Physics of Solar Wind and Terrestrial Magnetospheric Plasma Interactions With the Moon

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with help from
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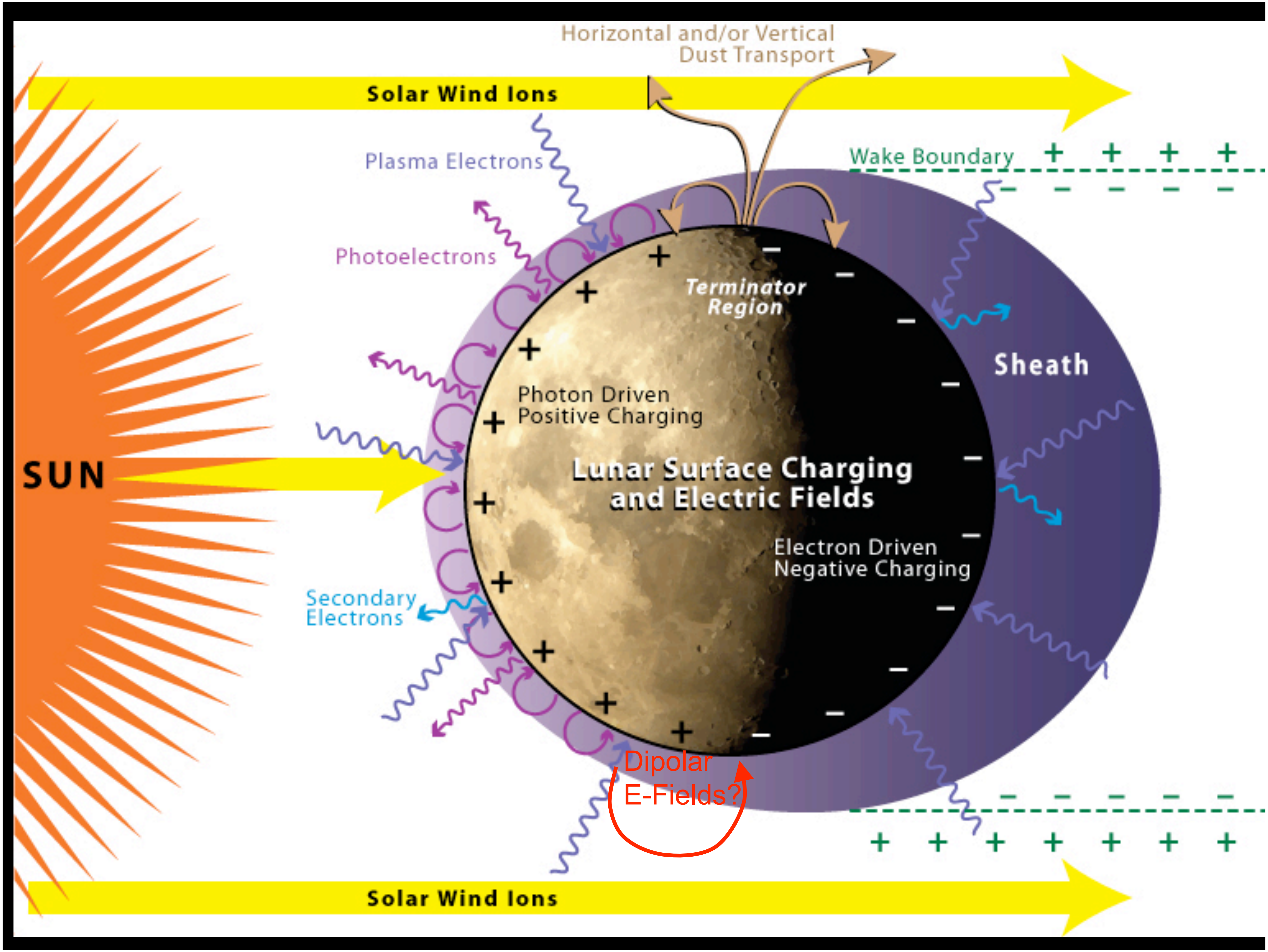
Plasma Interaction with the Moon and Dust

Plasma Physics of the Distant Magnetotail

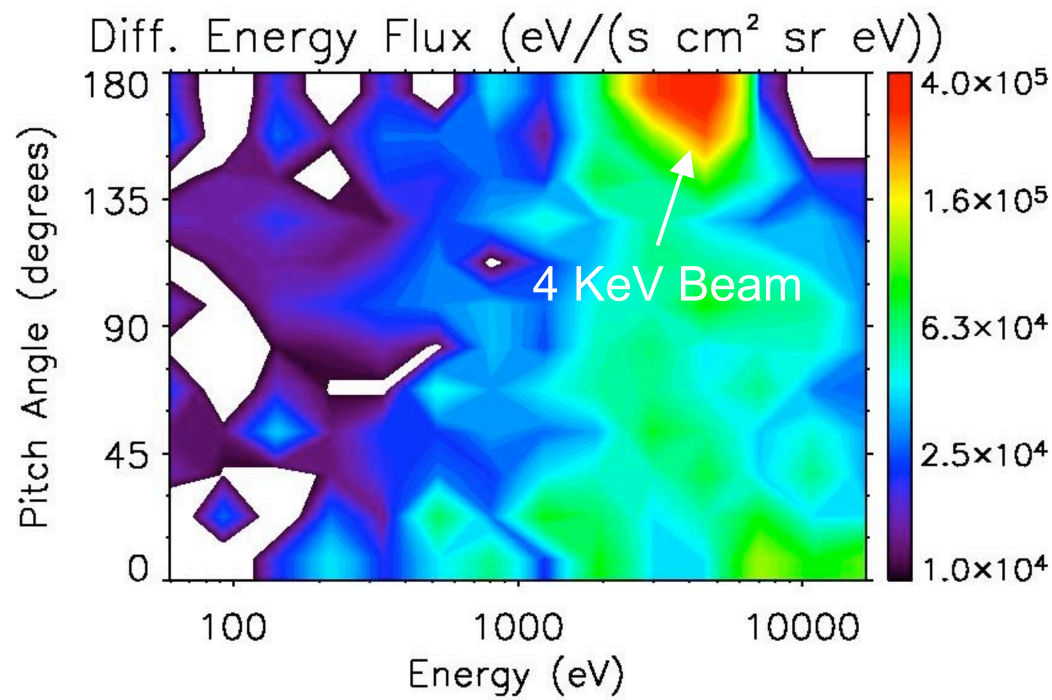
Plasma Interaction with Mini-Magnetospheres


Horizontal and/or Vertical Dust Transport
Solar Wind Ions
Plasma Electrons
Wake Boundary
Photoelectrons
Terminator Region
Sheath
Photon Driven Positive Charging
SUN
Lunar Surface Charging and Electric Fields
Electron Driven Negative Charging
Secondary Electrons
Dipolar E-Fields?
Solar Wind Ions

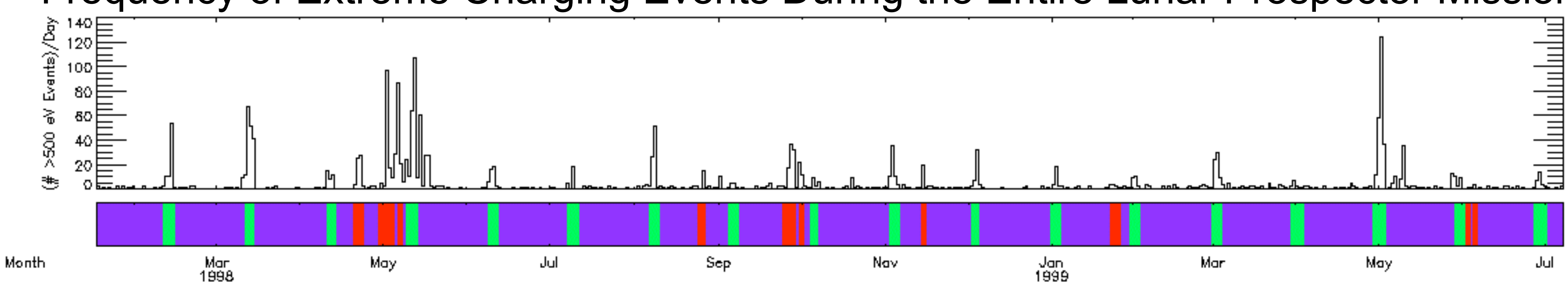
Extreme Surface Charging

Surface potentials of up to several kV (negative) found:

- In the terrestrial plasmasheet, where we encounter high plasma temperature.
- During Solar Energetic Particle events

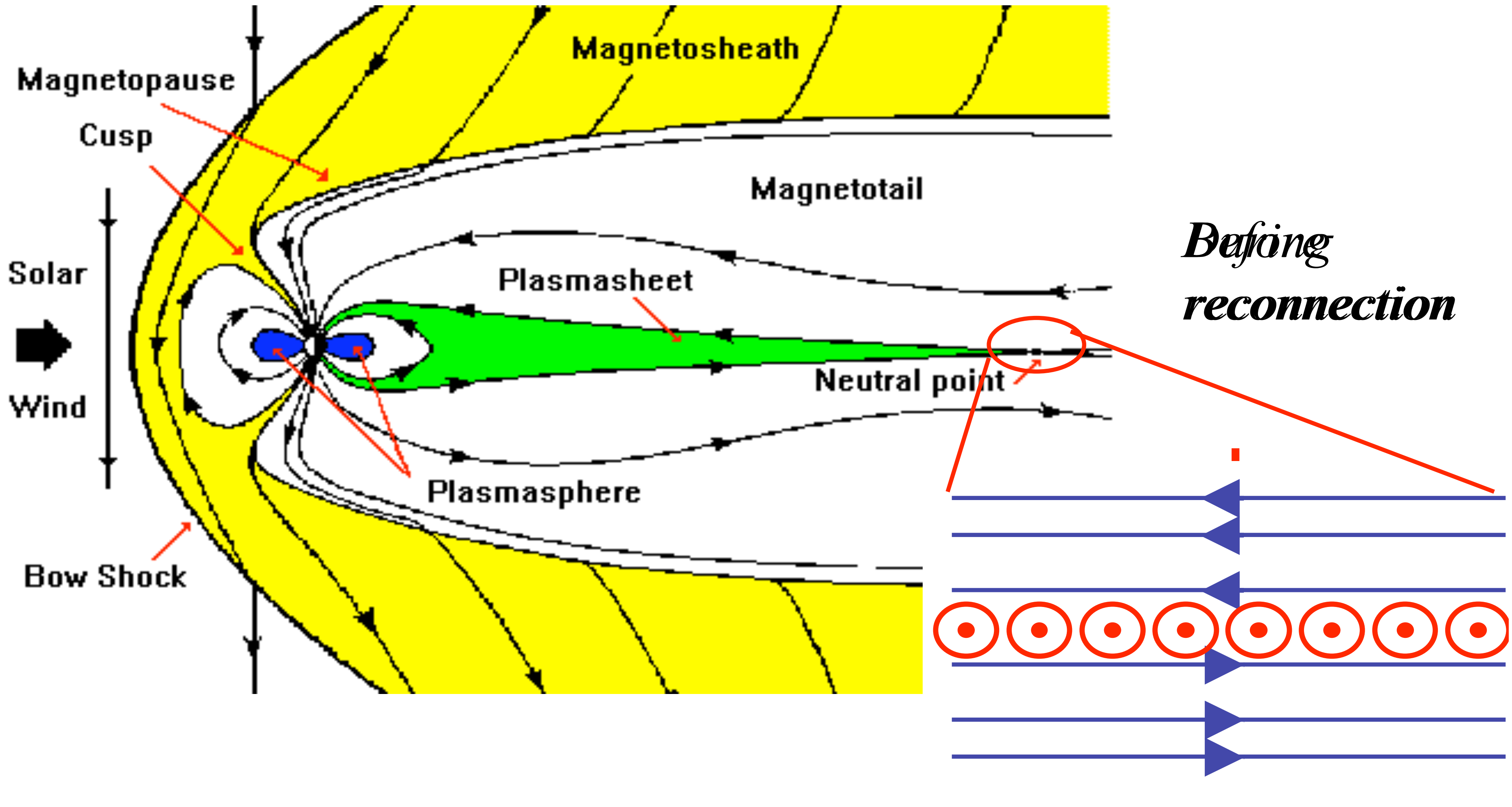


Frequency of Extreme Charging Events During the Entire Lunar Prospector Mission



- Green in color bar indicates magnetospheric tail passages, red indicates major SEP events

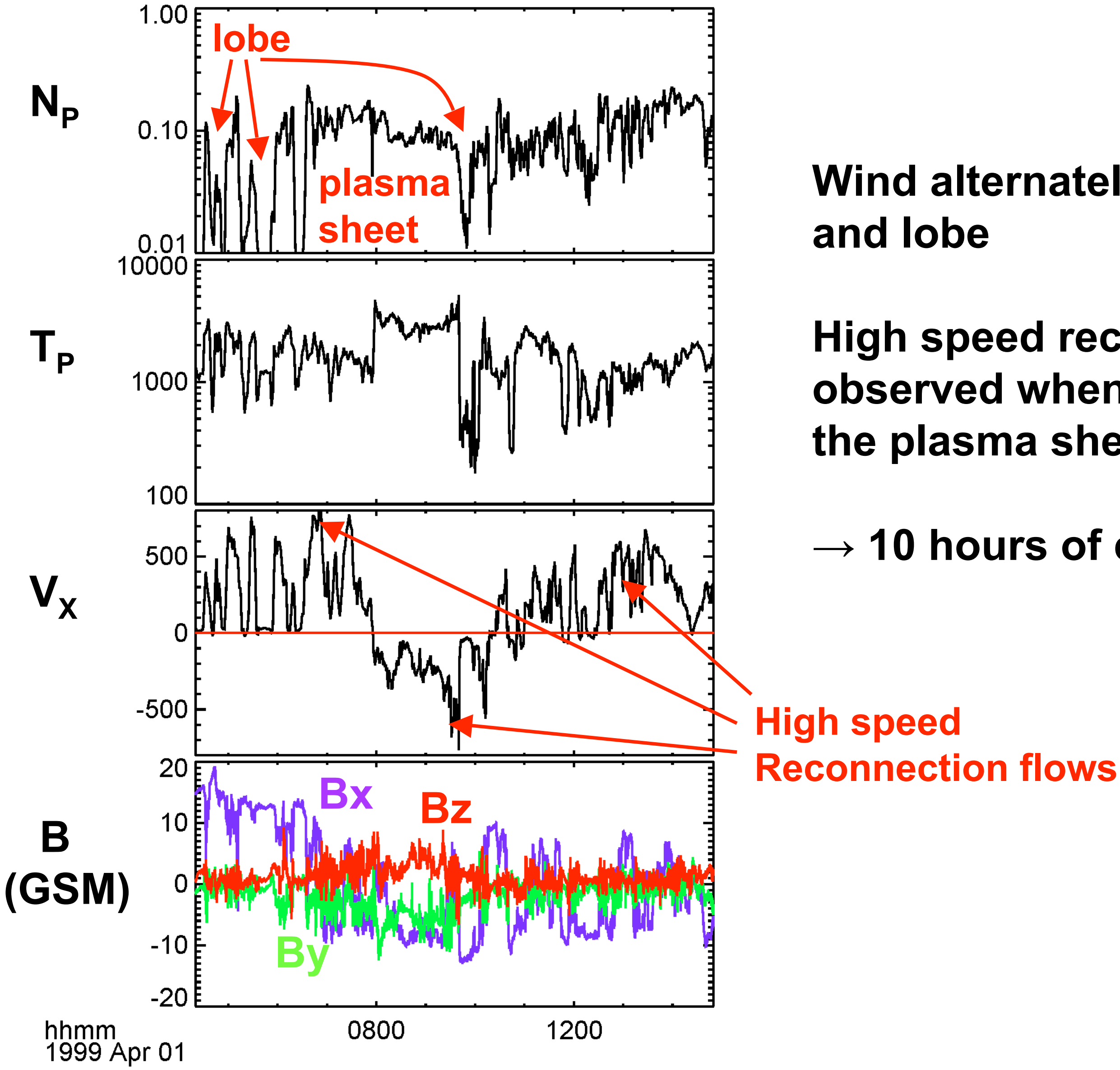
The Earth's magnetic shield



reconnection

Dungey, Philos. Mag. 55, (1953)

Wind observed 10 hours of reconnection flows at lunar distance (X_{GSE}=-60 R_E)

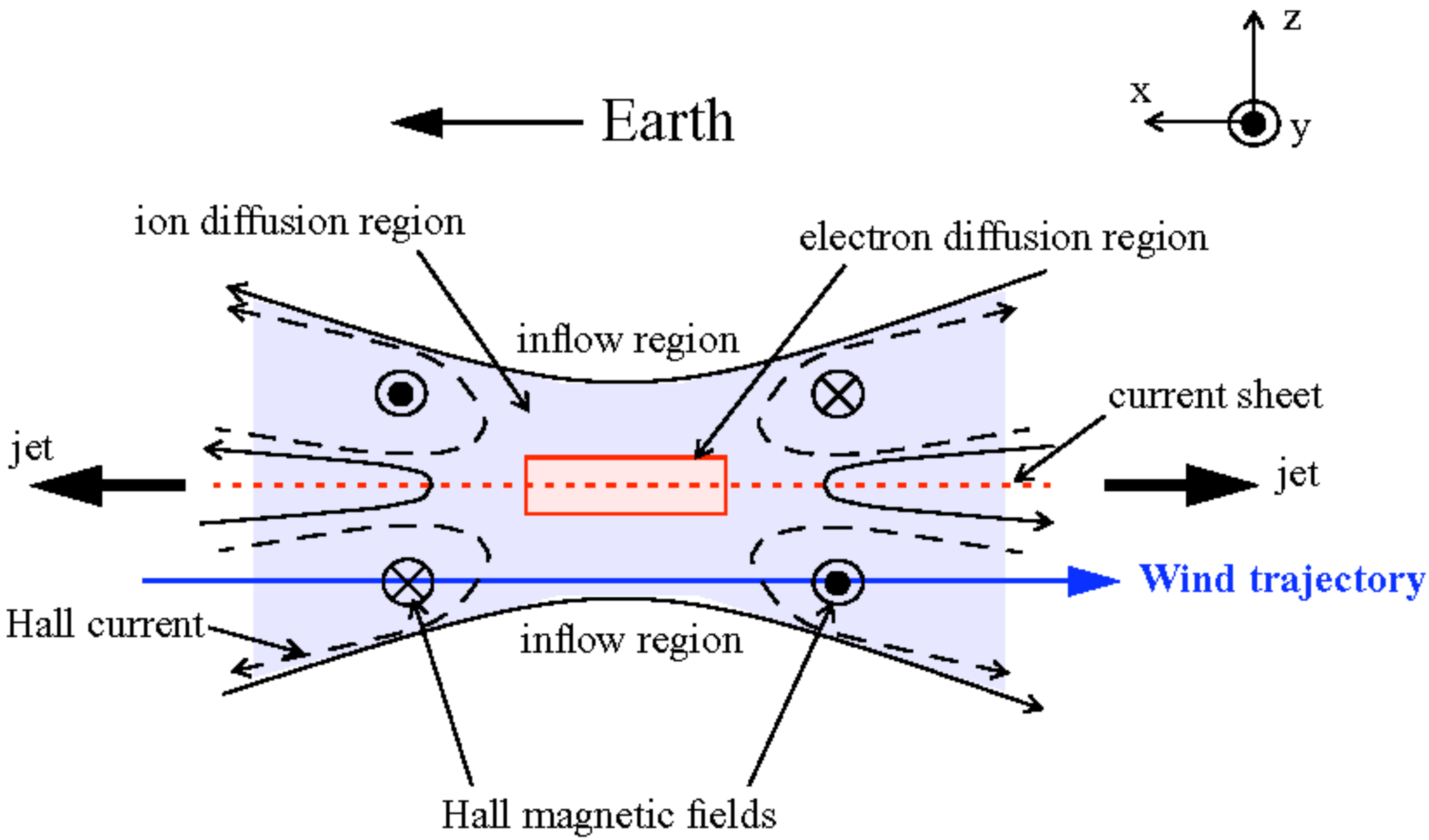


Wind alternately inside plasma sheet and lobe

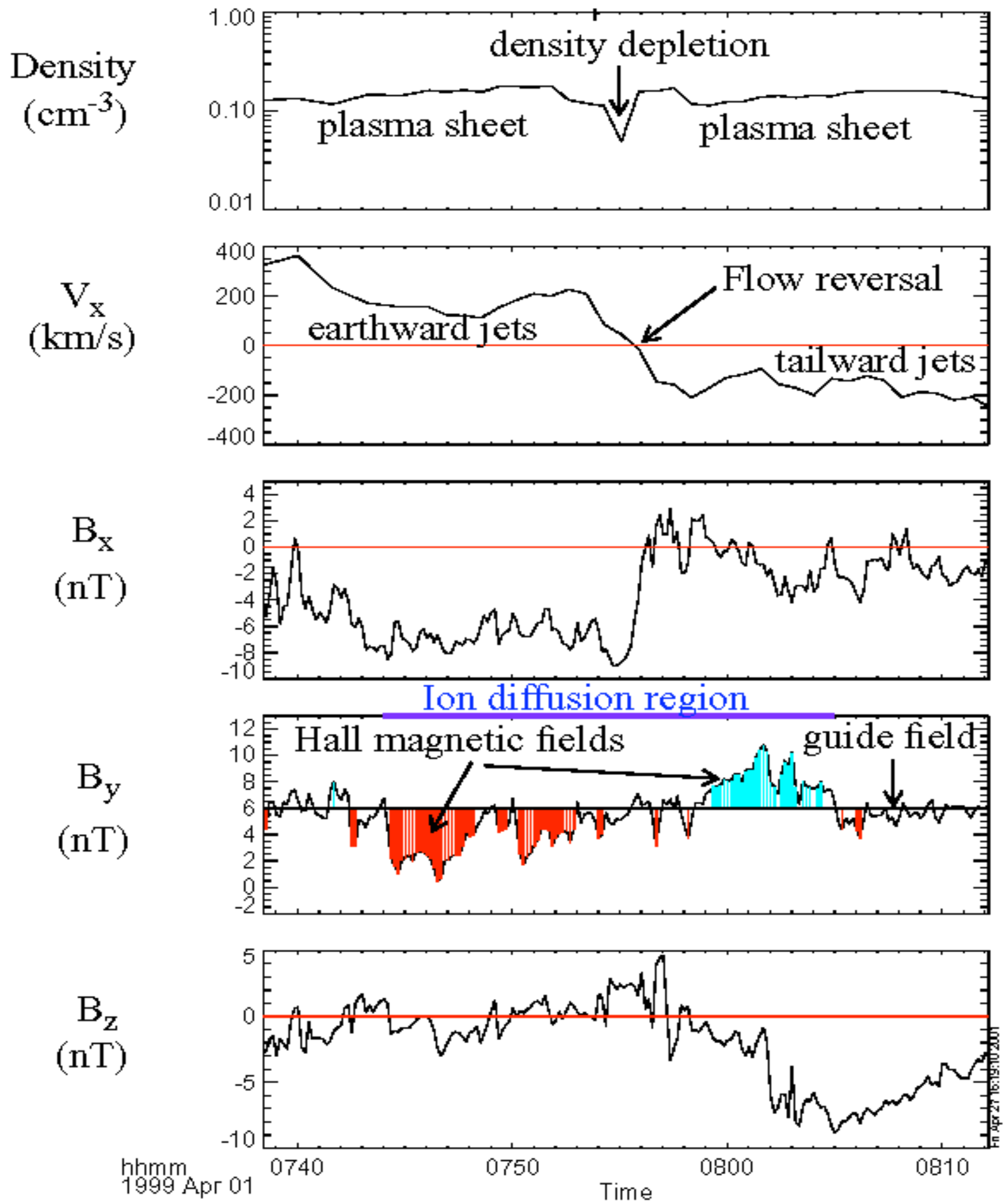
High speed reconnection flows always observed when the spacecraft was in the plasma sheet

→ 10 hours of continuous reconnection

(Oieroset et al., 2000)


z
x
y
Earth
ion diffusion region
electron diffusion region
inflow region
current sheet
jet
jet
Wind trajectory
Hall current
inflow region
Hall magnetic fields

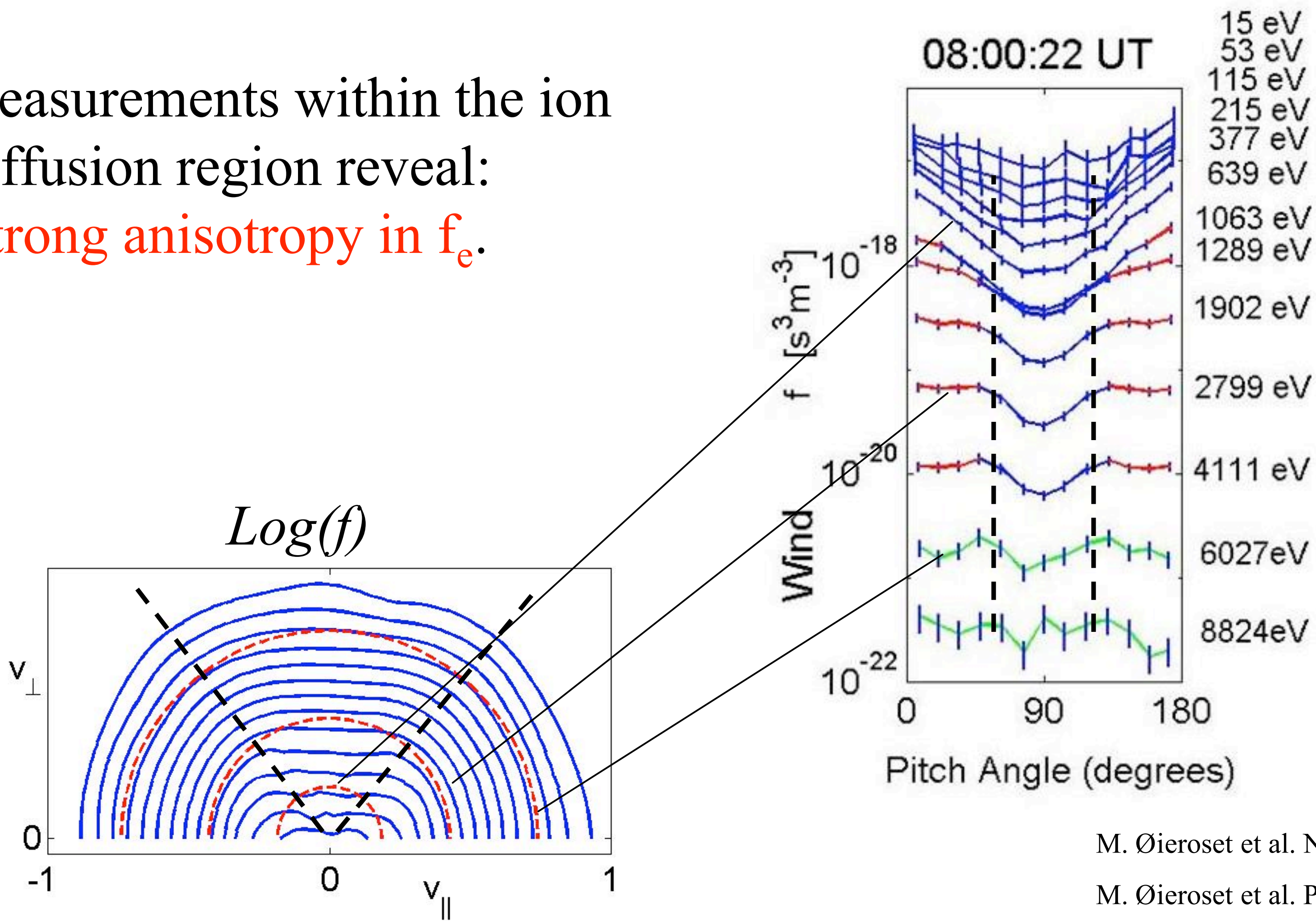
Hall magnetic fields in the diffusion region



(Øieroset et al., NATURE, 2002)

Wind satellite observations in distant magnetotail, $60R_E$

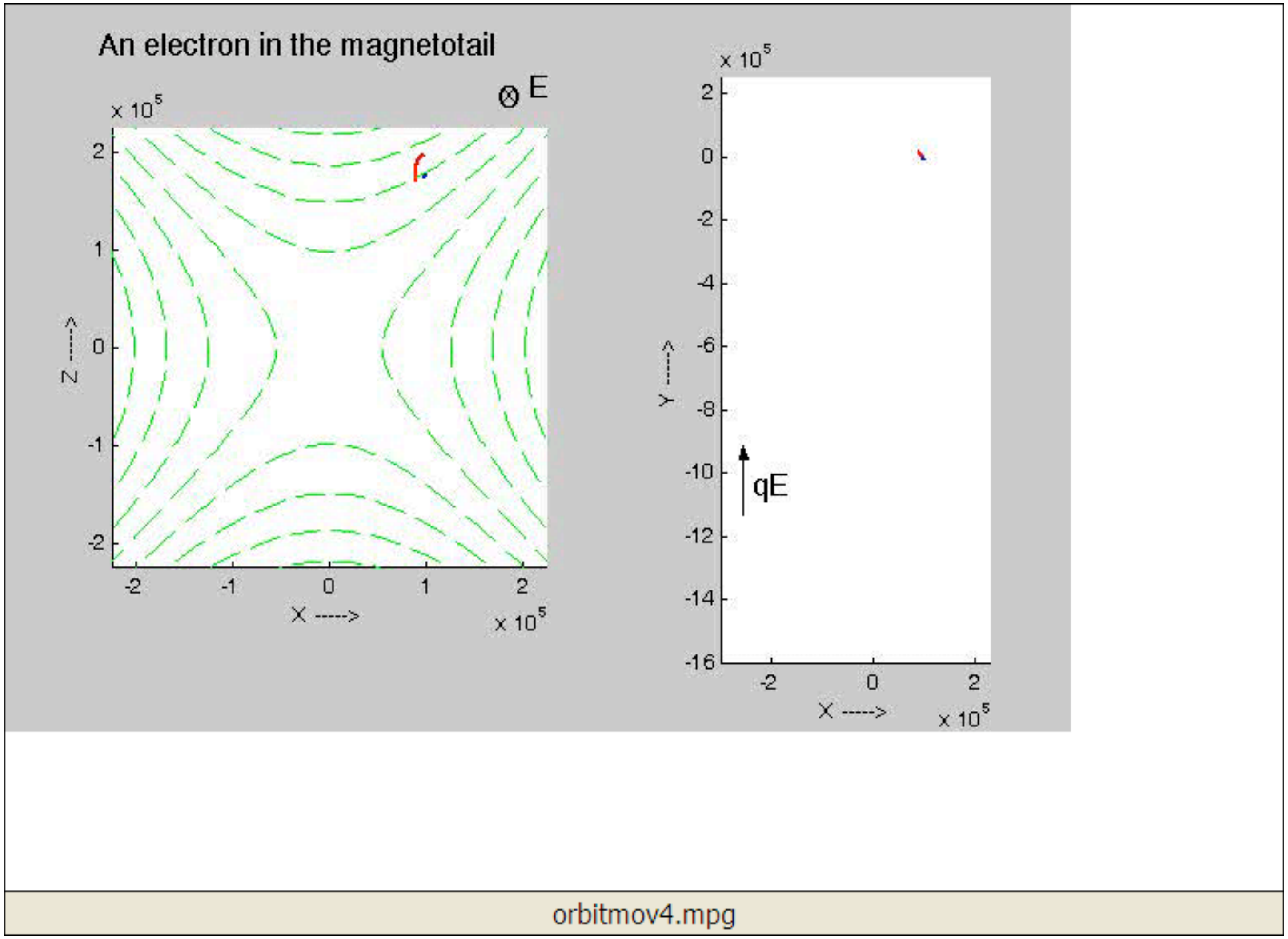
- Measurements within the ion diffusion region reveal: Strong anisotropy in f_e.



M. Øieroset et al. Nature **412**, (2001)

M. Øieroset et al. PRL **89**, (2002)

A trapped electron in the magnetotail



The magnetic moment: $\mu = \frac{m v_{\perp}^{2}}{2B} = \frac{m(v^2 - v_{\parallel}^{2})}{2B}$

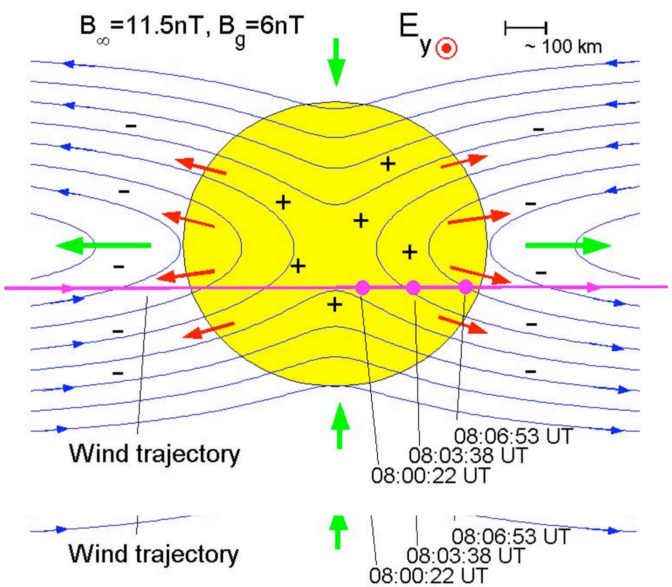
Drift kinetic modeling of Wind data

- Applying $f(\mathbf{x}_0,\mathbf{v}_0) = f_\infty(|\mathbf{v}_1|)$ to an X-line geometry consistent with the Wind measurements
- A potential, Φ_∞ needed for trapping at low energies
- Ion outflow: 400 km/s, consistent with acceleration in Φ_∞

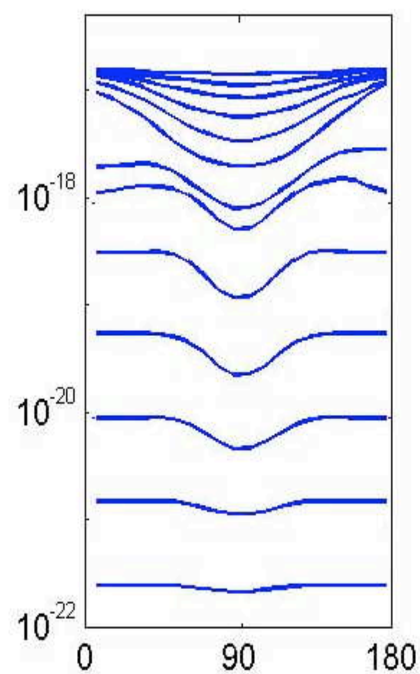
$\Phi_\infty \sim -300V$

$\Phi_\infty \sim -800V$

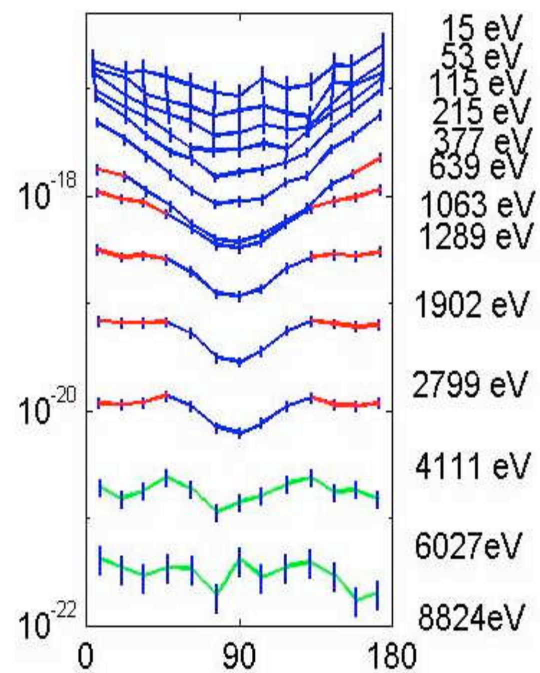
$\Phi_\infty \sim -1150V$



Theory

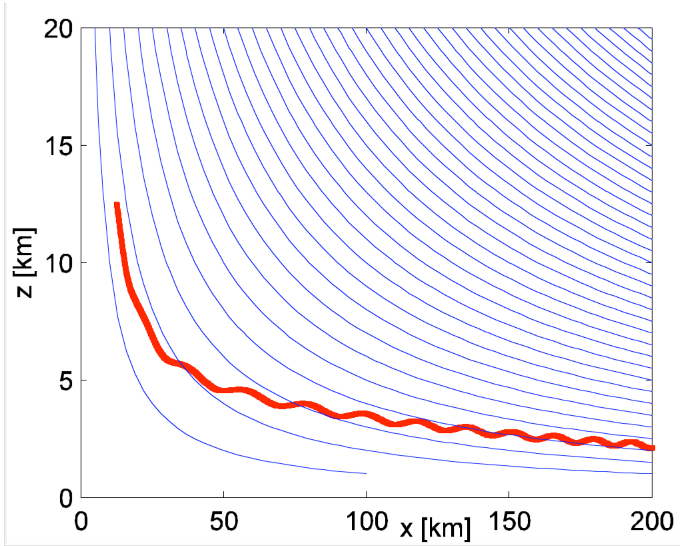


Wind

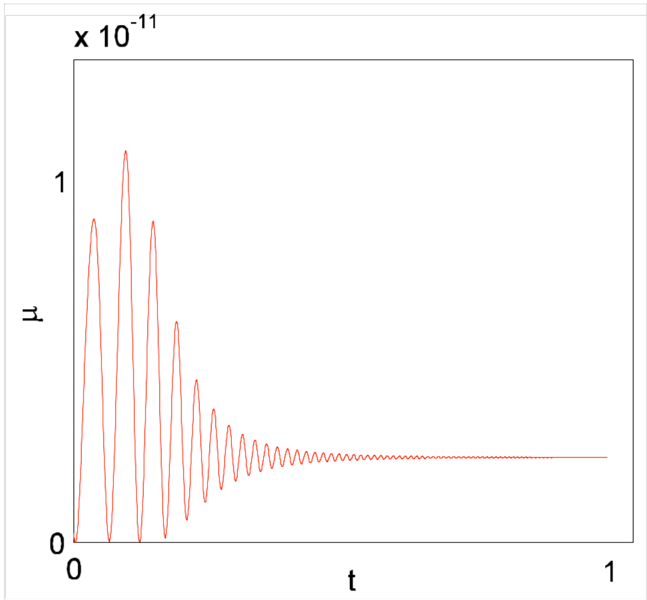


J. Egedal et al., (2005) Phys. Rev. Lett. **94**, 025006

Orbit with $v_\perp=0$

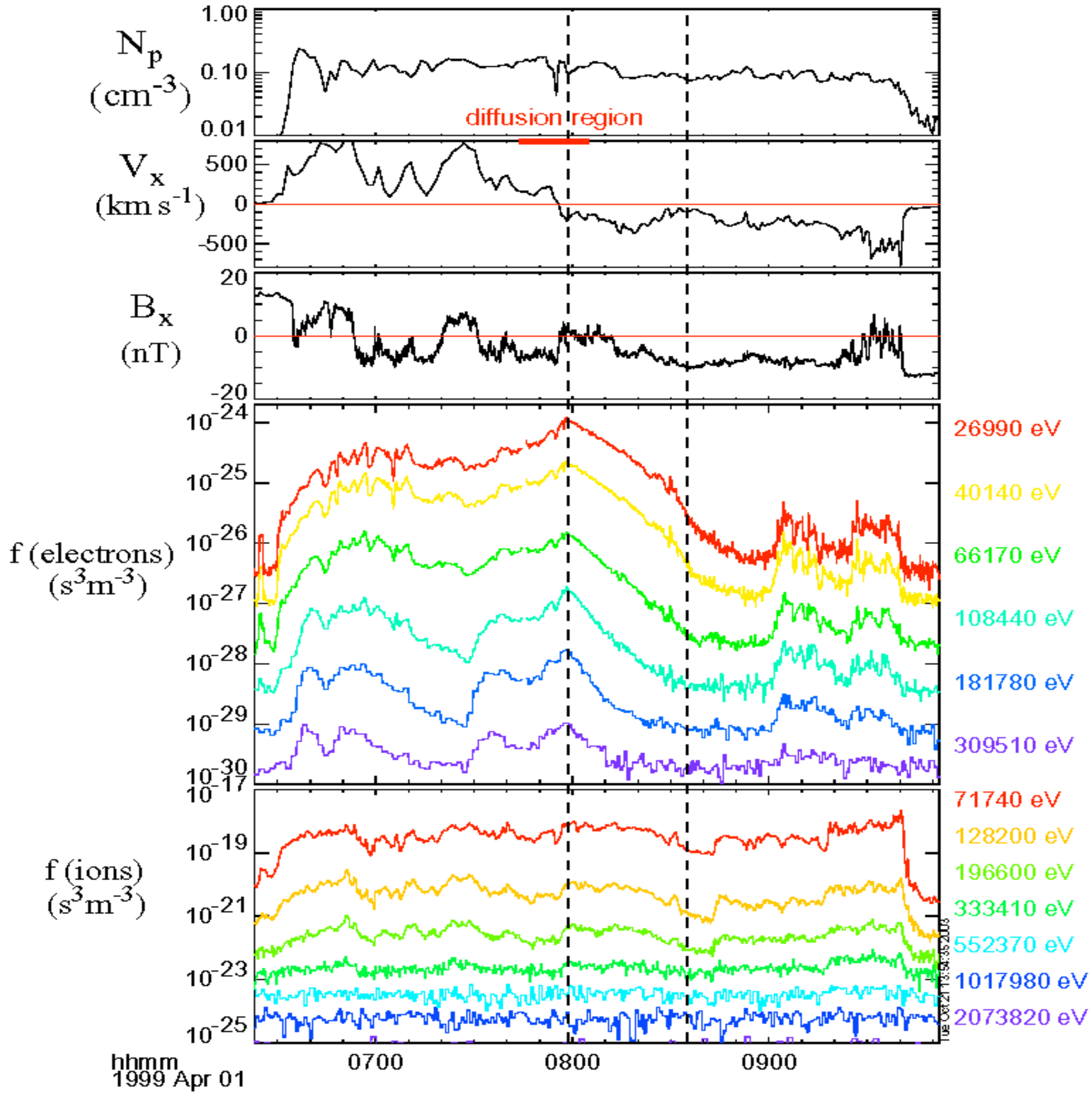


Orbit out of X-line region (160 eV electron)

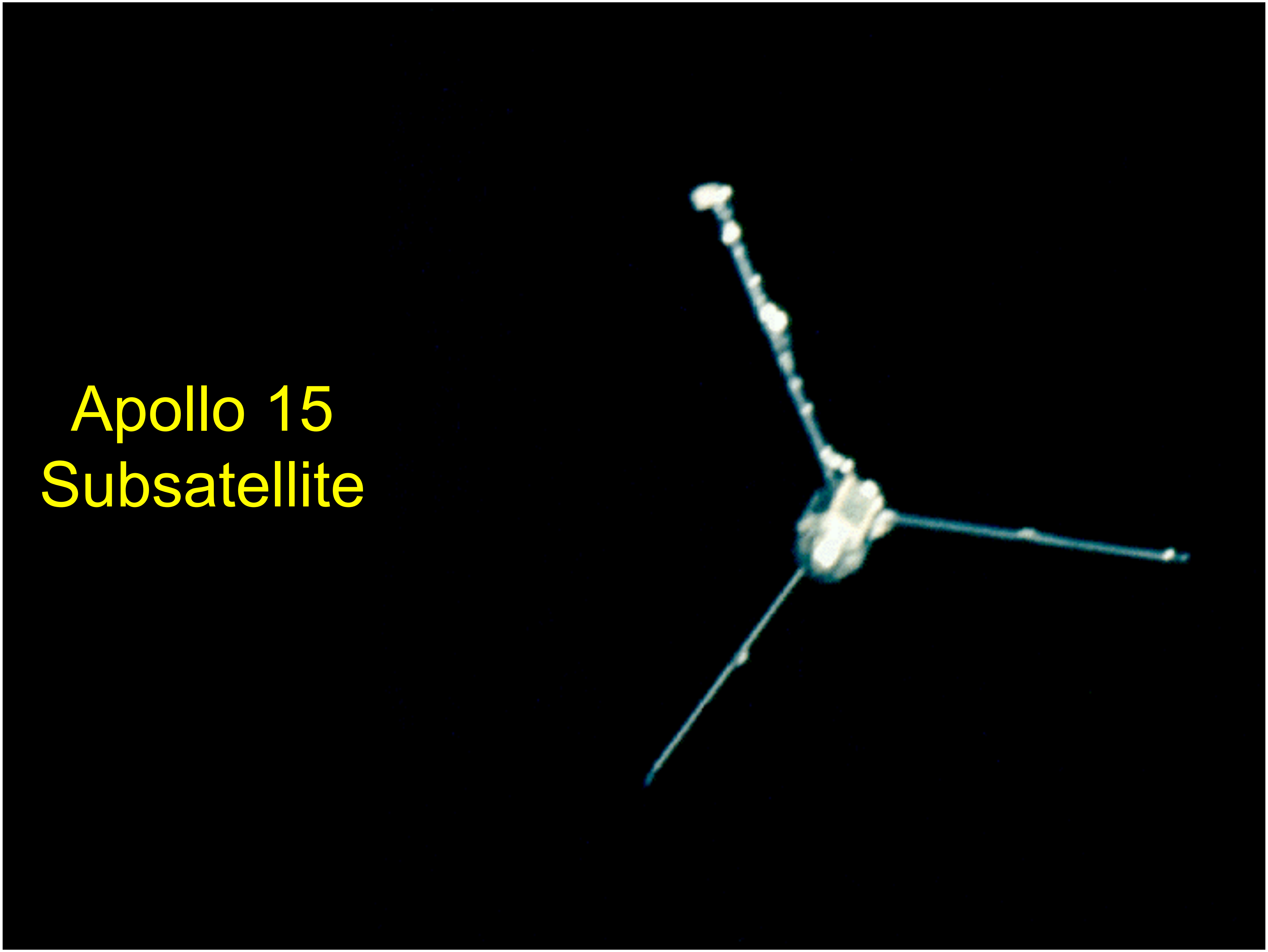


$0.5mv_\perp^2$

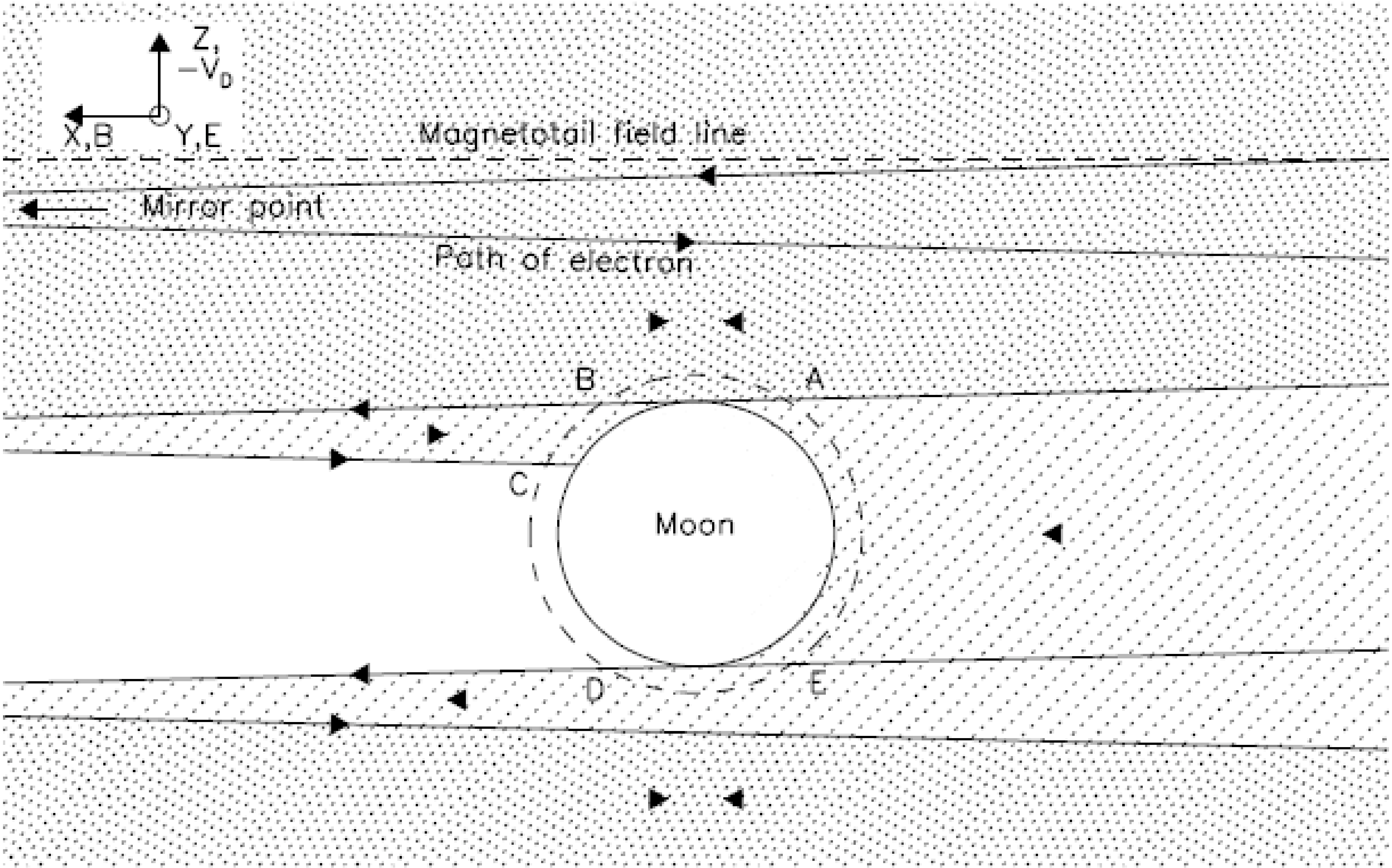
High energy particle observations

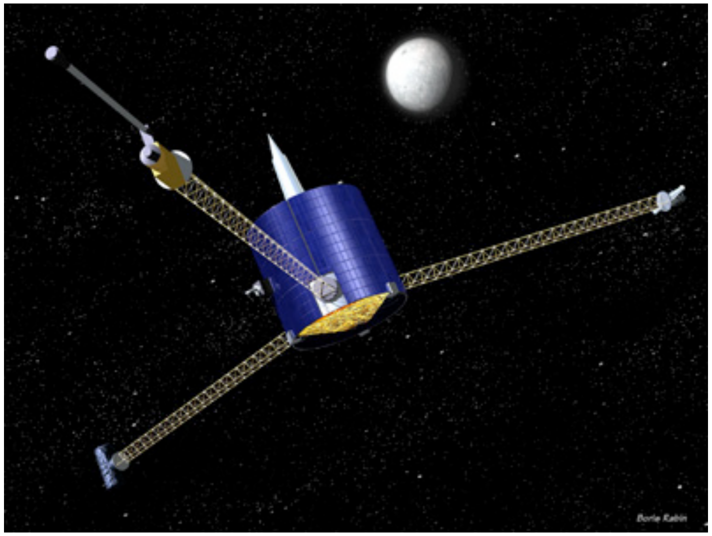


(Øieroset et al., PRL, 2002)


Apollo 15
Subsatellite

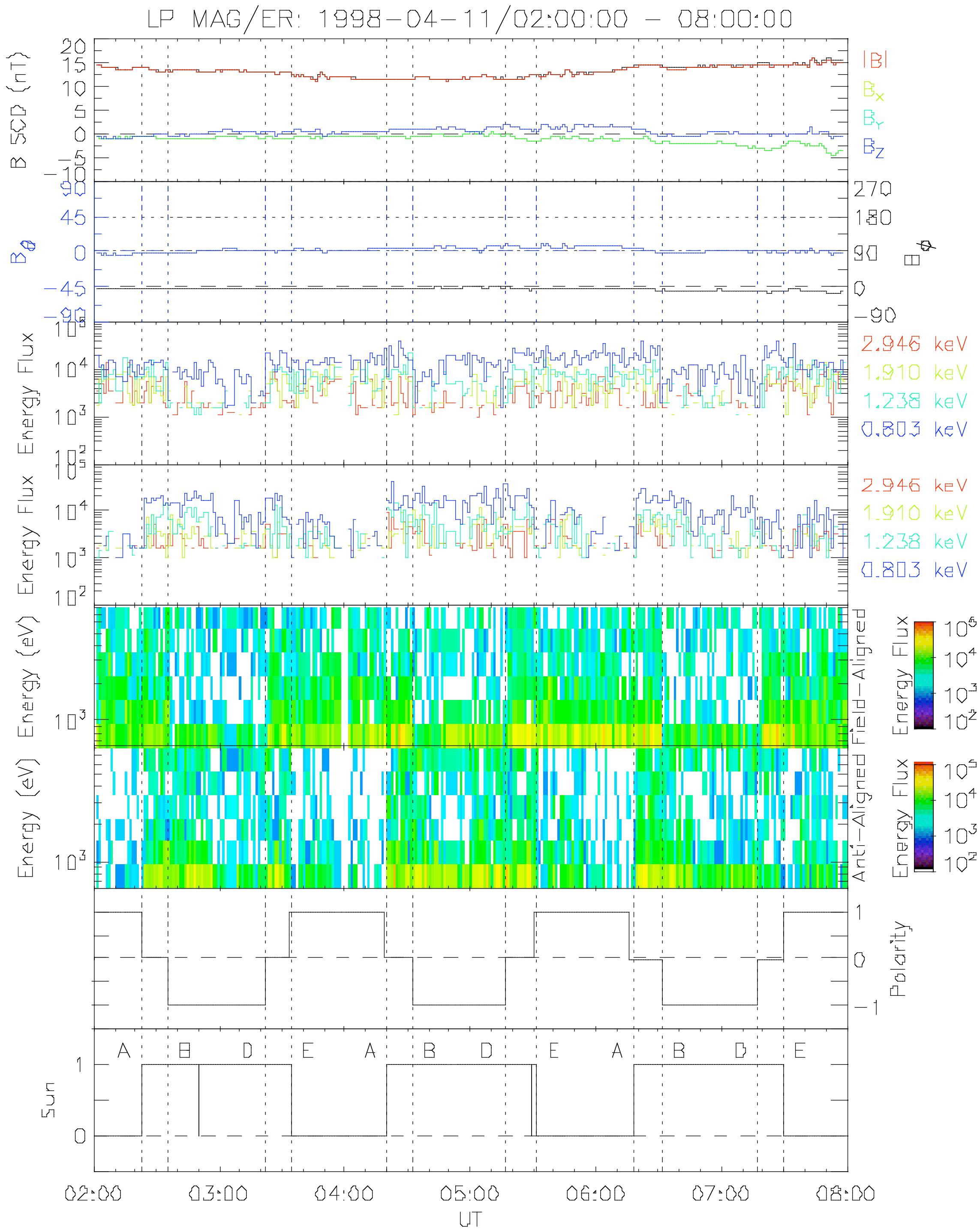
Lunar Shadowing



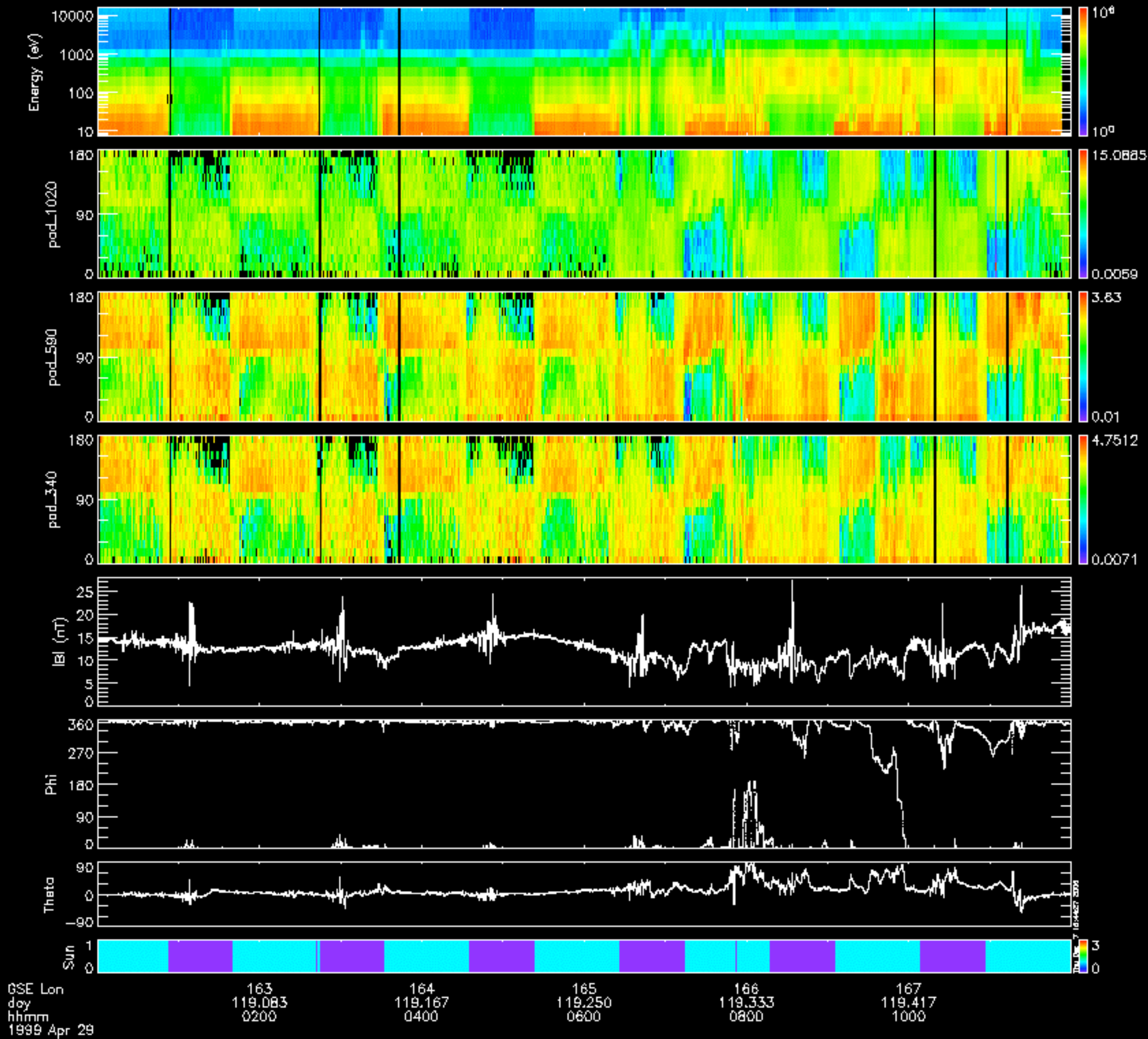


Lunar Prospector

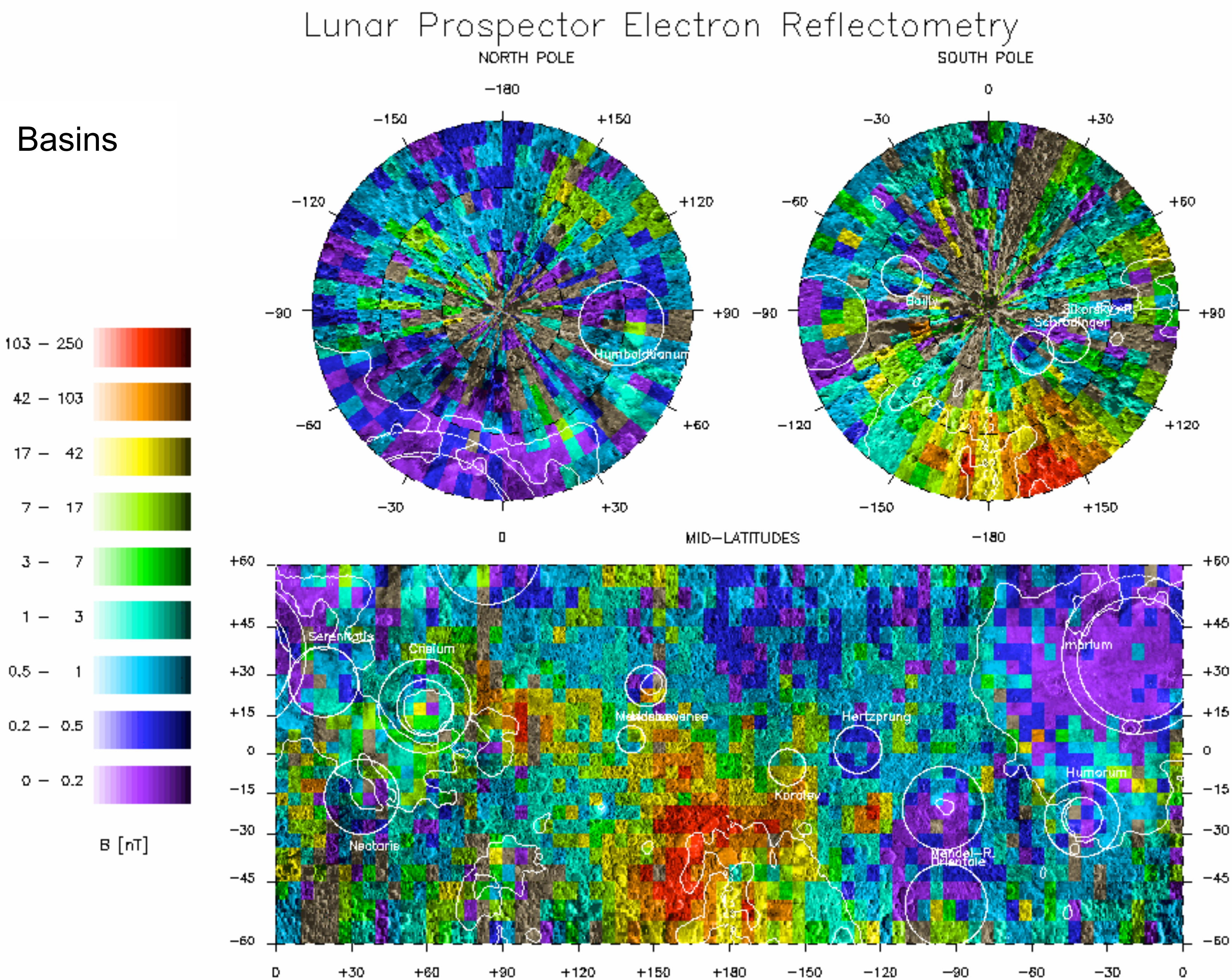
Lunar Shadows (Fillingim et al 2006)



Halekas et al, 2006

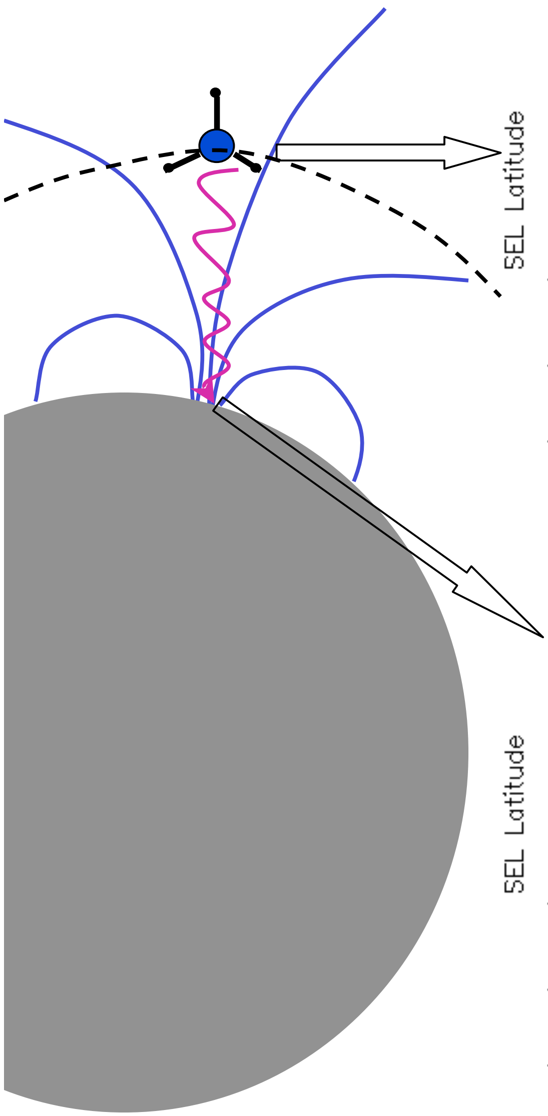


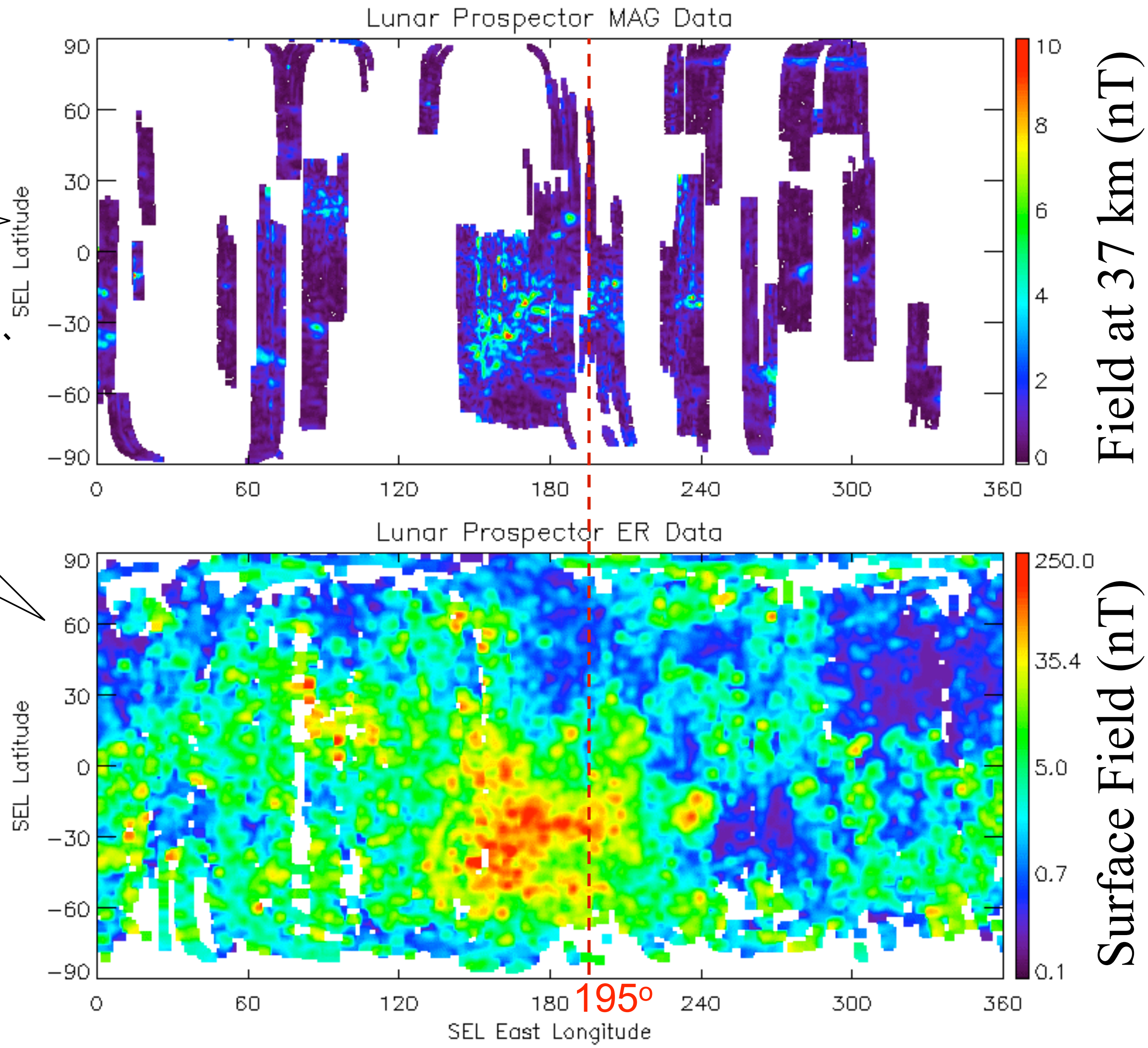
Basins



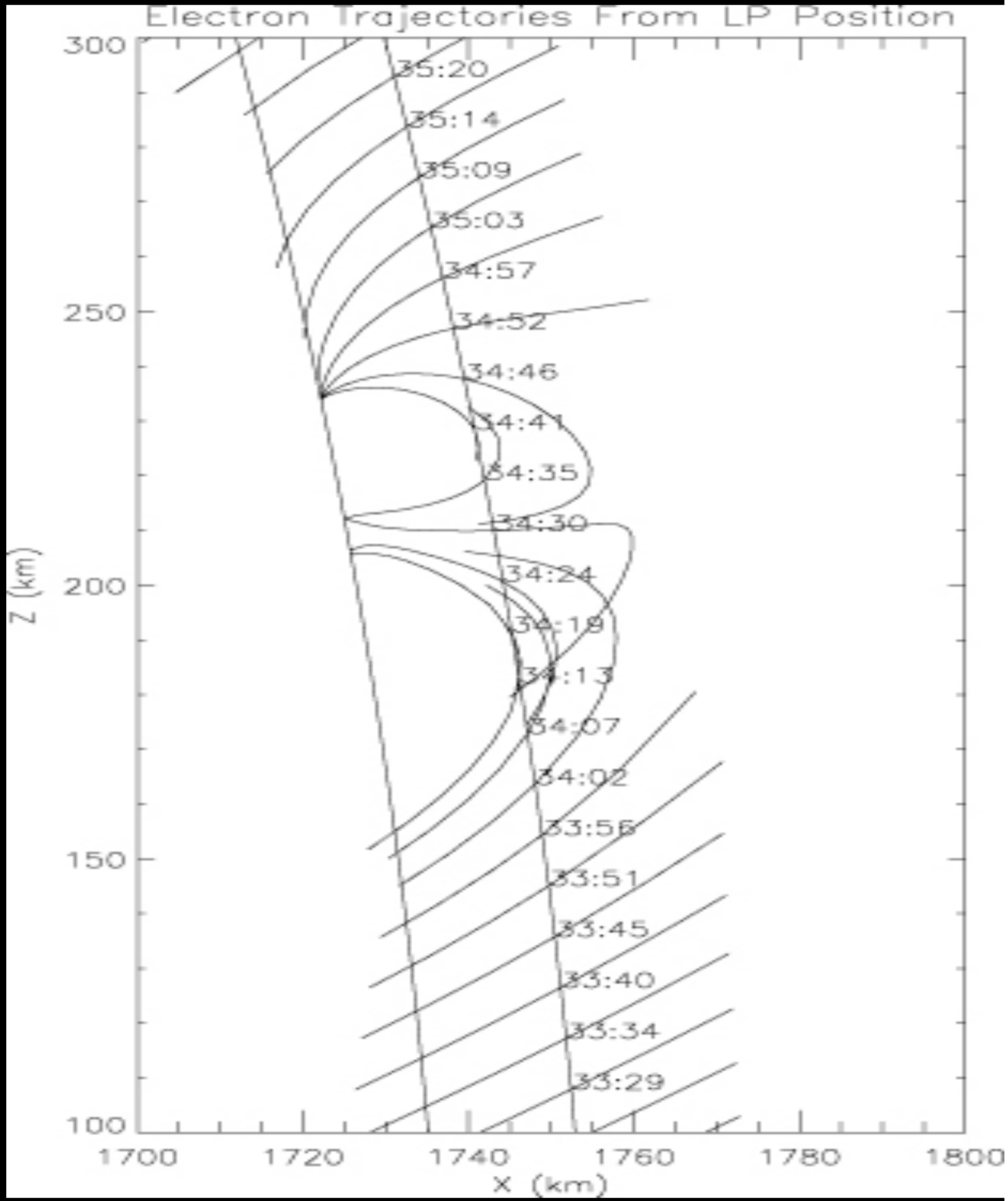
Lunar Prospector Electron Reflectometry
NORTH POLE
SOUTH POLE
MID-LATITUDES
103 – 250
42 – 103
17 – 42
7 – 17
3 – 7
1 – 3
0.5 – 1
0.2 – 0.5
0 – 0.2
B [nT]
Humboldtianum
Bailly
Sikorsky-R.
Schrodinger
Serenitatis
Crisium
Hertzsprung
Korolev
Nectaris
Humorum
Mendel-R.
Orientale

Crustal Magnetic Fields

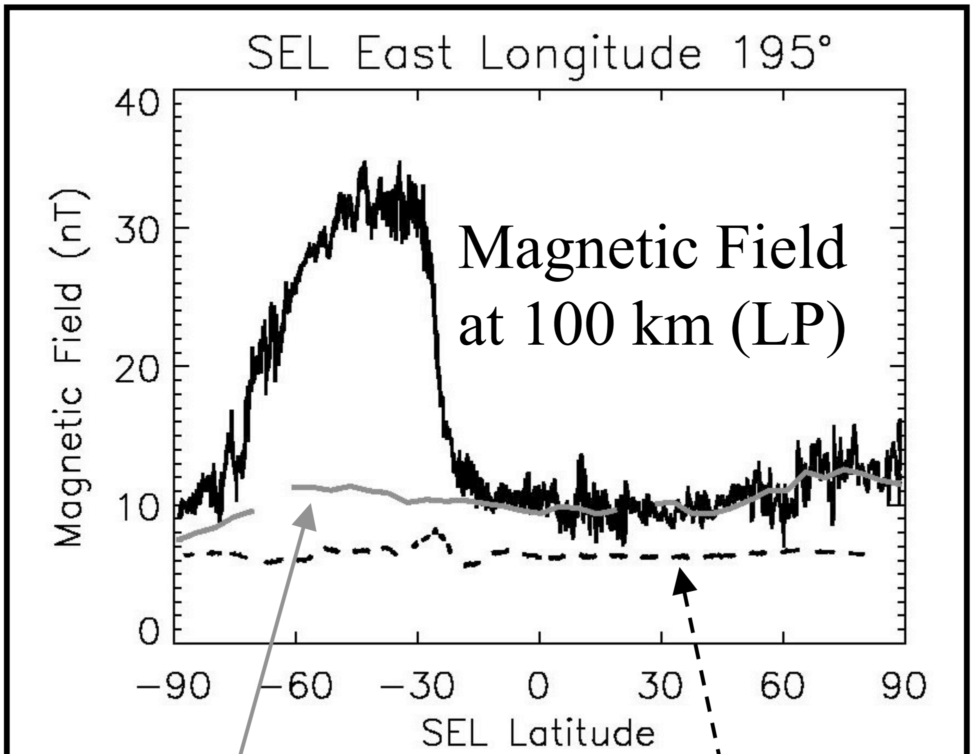




Lunar magnetic field

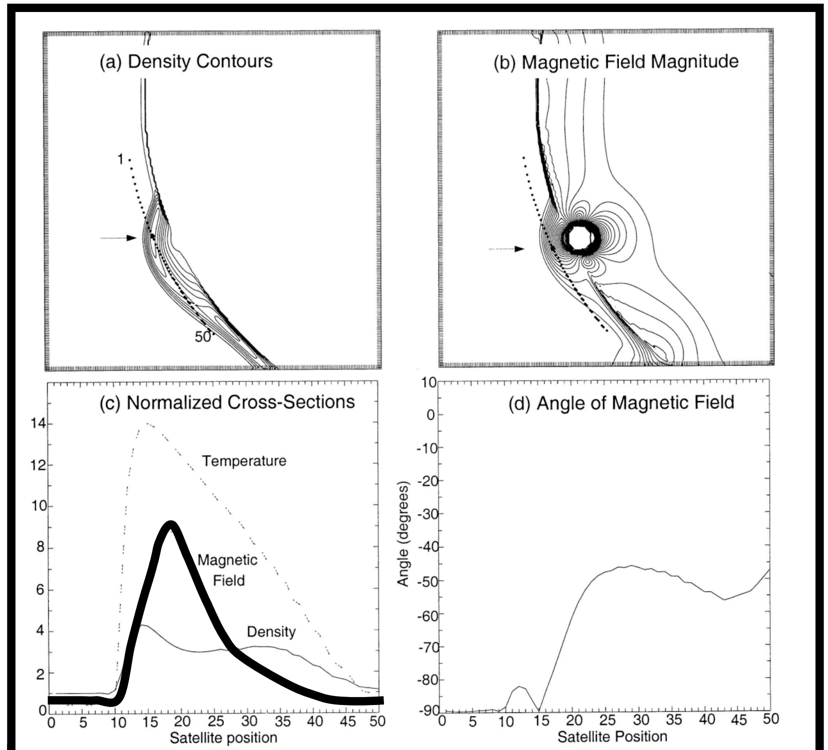


Solar Wind Interaction with Lunar Crustal Fields: Example "Limb Shock"



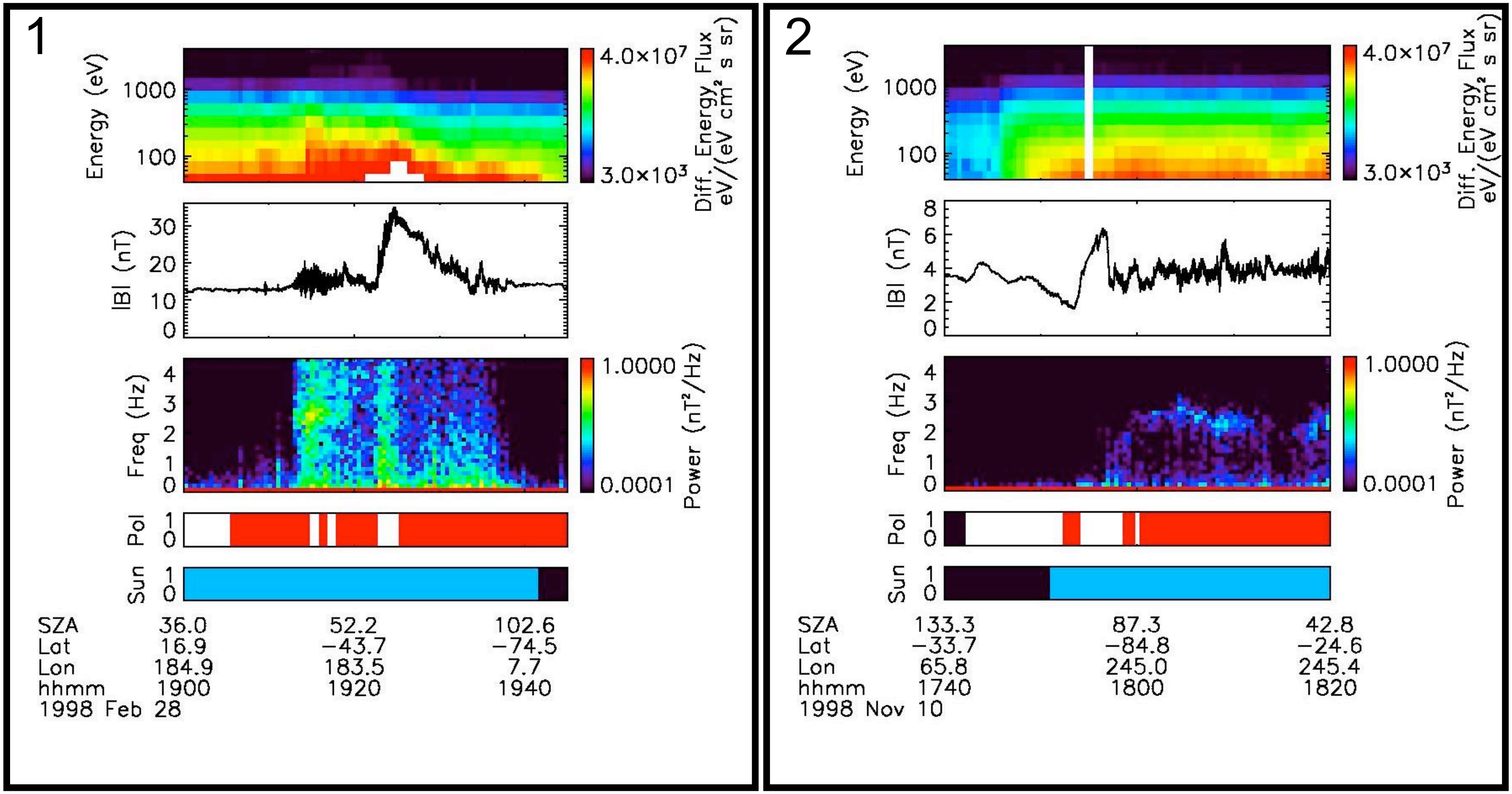
Solar Wind Field (WIND)

Unperturbed Crustal Field in Tail at 100 km (LP)



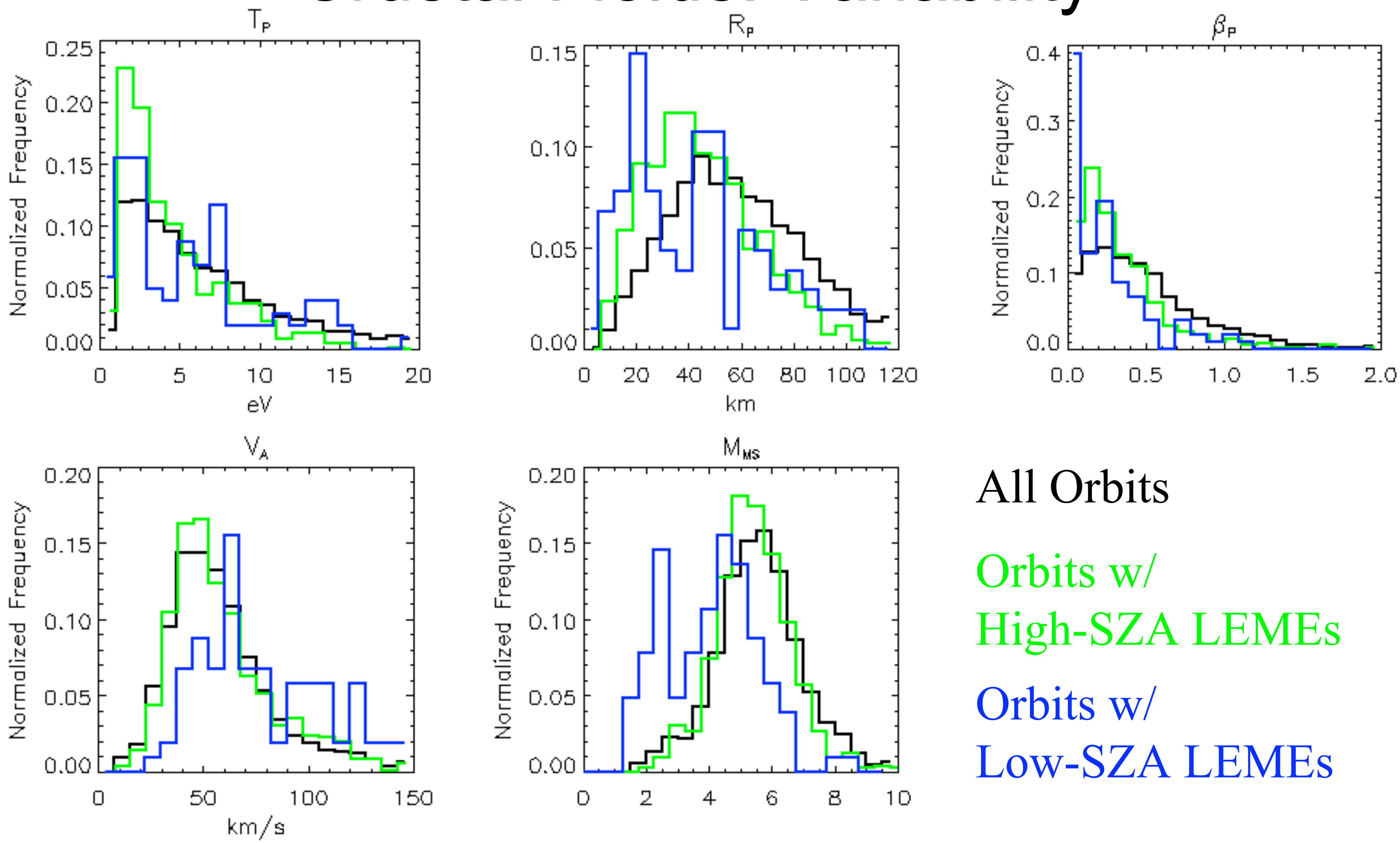
Simulation Results: Harnett & Winglee, 2000

Solar Wind Interaction with Lunar Crustal Fields: Electron Energization and Waves



- Significant electron energization and broadband turbulence observed during LEME 1.
- Little energization during LEME 2, but monochromatic circularly polarized waves.

Solar Wind Interaction with Lunar Crustal Fields: Variability

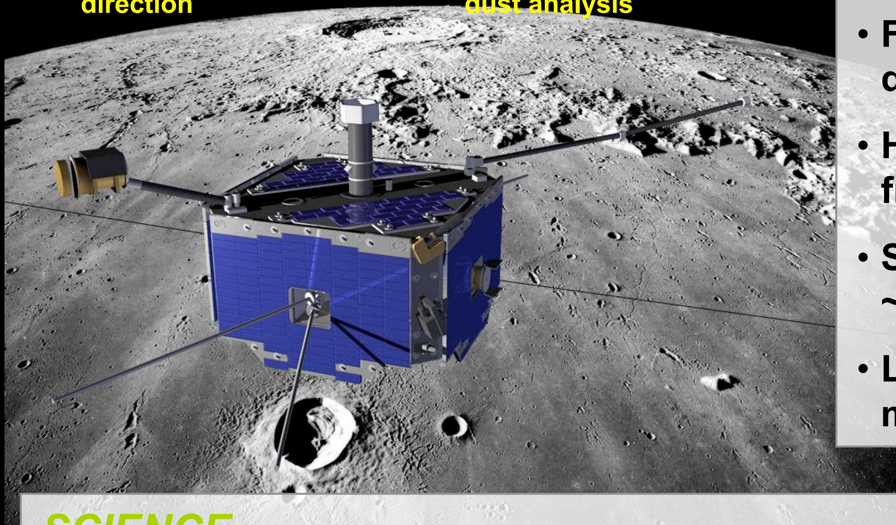


• Lower temperature, gyroradius, and beta favored. For LEMEs far from the limb, also high Alfven velocity and low Mach number (enabling larger standoff distance).

Comprehensive measurements of plasma and fields around the Moon will illuminate fundamental plasma physics phenomena in unique ways

Lunar Explorer for Elements & Hazards (LEEAH)

- Magnetic & Electric Fields
- Electron/ion spectra & direction
- Ion composition
- In-situ and remote dust analysis



CUTTING EDGE SCIENCE with PROVEN SYSTEMS

- Finalist for LRO Secondary Payload; funded Phase A development in 2006
- High-heritage instruments and spacecraft (TRL 7-9) from THEMIS, Lunar Prospector
- Science, operations, management teams in place; ~2.25 yr development schedule
- Low cost secondary (<$60M) or primary (<$100M) mission options on EELV, Minotaur, Delta-II

SCIENCE

- Lunar surface charging in response to solar and plasma environment
- Dust transport and dusty plasmas/exosphere
- Map surface composition and volatiles
- Fundamental space plasma physics and lunar-solar interactions

EXPLORATION

- Identify resources, including H_2O
- Quantify dust electrification and motion
- Correlate with environmental drivers for prediction and mitigation