Electrons on closed field lines of lunar crustal fields in the solar wind wake

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Lunar crustal magnetic fields

<table>
<thead>
<tr>
<th>Alt.</th>
<th>effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 km</td>
<td>1-2 nT</td>
</tr>
<tr>
<td>30 km</td>
<td>~20 nT</td>
</tr>
<tr>
<td>surface</td>
<td>~300 nT</td>
</tr>
</tbody>
</table>

Lunar radius = 1738 km

Scale of magnetized area ~ 100-1000 km
(Smaller than Mars’)

Kaguya L Maggie 30 km alt.

SPA (South Pole - Aitken) basin

Crisium Antipode

Cf. Interplanetary magnetic field at 1 AU ~ several nT
More than 80% of time ...

- The moon stays in the solar wind
  - interaction between SW and the Moon

- Why important?
  - Wake formation behind the moon
  - Plasma refilling into the wake
  - Particle/dust acceleration
  - Hazardous in future missions
  - Space plasma and planetary surface
    - no thick atmosphere
    - no intrinsic magnetic field

- Solar wind
- Moon
- Lunar orbit
- Sun
- Dawn
What happens in the solar wind wake?

- Plasma cavity? (Cavity in the plasma void?)
- Mini-magnetosphere filled with plasma?

What happens here? Cavity or mini-magnetosphere?

Dyal et al. Nature 1972
Previous observations (Lunar Prospector)

- An enhancement in the magnetic field magnitude over the CA anomaly
- Decrease in the electron flux in the vicinity of the CA anomaly

(Halekas+2008 PSS)
Our data

- Kaguya (SELENE) observations
- PACE+LMAG
- 14-15 km over Crisium Antipode
- Longitude = 126° in SSE (night side)

- 80 nT, 0.1 keV $\Rightarrow r_{e_{\text{gyro}}} = 0.42$ km
SELENE orbit (1h)


14-15 km over Crisium Antipode

Longitude = 126° in SSE
Plasma and magnetic field over CA

Alt: 14-15 km over CA
- High electron flux
- Large variation in B
Enhancement of electron flux (21:37 UT)

Magnetic field and electron flux enhance.

ESA-S2
(incl. downward-going e-)

double loss cones
in the medium energy range
→ closed magnetic fields

ESA-S1
(incl. upward-going e-)
typical upward beams in the wake
field-aligned beams in the low energy range

15 km alt. over CA in the wake

Large variation in magnetic field direction along the orbit
⇒ Need to investigate high-resolution data
Bi-directional low-energy beams

Electron data at each energy are obtained for 0.5 sec

ESA-S2 (incl. downward-going e-)

ESA-S1 (incl. upward-going e-)

Closed magnetic field

<table>
<thead>
<tr>
<th>beam energy</th>
<th>data period</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>38 eV</td>
</tr>
<tr>
<td>S2</td>
<td>41 eV</td>
</tr>
<tr>
<td></td>
<td>21:37:17.5-21:37:18.0</td>
</tr>
</tbody>
</table>
Loss cone angle

- 300 nT at the footprints, 80 nT at 15 km altitude
- Loss-cone angle (at 15 km alt.) = 31 degrees
- Double loss-cone in the middle energy range
- Electron beams in the loss-cone angle are fresh electrons from the lunar night side surface

\[ \frac{B_0}{B_M} = \sin^2 \theta \]
Electron energy flux (about 100 eV)

Solar wind: $10^7$

dayside cavity est. $10^6$ (*1)

captured in wake: $10^{5.5-6}$

typical wake: $10^{4.5-5}$

cavity in wake: $<10^4$

*1 An order-of-magnitude density drop near the terminator (SZA~81 deg) (Halekas+2008, PSS)
Gradient B drift

- \( \text{grad } \mathbf{B} = 10 \text{ nT/km} \)
- 100 eV electron
- Gradient drift speed of 100 km/s
- Quick loss into the lunar surface
- *How are electrons there? Supply??*

\[
V_d = \left( \frac{\varepsilon_\perp}{qB^3} \right) \left( B \times \nabla B \right)
\]

\[
\varepsilon_\perp = \frac{1}{2} m v_\perp^2
\]
Summary & Discussion

• Trapped electrons 15 km over CA anomaly in the wake
• Bi-directional low-energy electron beams (<100eV)
• Double loss cones (medium energy)
  → Closed magnetic fields

• Loss into lunar surface by grad B drift at 100 km/s
• How are hot electrons supplied to the closed field lines?
  – Do electrons move around the surface to come to CA?
  – Direct supply of SW electrons along Parker-spiral IMF?

• What can we see at different altitudes (e.g. 50 km)?
• Comparison between observed and model fields