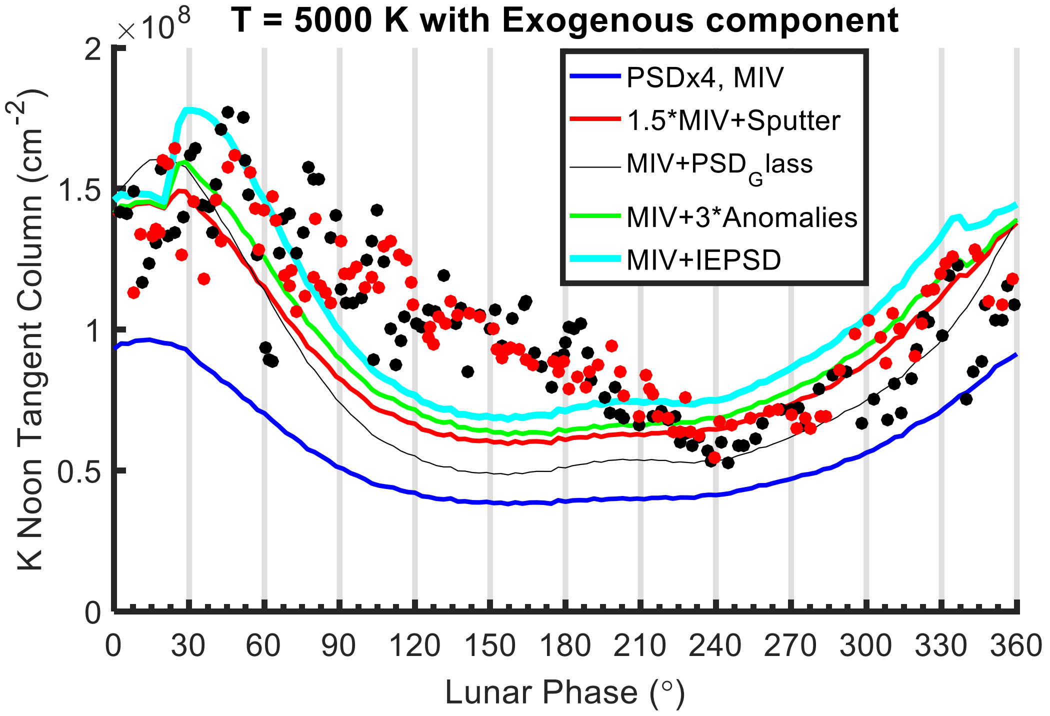


POSSIBLE SOURCES HAVE DIFFERENT INITIAL VELOCITY DISTRIBUTIONS, WHICH CAN BE USED TO DISTINGUISH AMONGST OPTIONS:

→Direct photodesorption from glass is an not the primary source for K

→Sporadic micrometeoroids must continuously populate the exosphere with fresh K atoms

Models with mixed sources better fit the monthly dependence of K



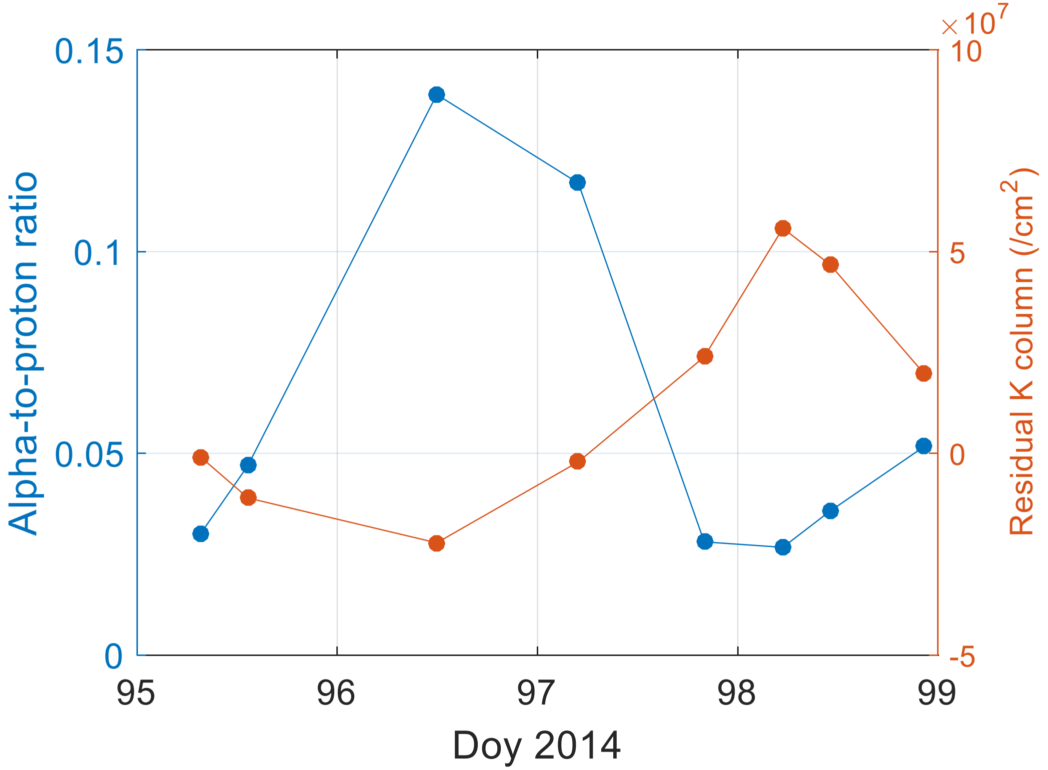
- Considering solutions with Ion-enhanced diffusion (IEPDS) (1 part to 3 parts from impact vaporization) moves peak to 30 deg past Full Moon as observed

  - ❑ **Microphysical parameters appear to be different for Highlands and Mare soils (thus a model with common parameters here fails over Highlands!)**

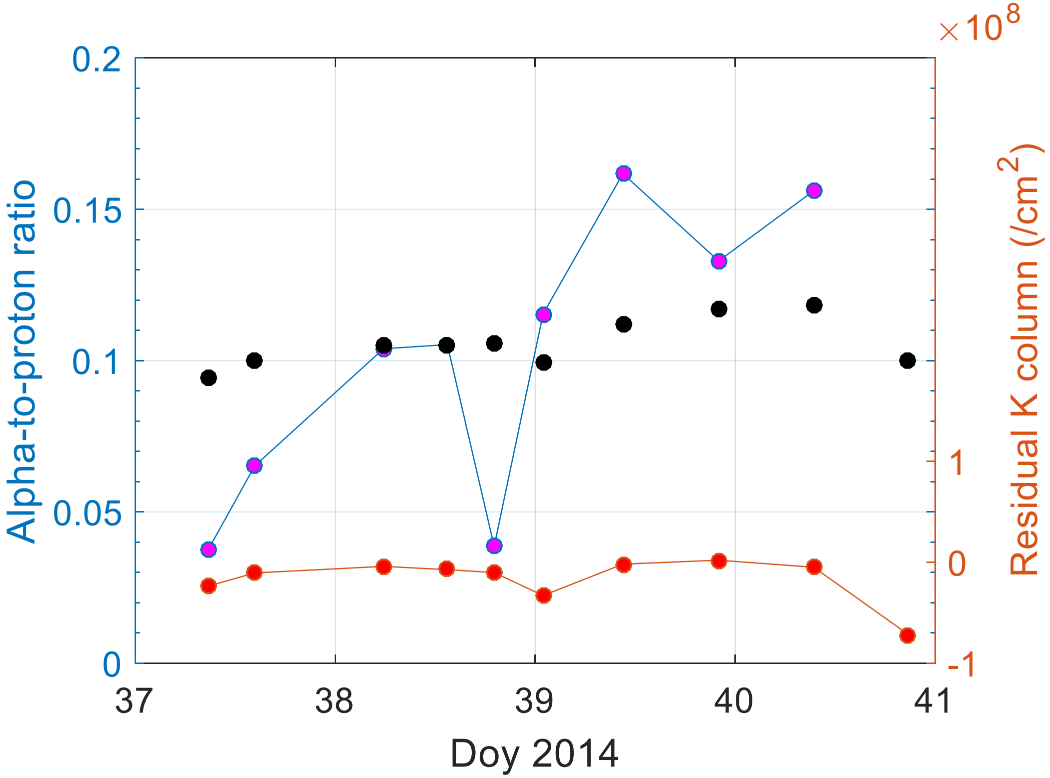
  -or perhaps an observational effect since it also appears on other species?

- Note: These simulations considered only the periodic pumping by a constant solar wind…fully time-dependent simulations with the ARTEMIS input are now being carried out

Final note on role of the solar wind: Response of K exosphere to large alpha abundance in 2014



Selenographic longitudes=80-120 East
Subtracted lunar phase trend



Selenographic longitudes=69-107 East
Subtracted lunar phase trend

- …effect of solar wind does not register. We get the typical lunar phase dependence. Suggestive of small sputtering yields once again.
- More work needed here

Conclusions

- Three pieces of evidence provided by LADEE and ARTEMIS appear to converge to the conclusion that impact vaporization is the main source of numerous metals in the lunar exosphere:
  a. Muted response to high proton flux preceding Geminids, whereas peak coincided with peak of meteor shower
     - Ti was more uncertain
  b. No correlation to solar wind alpha-to-proton ratio at New Moon or entering the magnetosphere, some correlation of Ti when exiting the magnetosphere
     - Suggestive of different sputtering yields for different soils
     - Correlation of Ti and alphas and proton flux coming out of the magnetosphere only occurs in later months, as if impact vaporization was reducing
  c. Monthly variation for exospheric Mg and Ti is well-reproduced by micrometeoroid vaporization with influx centered at apex of the Moon's motion
     - Potassium may require additional sources such as ion-enhanced photodesorption rates
     - Potassium response to large alpha events under investigation
- The findings suggest reduced loss rates of lunar material by virtue of reduced sputtering rates

Backup

Ultraviolet Lines from LADEE UVS