Observations of Ionospheric Oxygen in the Vicinity of the Moon

M. O. Fillingim, J. S. Halekas, A. R. Poppe,
Space Sciences Laboratory, University of California, Berkeley

V. Angelopoulos
Institute of Geophysics and Planetary Physics, UCLA

Lunar Science Virtual Forum July 16 – 18, 2013
30 Second Summary

• I want to try to convince you that...

• What:
  • ARTEMIS observes oxygen in the deep magnetotail (−60 R_E)

• How:
  • Secondary energy peaks in ion flux (no composition measurements)

• Two examples:
  • O^+
  • O_2^+ (we think)

• Why:
  • Can be important for magnetospheric dynamics and lunar exosphere

Lunar Science Virtual Forum

July 16 – 18, 2013
Motivation

• Motivated by presence of energetic bands on ion energy spectrograms

• Could these be ionospheric in origin? (Our initial interpretation is yes!)

• Can we determine mass, properties, statistical probabilities? (Not yet)
Criteria/Methodology

• Visually inspect ARTEMIS ion energy spectrograms

• Restrict to times when ARTEMIS is in the magnetotail
  → removes about ¾ of the data

• Look for a “noticeable” band above “normal” flux (subjective criteria)
  → easiest to find in lobe and plasma sheet boundary layer (PSBL)

• ARTEMIS Electrostatic Analyzers (ESAs) measure $E/q$, where $E = \frac{1}{2}mv^2$

• If we assume that all the plasma is flowing at the same velocity,
  more massive particles will have higher energy
  → the increase in energy is proportional to the increase in mass

• Determine mass from energy shift

Lunar Science Virtual Forum
July 16 – 18, 2013
Example 1: 2012-06-03

Lunar Science Virtual Forum

July 16 – 18, 2013
Example 1: 2012-06-03

- Quiet PSBL
- \( \mathbf{B} \approx -B_x \approx 10 \text{ nT} \)
- \( n \approx 0.2 \text{ cm}^{-3} \)
- \( v_i \approx -v_x \leq 100 \text{ km/s} \)
- \( T_i \approx 100 \text{ eV} \)
- Main ion flux centered around 100 eV; fainter band at 1 – 2 keV (more prominent at ARTEMIS P1)
- Higher energy band (red) \( \sim 16 \times \) the energy of the main band (black) \( \rightarrow \) O\(^+\) \( 16 \times \) the mass of H\(^+\)
Example 1: 2012-06-03

- Cuts through the ion energy spectrogram
- Somewhat broad secondary peak
  - $\sim 1$ order of magnitude lower flux
  - $\sim 16 \times$ higher energy – consistent with $O^+$
Example 1: 2012-06-03

- Angular spectrograms
- Lower energy component centered at 180° (tailward & field aligned)
  - consistent with observed $v$
- Higher energy component broader but still tailward
  - consistent with our assumption that all plasma flows together
Example 2: 2012-10-01

Lunar Science Virtual Forum

July 16 – 18, 2013
Example 2: 2012-10-01

- LL/PSBL near the magnetopause – magnetosheath excursions
- \( B \approx B_X \approx 20 \text{ nT} \)
- \( n \approx 0.1 \rightarrow 1 \text{ cm}^{-3} \) (in strong, steady \( B \) region)
- \( v_i \approx -v_X \leq 200 \text{ km/s} \) (\( \approx 400 \text{ km in the sheath} \))
- \( T_i \approx 100 \text{ eV} \) (higher in the sheath)
- Outside of sheath, main ion flux varies from few 10 eV to few 100 eV; fainter band varies from 1 – 10 keV
- Higher energy band is \textbf{not} 16 X the energy of the main band
- Higher energy band is \( \sim 32 \) X the energy of the main band \( \rightarrow O_2^+!? \)
Example 2: 2012-10-01

- Cuts through the ion energy spectrogram
- Somewhat narrow secondary peak
  - ~ 2 orders of magnitude lower flux
  - ~ 32 X higher energy – consistent with \( \text{O}_2^+ \) or \( \text{S}^+ \) or ?

Lunar Science Virtual Forum

July 16 – 18, 2013
Example 2: 2012-10-01

- Angular spectrograms
- Both components centered at 180° (tailward & anti-field aligned)
  - again, consistent with our assumption of flowing plasma
30 Second Summary (Revisited)

• I hope I convinced you that...

• What:
  • ARTEMIS observes oxygen in the deep magnetotail (−60 RE)

• How:
  • Secondary energy peaks in ion flux (no composition measurements)

• Two examples:
  • O⁺
  • O₂⁺ (we think)

• Why:
  • Can be important for magnetospheric dynamics and lunar exosphere
30 Second Summary (Revisited)

• I hope I convinced you that...

• What:
  • ARTEMIS observes oxygen in the deep magnetotail (–60 \( R_E \))

• How:
  • Secondary energy peaks in ion flux (no composition measurements)
    • Only works if all ions flow with a single velocity
      (well, they are going in the same field-aligned direction)
      Perpendicular: expect same velocity due to convection
      Parallel: what gives them the same velocity (rather than energy)?
  • Mixing of different populations? – Why would energies track?
30 Second Summary (Revisited)

• I hope I convinced you that...

• What:
  • ARTEMIS observes oxygen in the deep magnetotail (−60 $R_E$)

• How:
  • Secondary energy peaks in ion flux (no composition measurements)

• Two examples:
  • $O^+$: not new
  • $O_2^+$ (we think): is this new?
    How do you get it out?
    AE peaks $> 1000$ nT during 2$^{nd}$ interval (few 100 for 1$^{st}$ interval)
    Why no $O^+$ in 2$^{nd}$ interval?
30 Second Summary (Revisited)

• I hope I convinced you that...

• Why:
  • Can be important for magnetospheric dynamics and *lunar exosphere*

• Lunar exosphere
  • Produced in part by sputtering – ion impact releases neutrals
  • Sputtering efficiency increases with impacting ion mass
  • O\(^{+}\) much more efficient than H\(^{+}\); O\(_{2}\)\(^{+}\) much more efficient than O\(^{+}\)
  • Pumping up of exosphere during ion outflow?

• Final thoughts:
  • A lot of open questions
  • A lot of work left to do
    • Ion properties, statistics, and effects