Planetary Pickup Ions

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Purpose

1. Review the MESSENGER flyby observations
2. Identify scientific questions that must be elucidated by ion transport modeling
3. Estimate the contribution of exospheric ions to the magnetospheric structure and dynamics.

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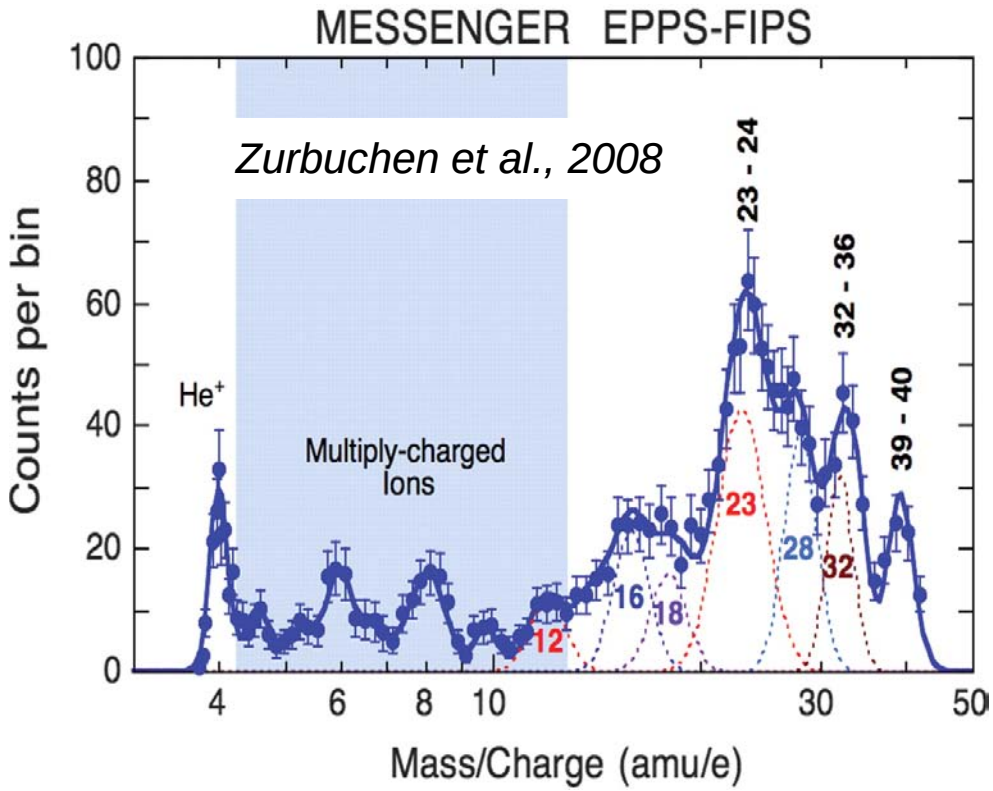
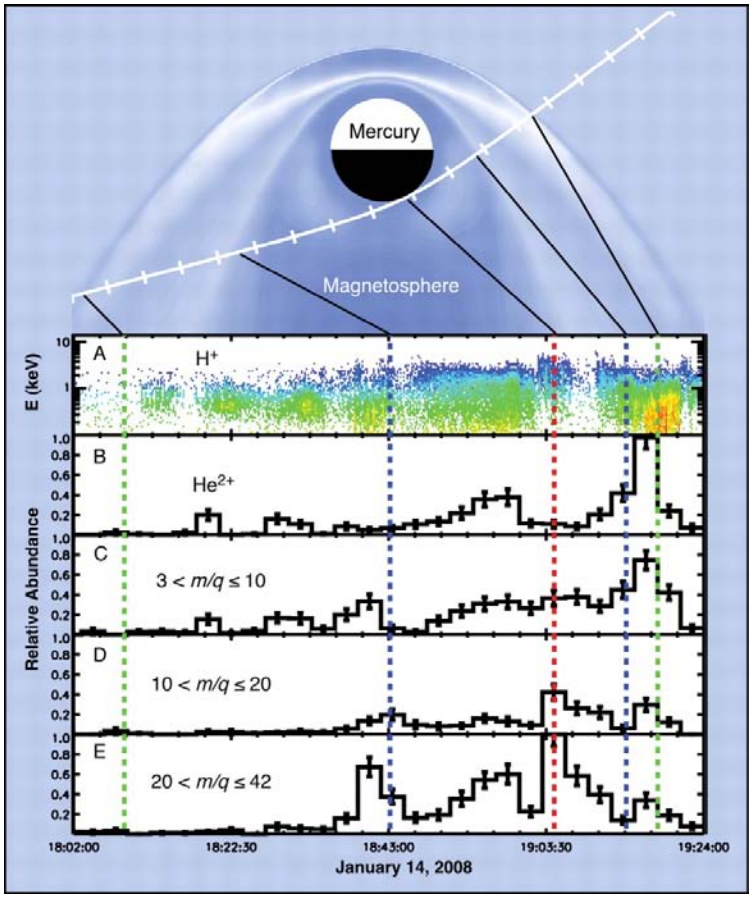
Planetary Ion Composition





Q1: Do these measurements portray relative abundance?

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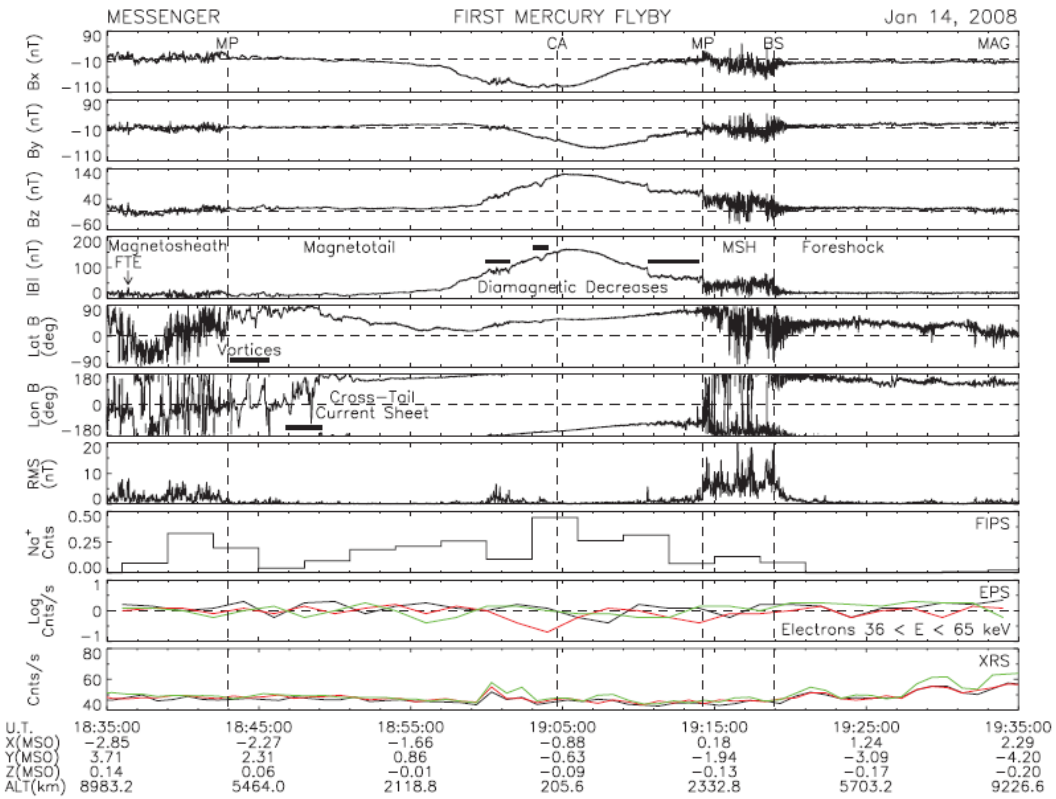
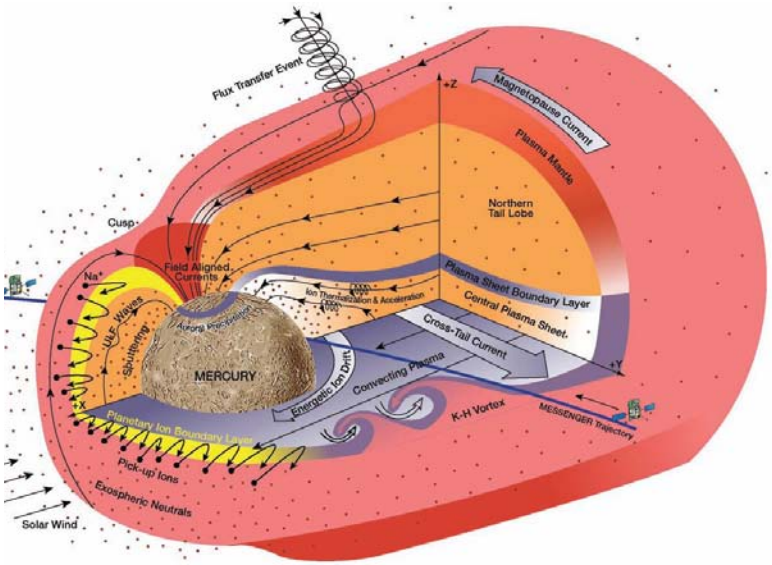
A role for pickup ions?

- *(Zurbuchen et al., 2008; Slavin et al., 2008)*





Q2: Do ions observed above the magnetopause originate from energetic neutrals?

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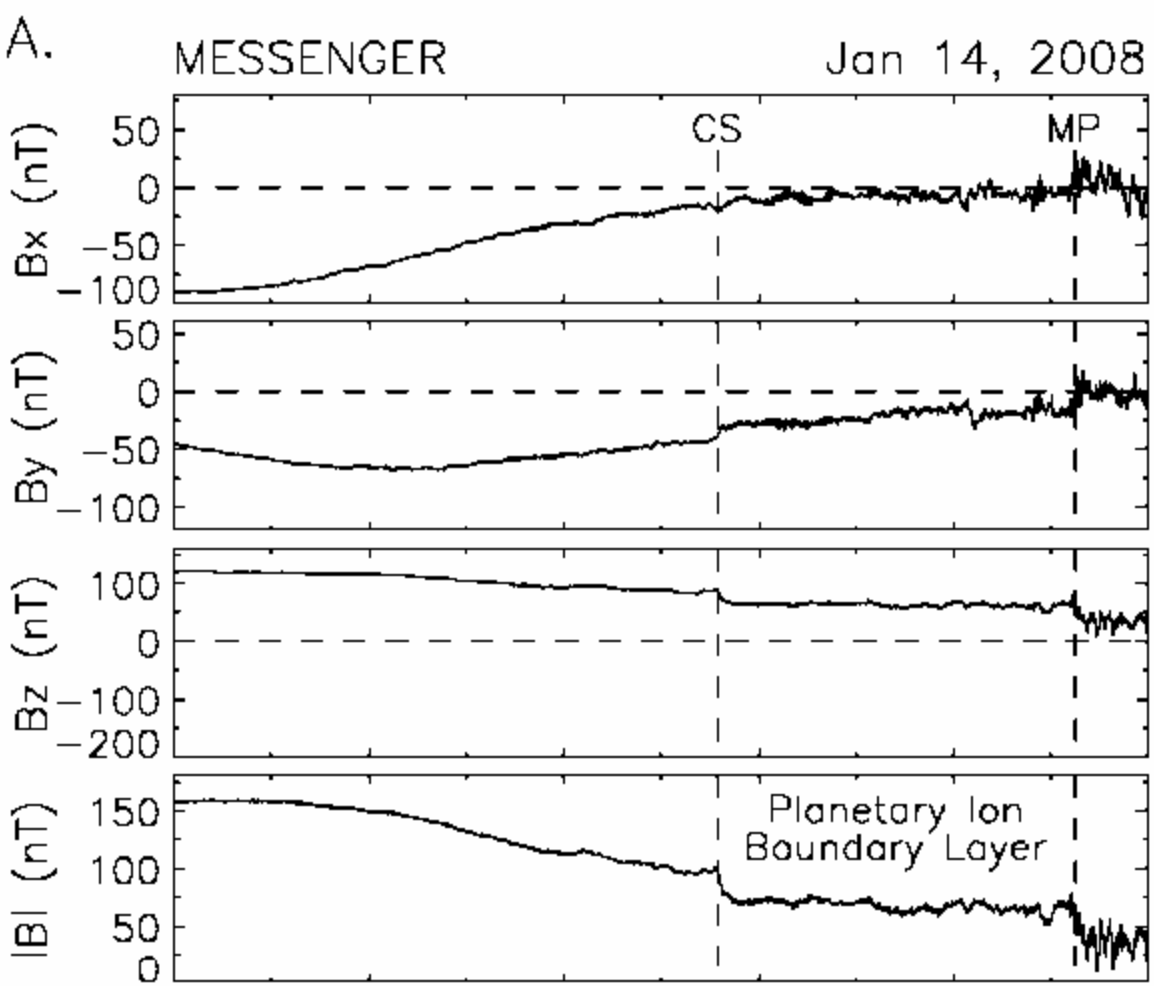
"Double" Magnetopause



Mercury's magnetosphere is bounded by two current layers

Q3: Are diamagnetic depressions caused by the presence of Heavy Planetary Ions?

Slavin et al., 2009

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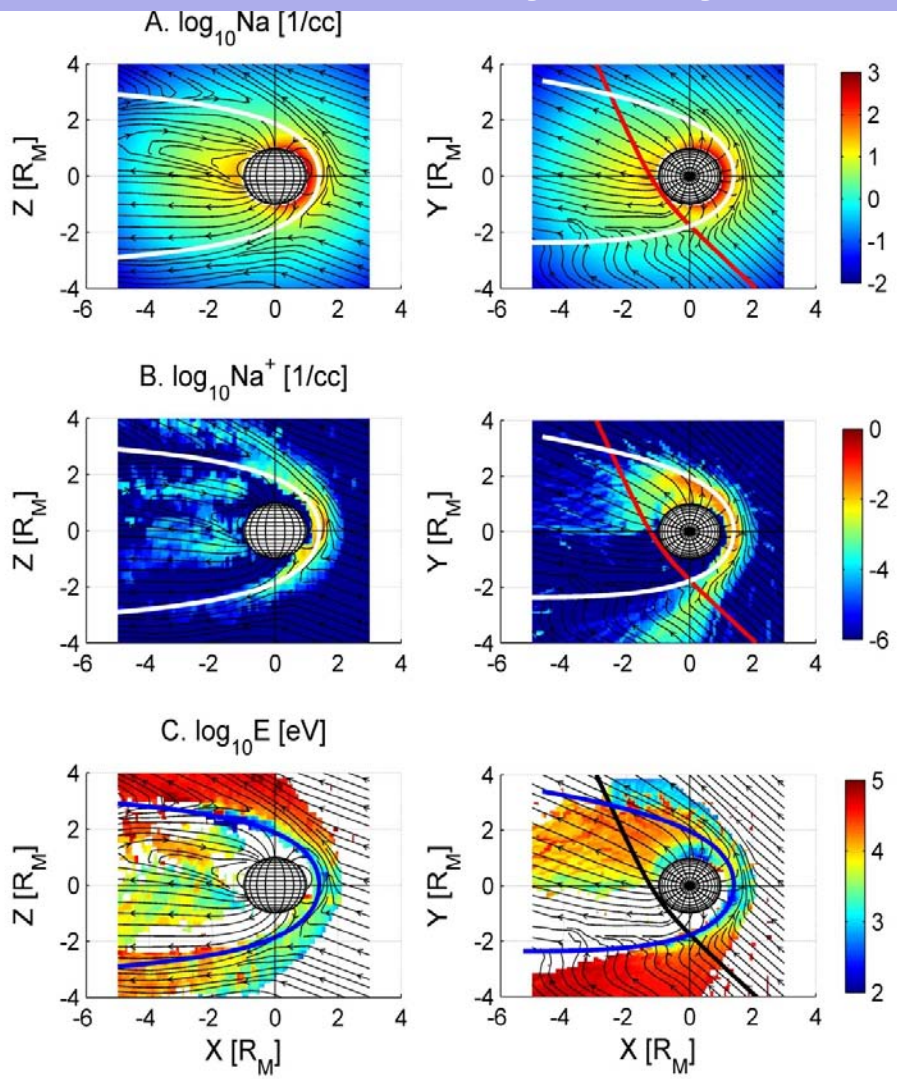
Single Particle Pickup Ion Tracings

Hot Planetary Ions may penetrate deeply into this small magnetosphere – Dawn-Dusk Asymmetry controlled by IMF direction.



- <u>Exosphere Model:</u>
  - Mura et al. 2007
- <u>Magnetosphere Model:</u>
  - MHD simulation by Benna et al. [2010]
- <u>Single Particle tracer for Na^+ in MHD fields</u>

(Sarantos et al., GRL, 2009)

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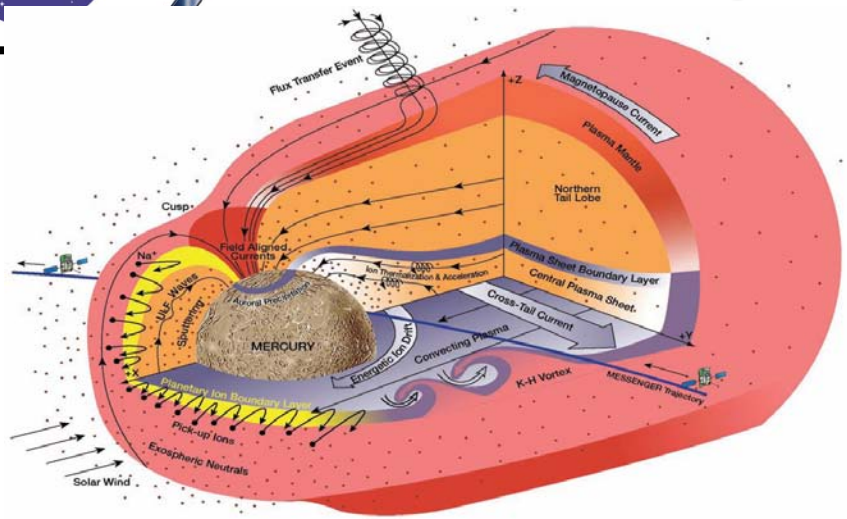
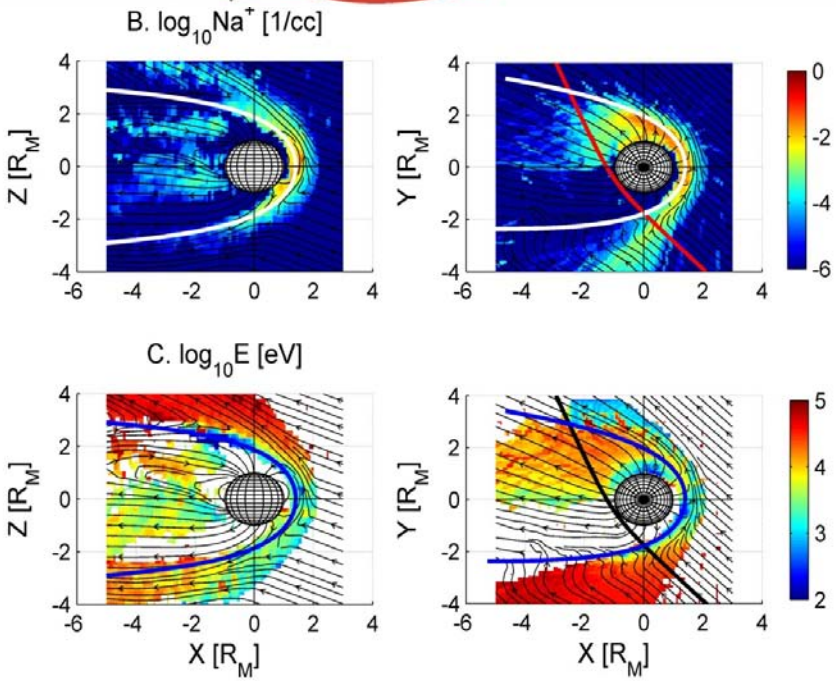
Pickup Ion Parameters





- Overlapping of the magnetosphere with the exosphere consistent with sputtering & extended PSD
- 10-100 keV particles along MESSENGER's trajectory
- i.e., within FIPS energy range, plus favorable pointing (duskside)
- Brief energization timeline (≤ 1 min)

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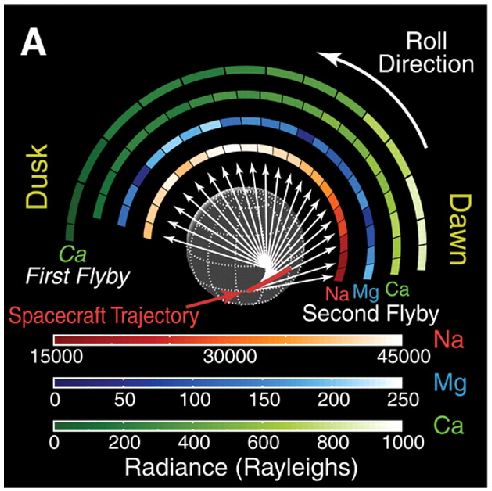
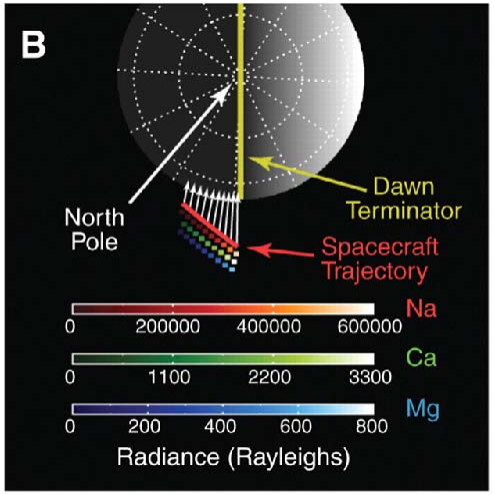
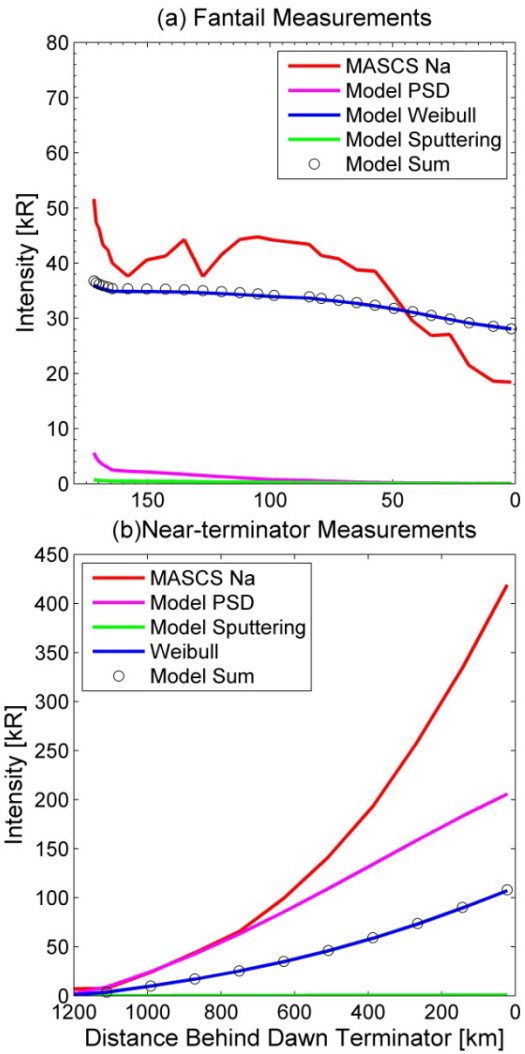
Sodium exosphere

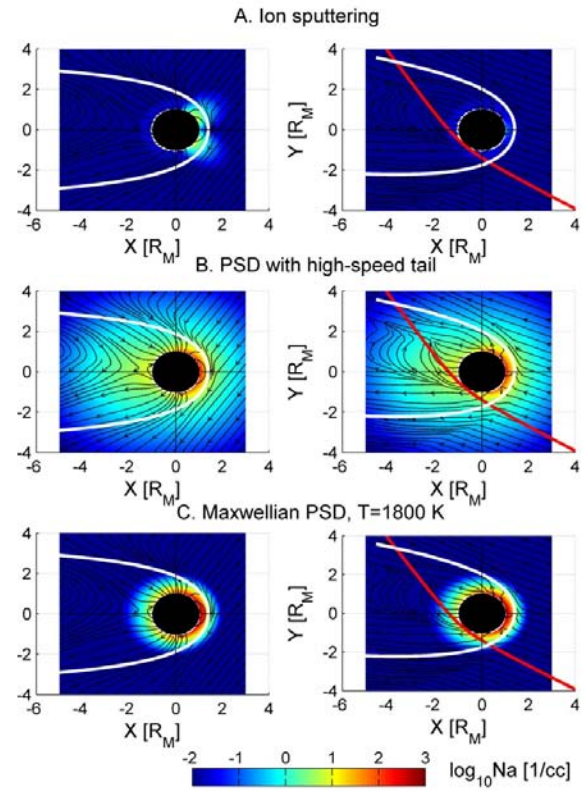






McClintock et al. [2009]

Model: Mura et al. [2007]



Global distribution consistent with both cold and hot components

(Burger et al., 2010; Mouawad et al., 2010)

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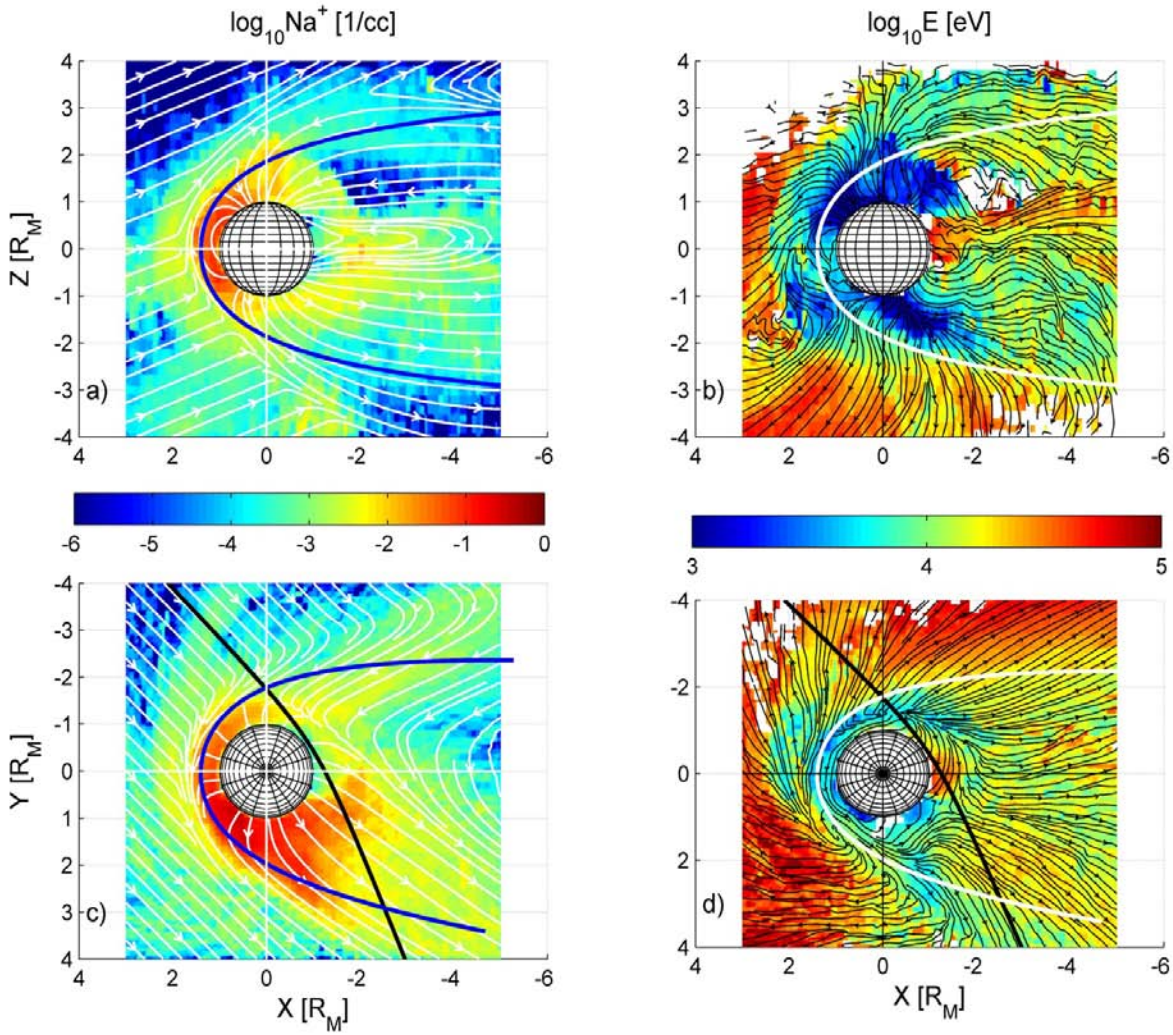
Sodium ions: Northward IMF (M1)

IMF (Bx, By, Bz)= (-12, 12, 5) nT



WHITE: **magnetic field lines**

BLACK: **streamlines of heavy ion motion**

- **Sodium ion "belt"/ "ring"** (also: Yagi et al, 2010; Paral et al, 2010)
- **"Pickup ions" might be escaping through magnetopause even under Northward IMF?**

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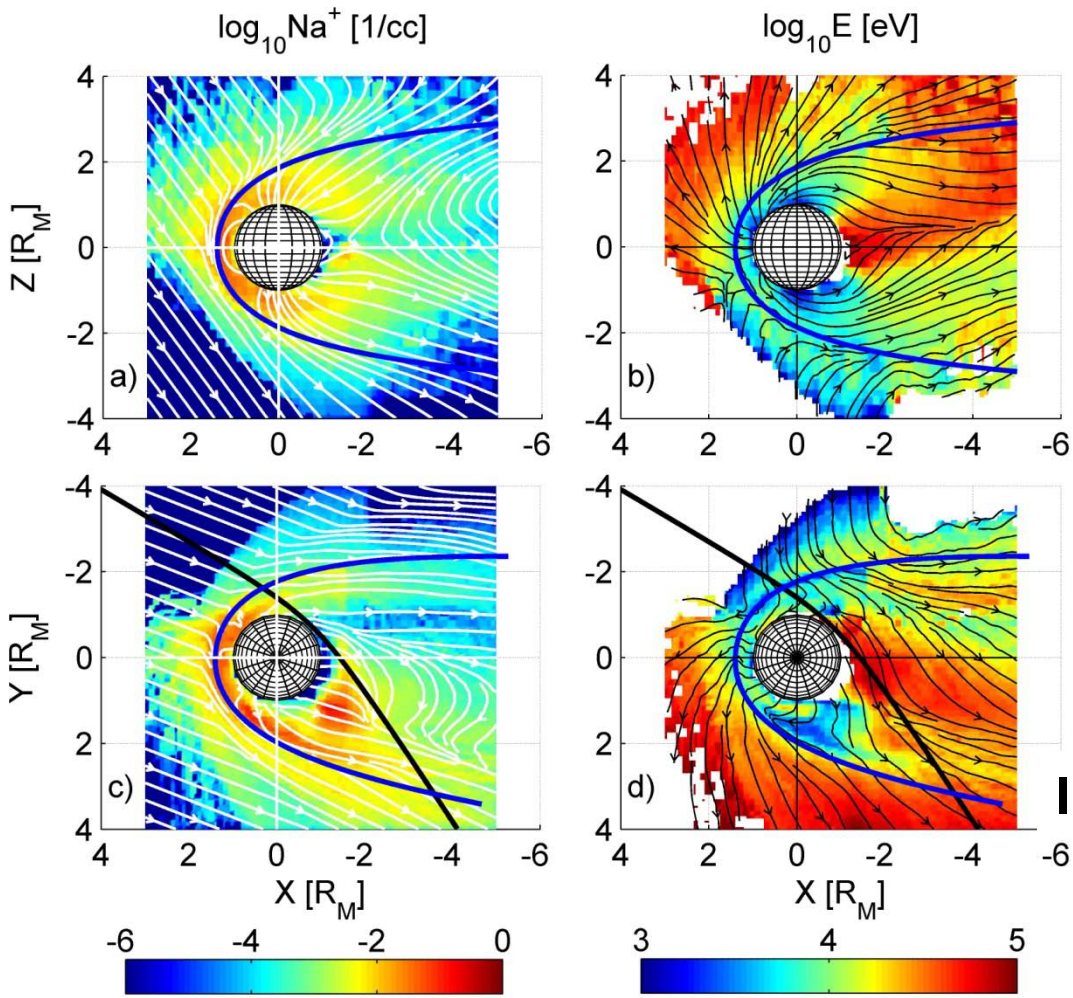
Sodium ions: Southward IMF (M2)



- Penetration of pickup ions into dawn magnetopause due to finite Larmor radius effects
- <u>But the primary effect under southward IMF appears to be the formation of a porous (very "open") magnetopause</u>

IMF (Bx, By, Bz)= (-13, 10, -9) nT

Sodium exosphere similar to that from M1; Main difference: <u>Southward IMF</u>

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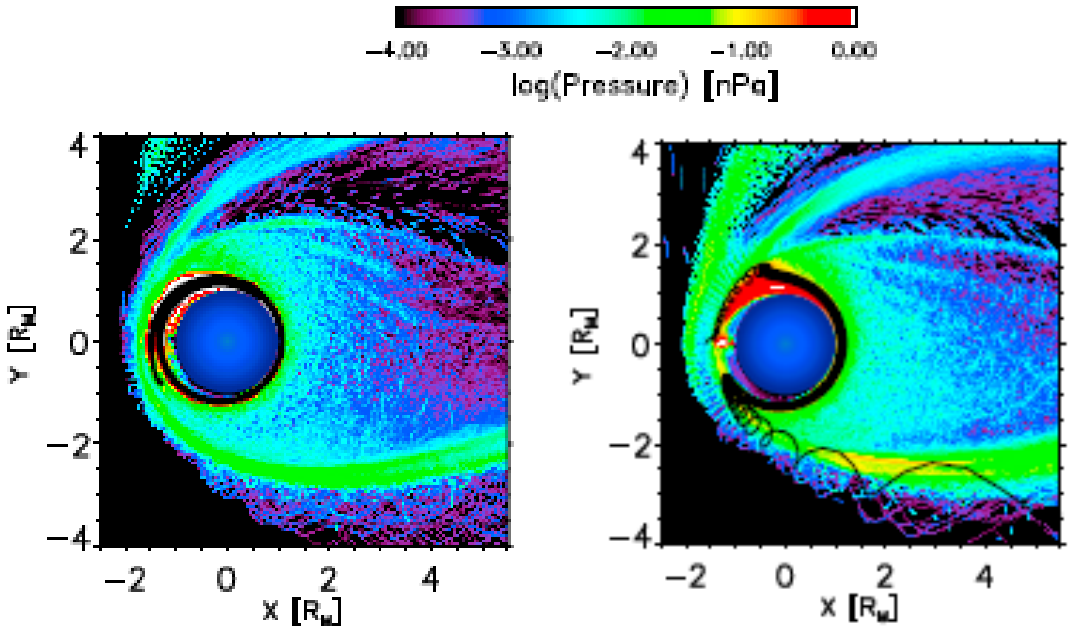
Sodium “ring”: a different view



Ring is due to westward motion, and controlled by solar wind pressure for the same IMF (Yagi et al, 2010)

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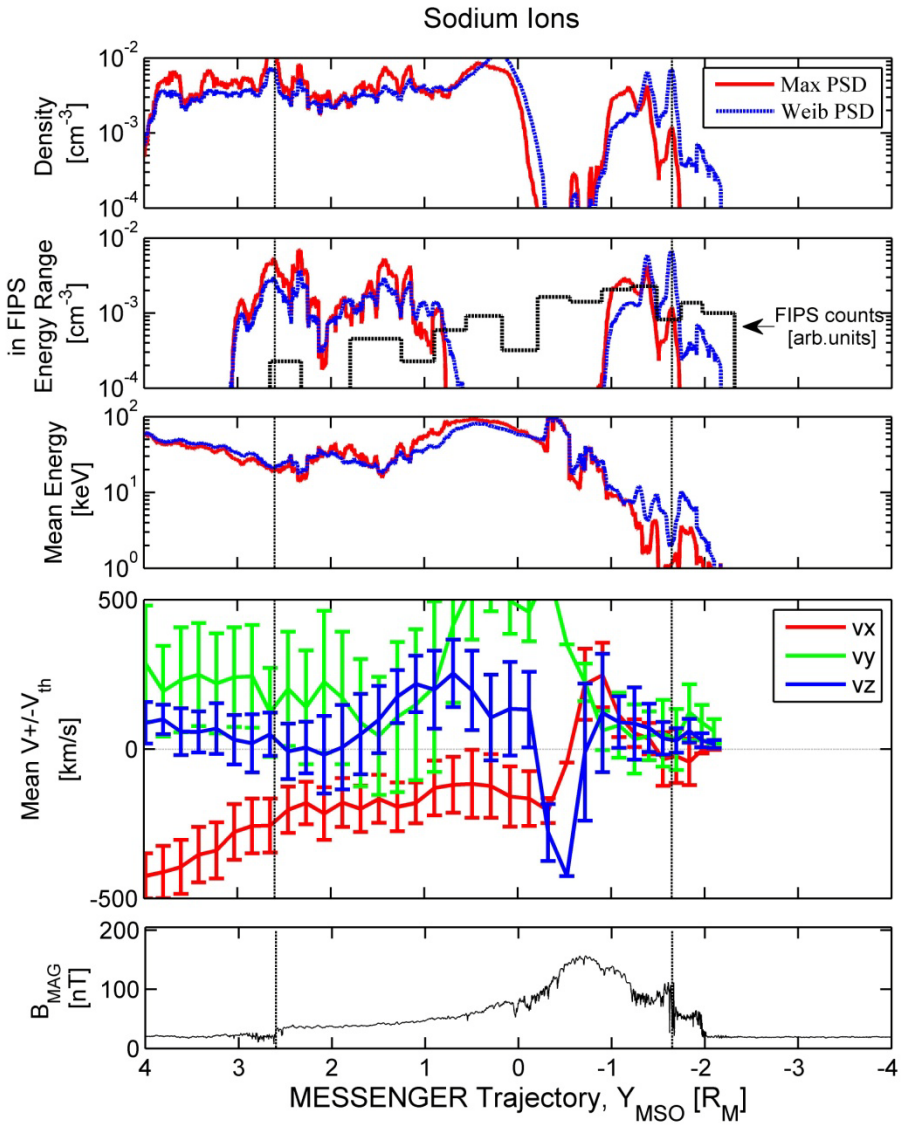
Na^+ along MESSENGER's Trajectory (M2)



- The FIPS instrument output is influenced by FOV effects where the heavy ions are beaming
- Near the surface (and inside the boundary layer), Na^+ distribution function is almost isotropic
- **Density, temperature appear to correlate to diamagnetic depressions**

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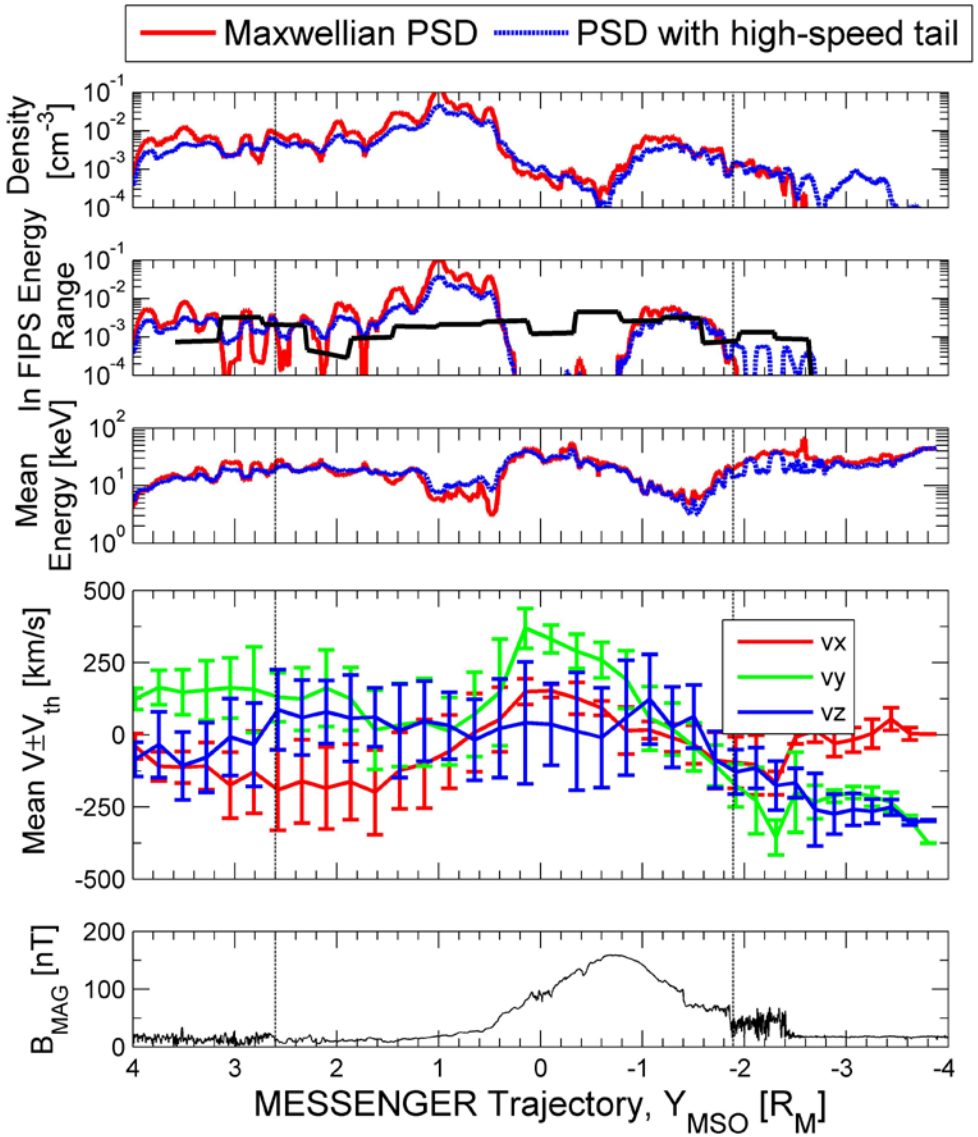
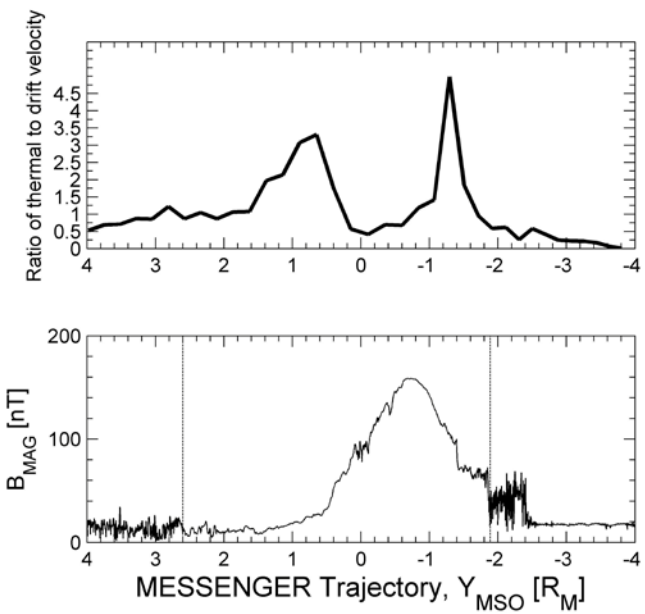
Na^+ along MESSENGER's Trajectory (M1)



- No good agreement to "inner" boundary layer (?)
- Cannot distinguish between hot and cold neutral sodium components



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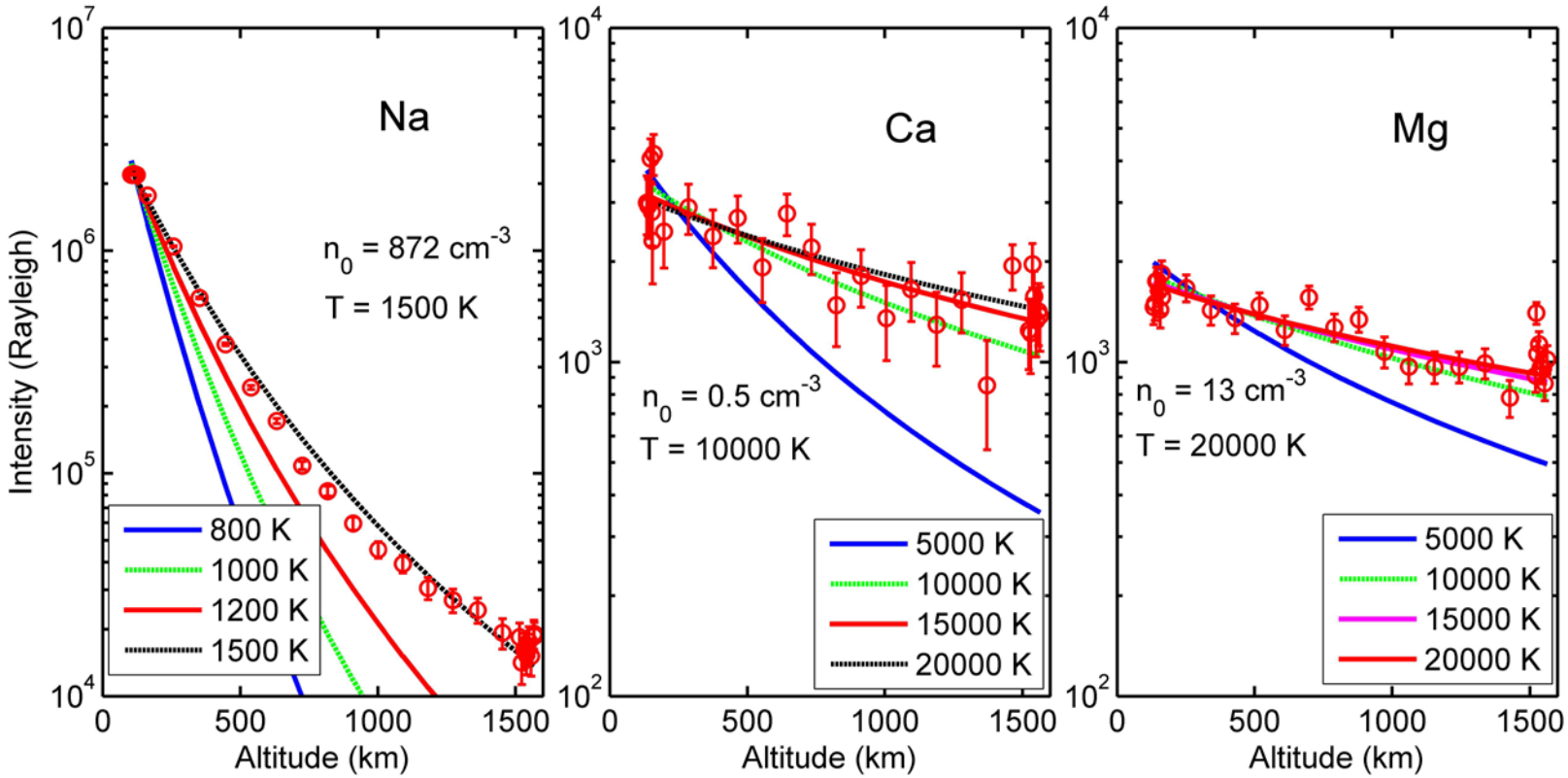
Fits to MESSENGER M3 UV Data

Chamberlain models over the south pole



Observations from Vervack et al., 2010

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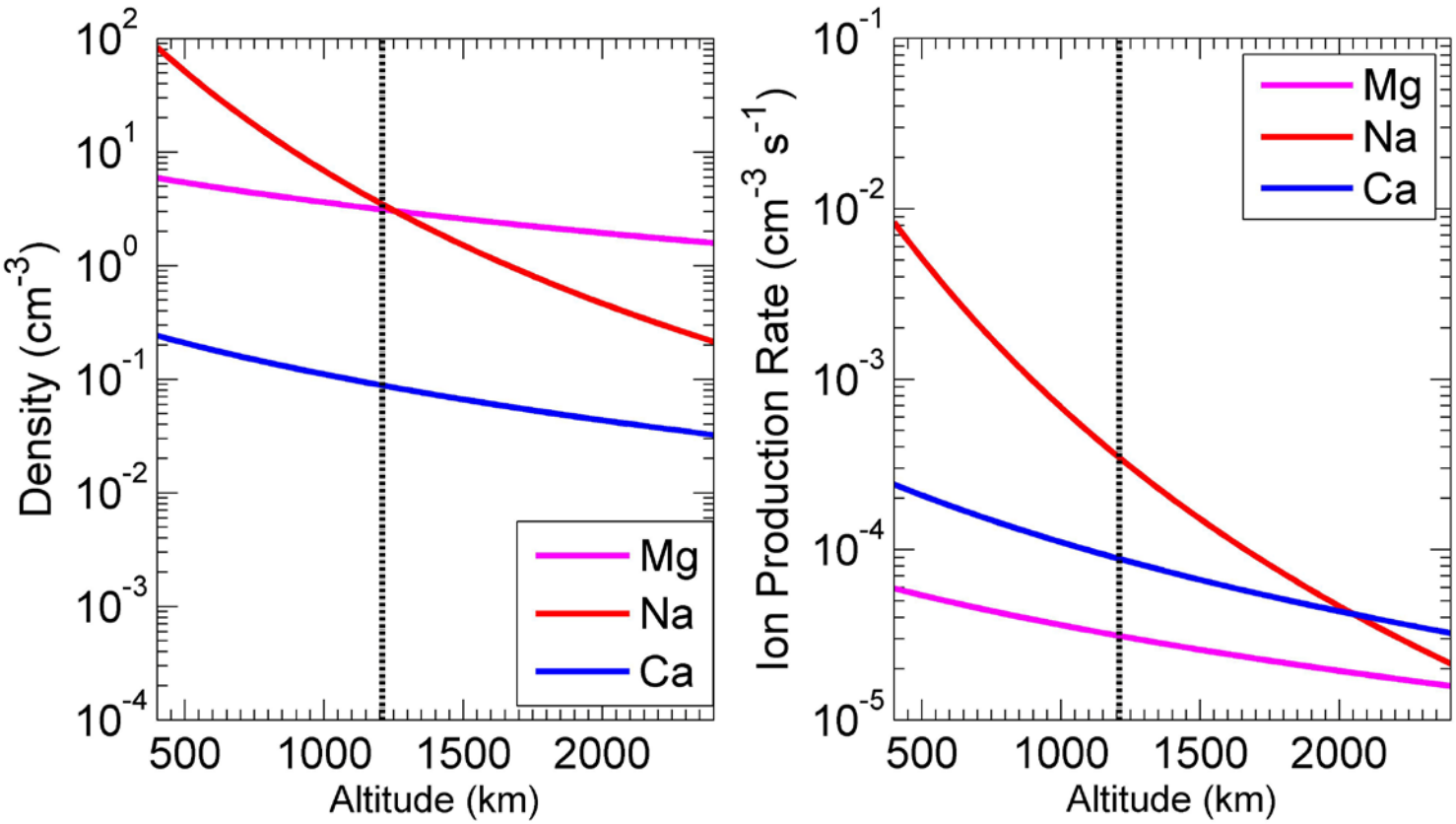
Ions beyond the magnetopause



Ca^{+} should be at least as important in the flanks

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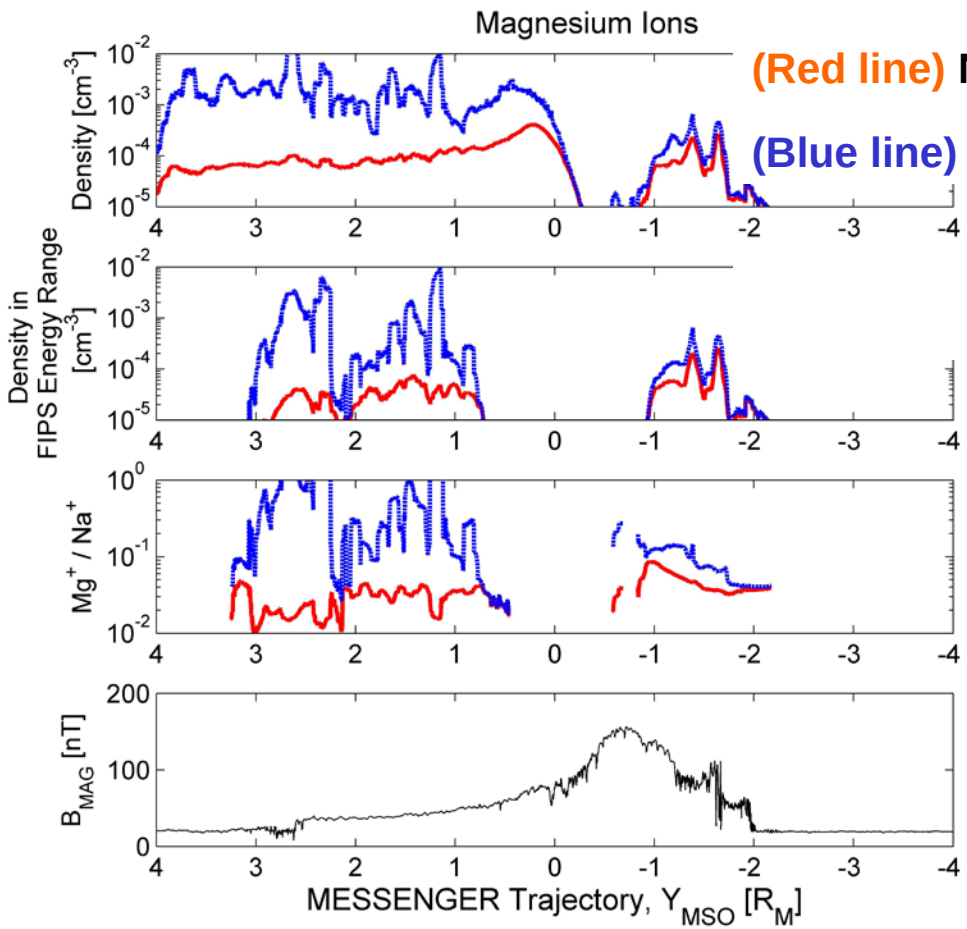
Inferences for Mg+



(Red line) No "cold" source

(Blue line) With "cold" source

Mg+/Na+ < 0.1 unless Mg is produced by a large dayside source

Implications for the magnetosphere

Interpretation of exosphere, plasma, and magnetometer measurements requires improved planetary ion models

- Penetration of hot pickup ions into the dusk (dawn) magnetosphere for Northward (Southward) IMF
- Unclear whether pickup ions originate strictly above the magnetopause even under northward IMF conditions
- Porous magnetopause, formation of near-Mercury X-line, reduces ion density in magnetotail during southward IMF
- A model-predicted, high-pressure sodium ion region near the planet appears consistent with measurements but physics is unclear