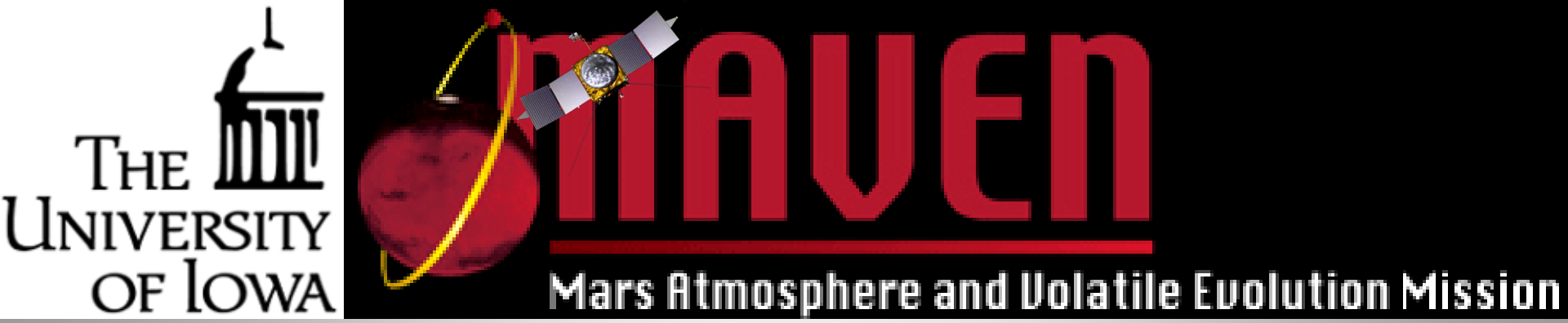

Momentum Transfer and Boundary Layer Structure at Mars

J. S. Halekas*, D.A. Brain, Y. Ma, J.G. Luhmann,
G.A. DiBraccio, S. Ruhunusiri, J.P. McFadden, D.L. Mitchell

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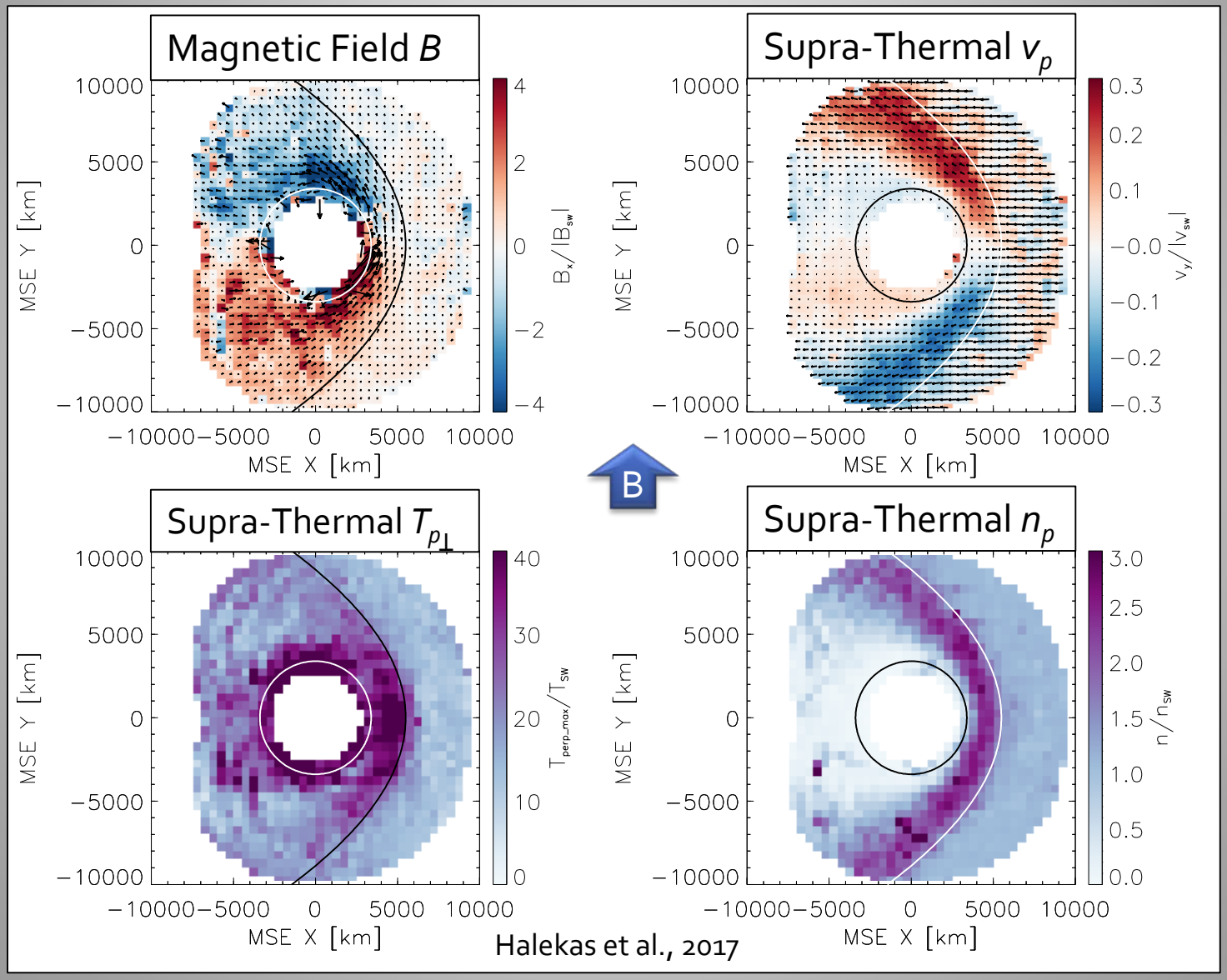
Mars-Solar Wind Interaction



Halekas et al., 2017

Multi-Fluid Force Model

Momentum Coupling (Pickup, Mass-Loading)

Magnetic Pressure/ Tension

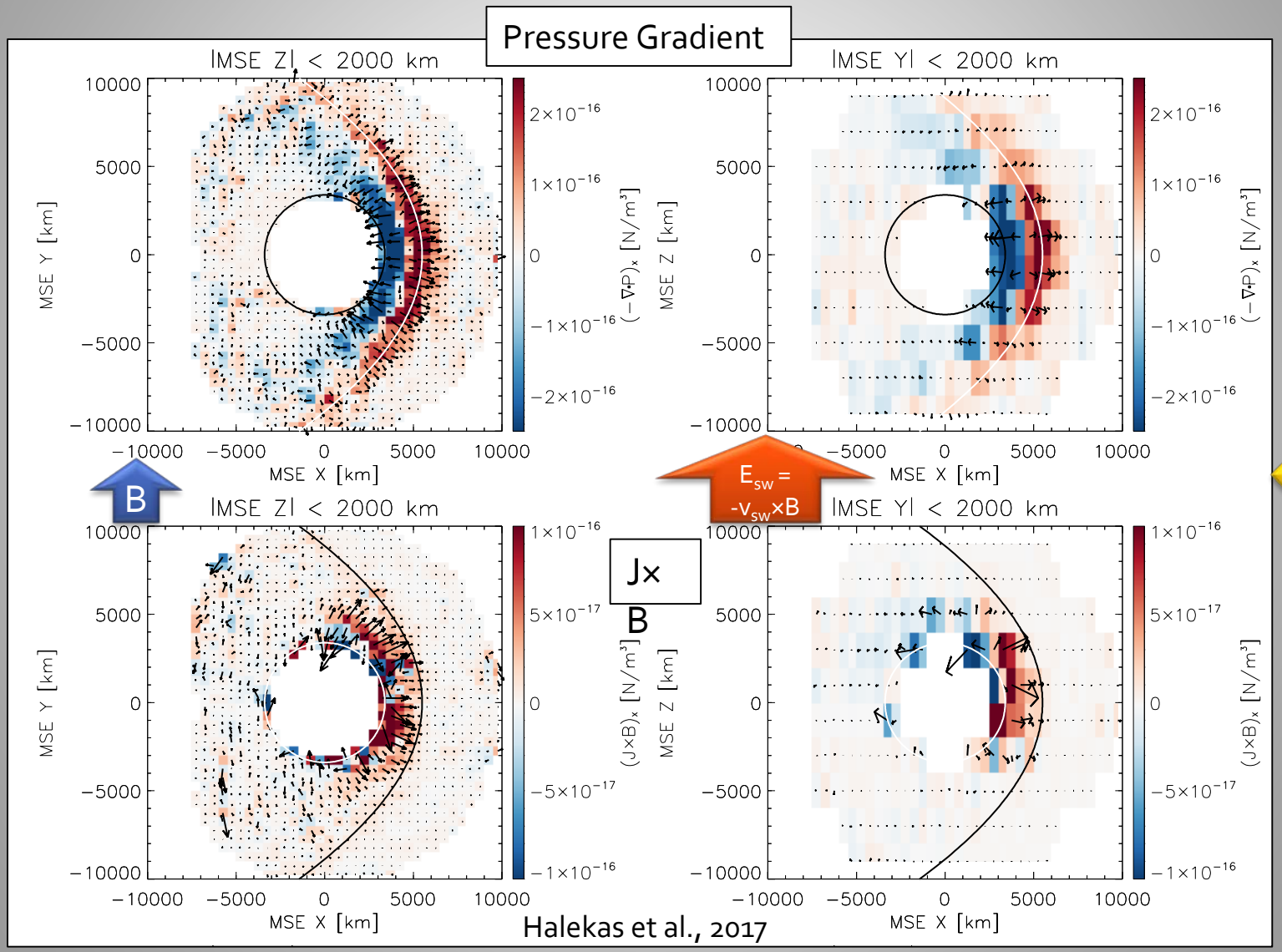
Particle Pressure

$$\overrightarrow{F_p} = m_p n_p \left(\frac{\partial}{\partial t} + \overrightarrow{v_p} \cdot \nabla \right) \overrightarrow{v_p} = \frac{n_p}{n_e} \left[q n_h \left(\overrightarrow{v_p} - \overrightarrow{v_h} \right) \times \overrightarrow{B} + \overrightarrow{J} \times \overrightarrow{B} - \nabla P_e \right] - \nabla \cdot \overleftrightarrow{P_p}$$

$$\overrightarrow{F_h} = m_h n_h \left(\frac{\partial}{\partial t} + \overrightarrow{v_h} \cdot \nabla \right) \overrightarrow{v_h} = \frac{n_h}{n_e} \left[q n_p \left(\overrightarrow{v_h} - \overrightarrow{v_p} \right) \times \overrightarrow{B} + \overrightarrow{J} \times \overrightarrow{B} - \nabla P_e \right] - \nabla \cdot \overleftrightarrow{P_h}$$

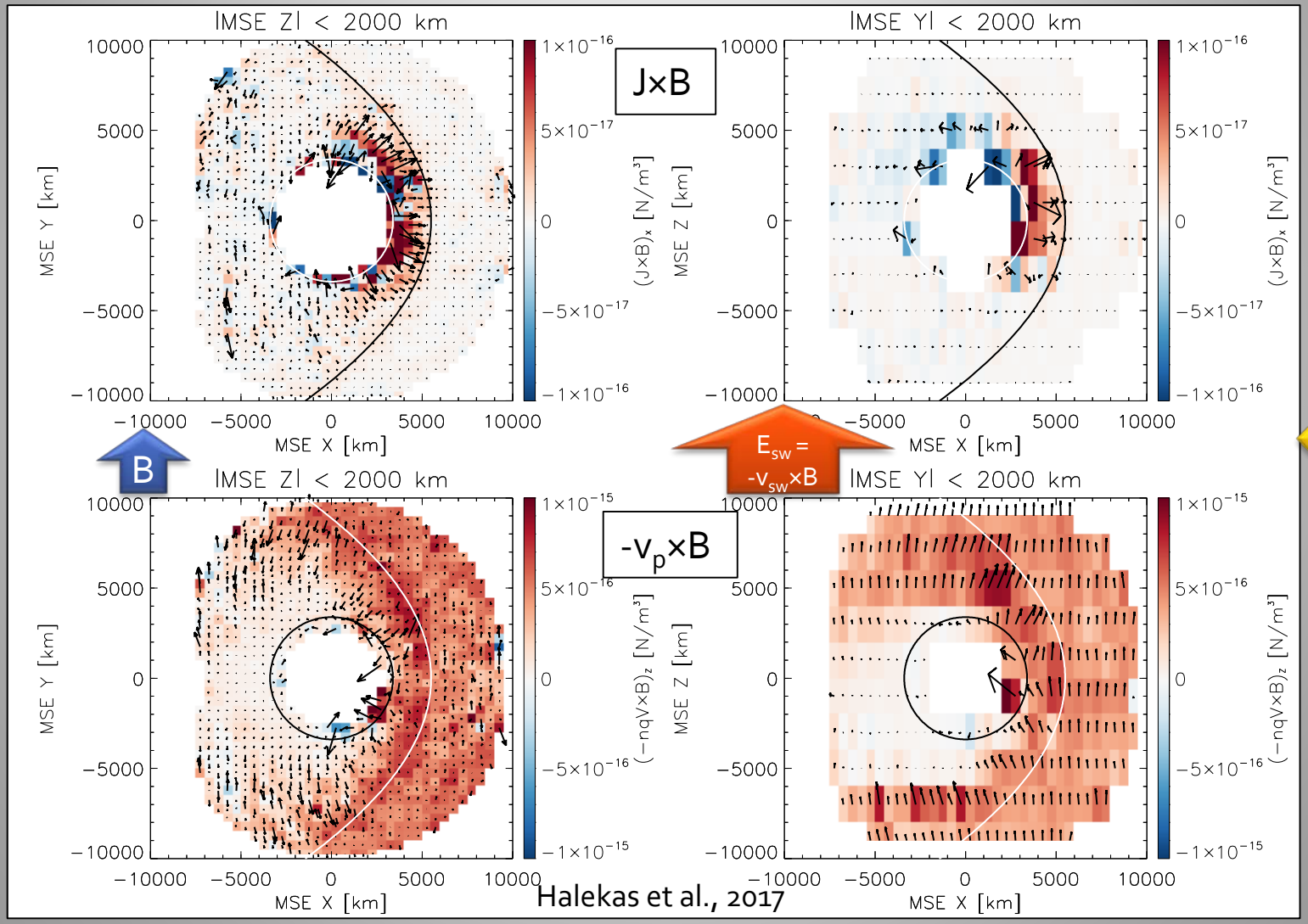
First order model for solar wind protons interacting with heavy planetary ions

Forces on Solar Wind Protons



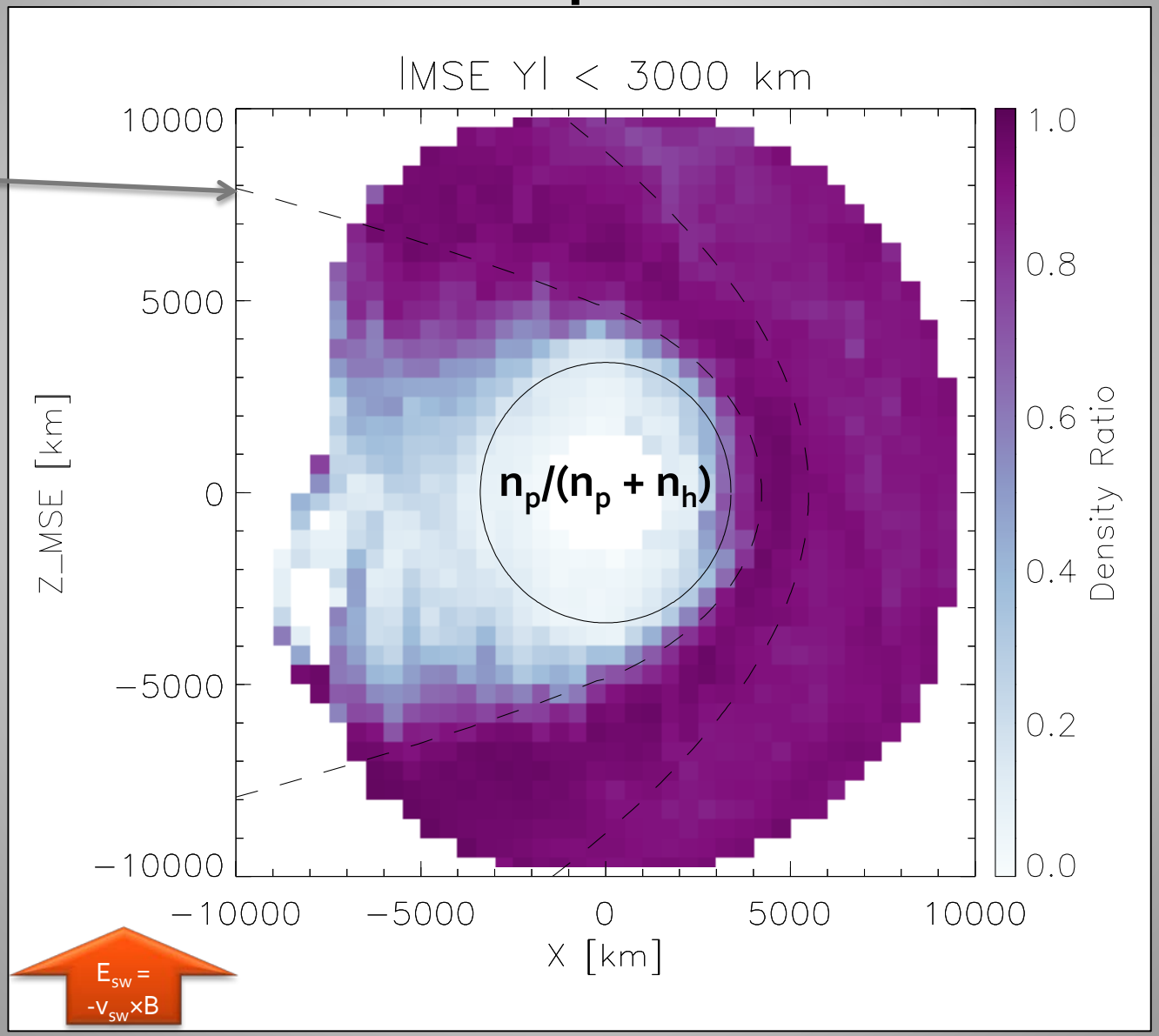
Also:
Grad P_e
v×B

Forces on Martian Heavy Ions



Also:
Grad P_h
Grad P_e

Ion Composition



Nominal MPB [Trotignon et al., 2006]

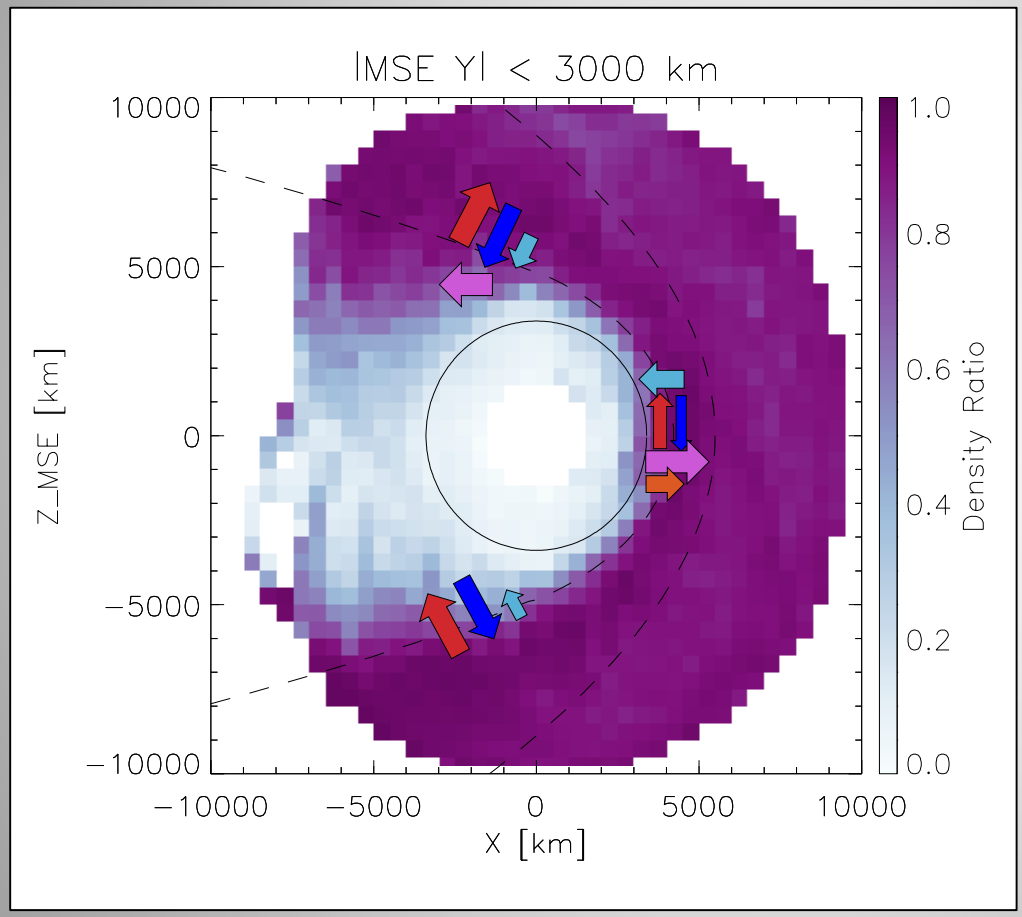
V_{sw}

$E_{sw} = -v_{sw} \times B$

Ion Composition Boundary Forces

Thicker boundary expected in $+E_{sw}$

Narrower boundary expected in $-E_{sw}$



v×B force on heavies

GradP_h force on heavies

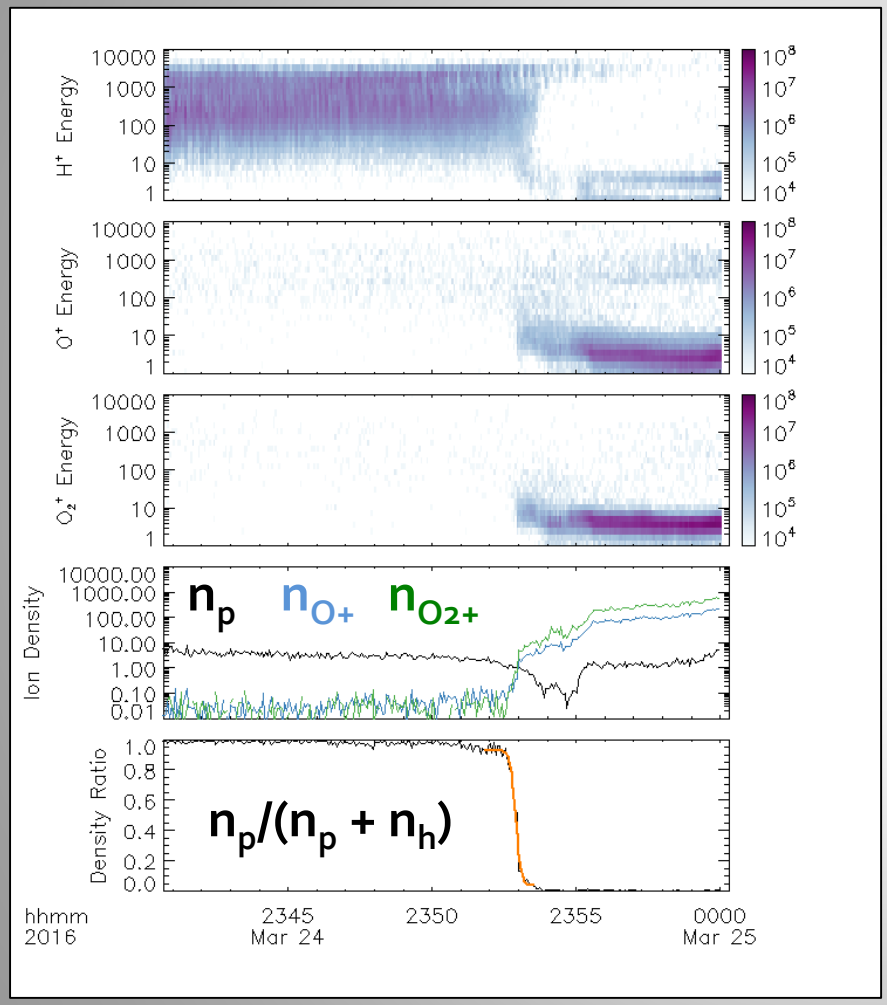
v×B force on protons

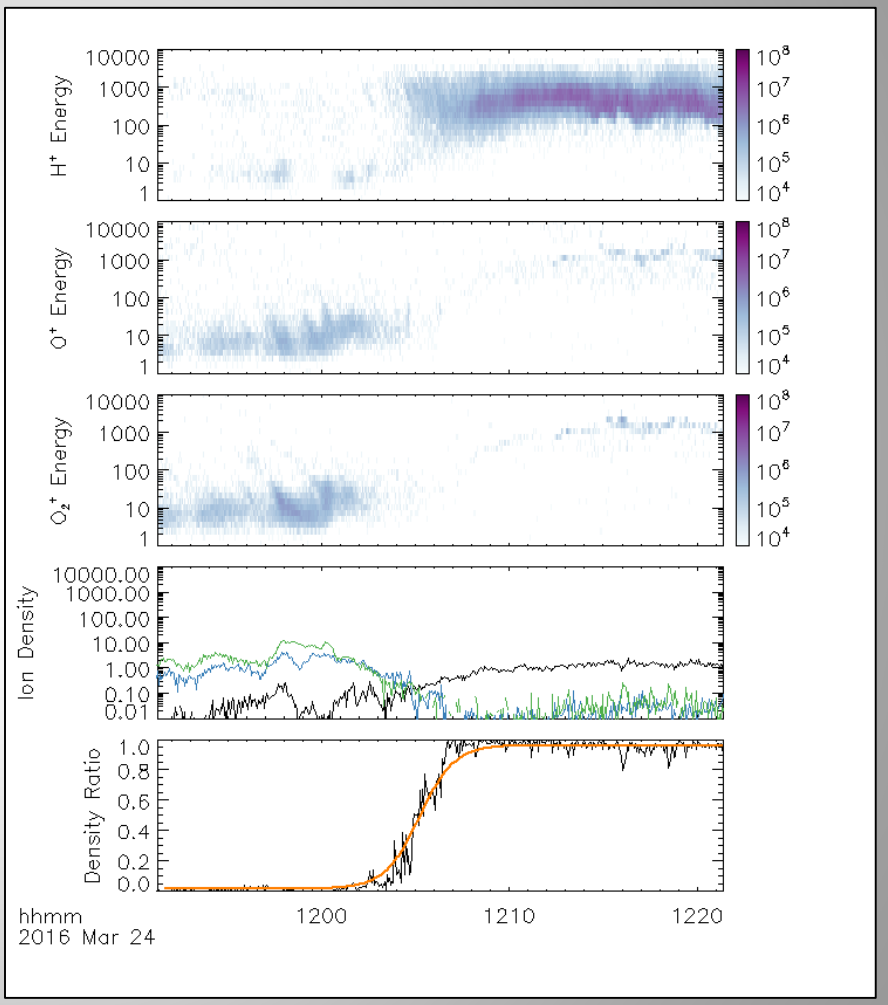
GradP_p force on protons

J×B force on all ions

GradPe force on all ions?

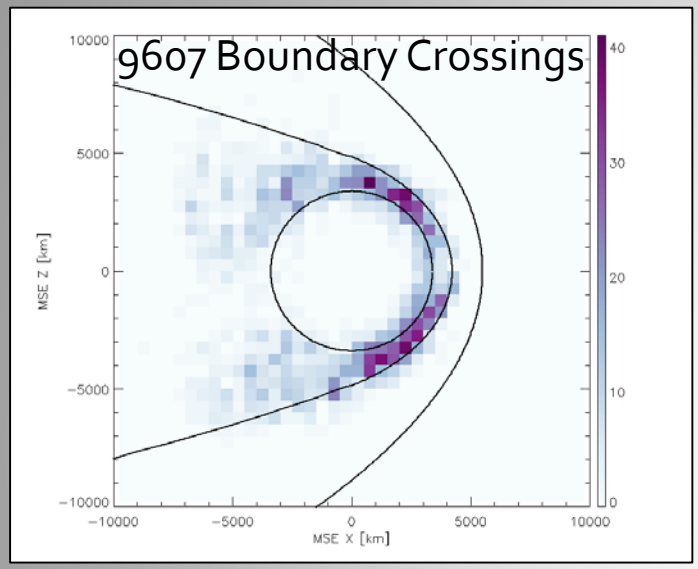
Boundary Layer Fits

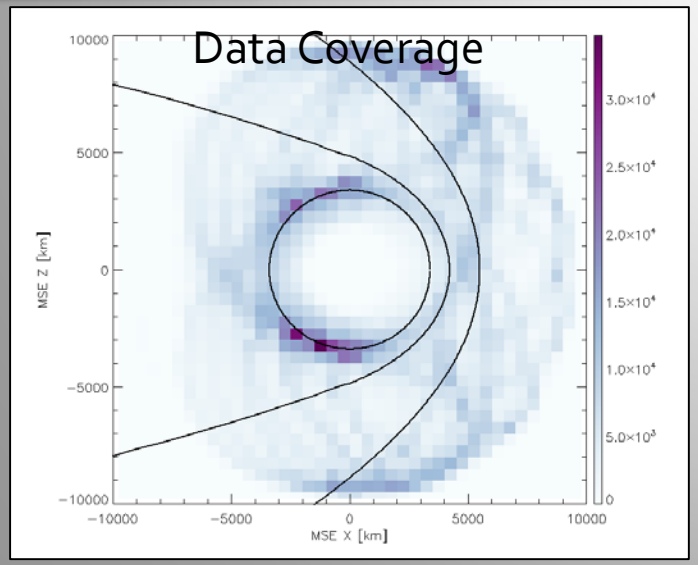




- Fit boundary density ratio to functional form $f(t) = A_0 + A_1 * \tanh[(t-A_2)/A_3]$
- Convert $2*A_3$ to spatial thickness using spacecraft velocity normal to average boundary

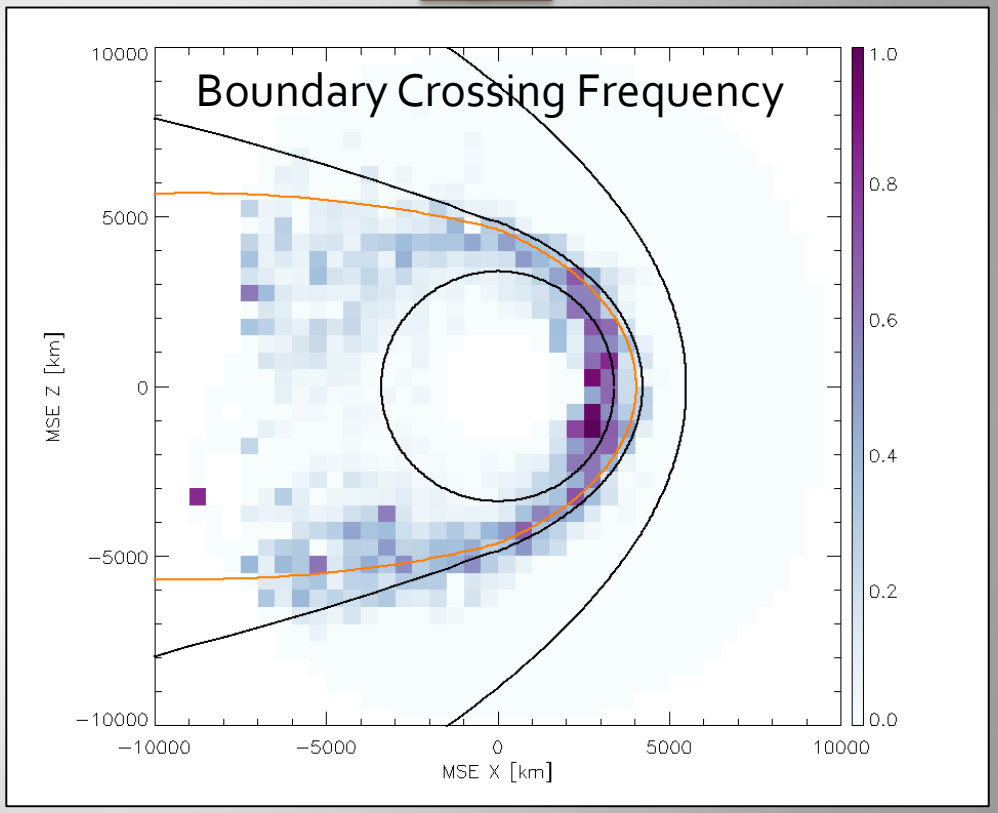
Boundary Layer Position





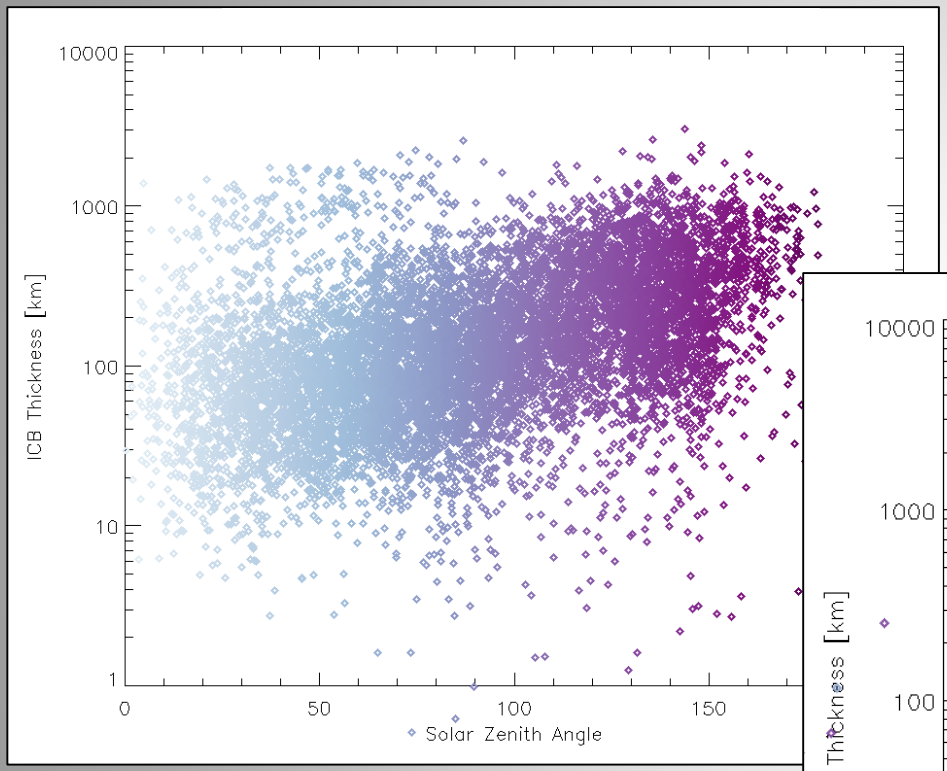
=

$E_{sw} = -v_{sw} \times B$



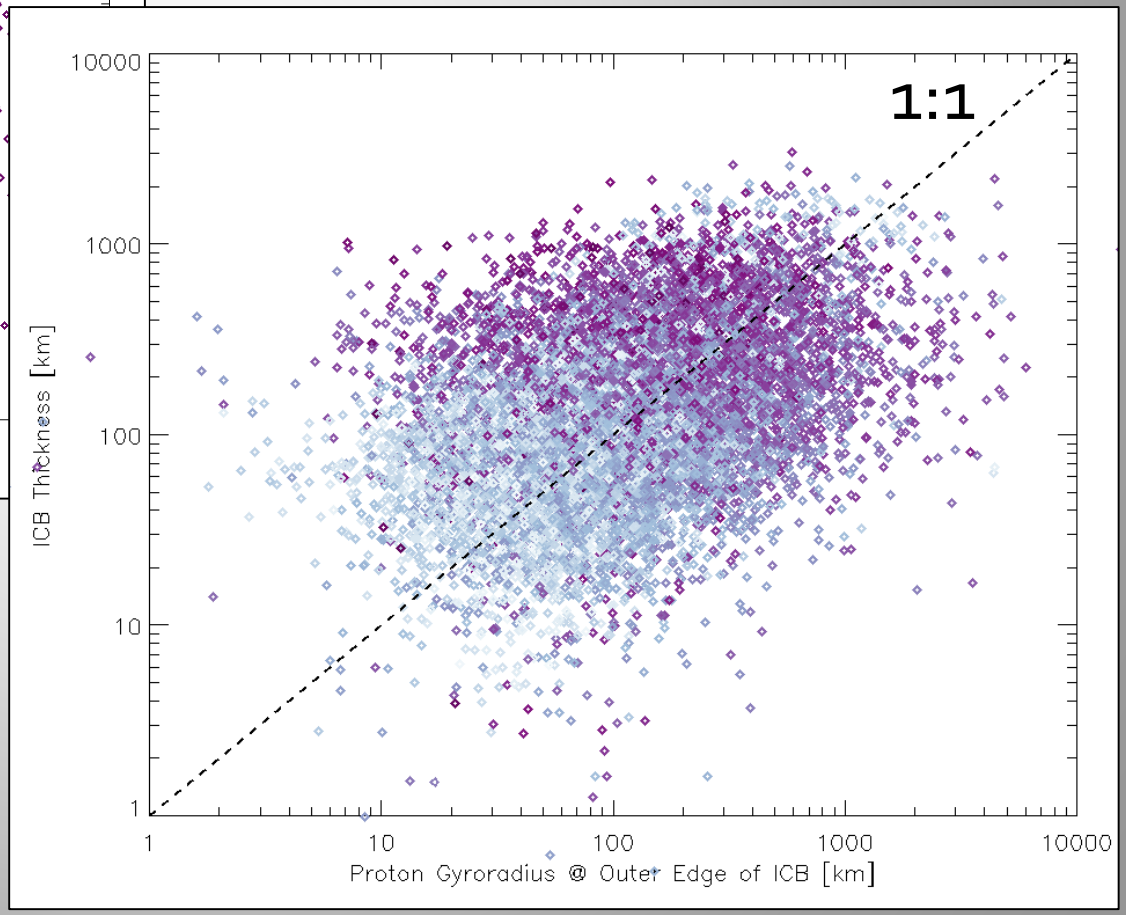
- Average ICB close to nominal MPB, but less flared in tail
- ICB asymmetric in MSE

Boundary Layer Thickness



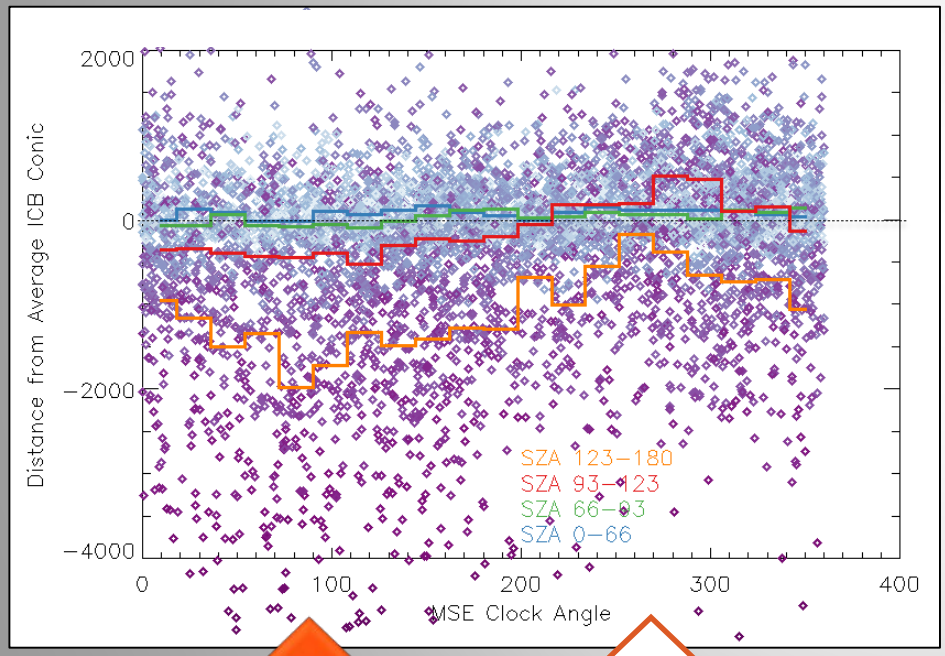
Thickness increases with SZA

Thickness scales with gyroradius

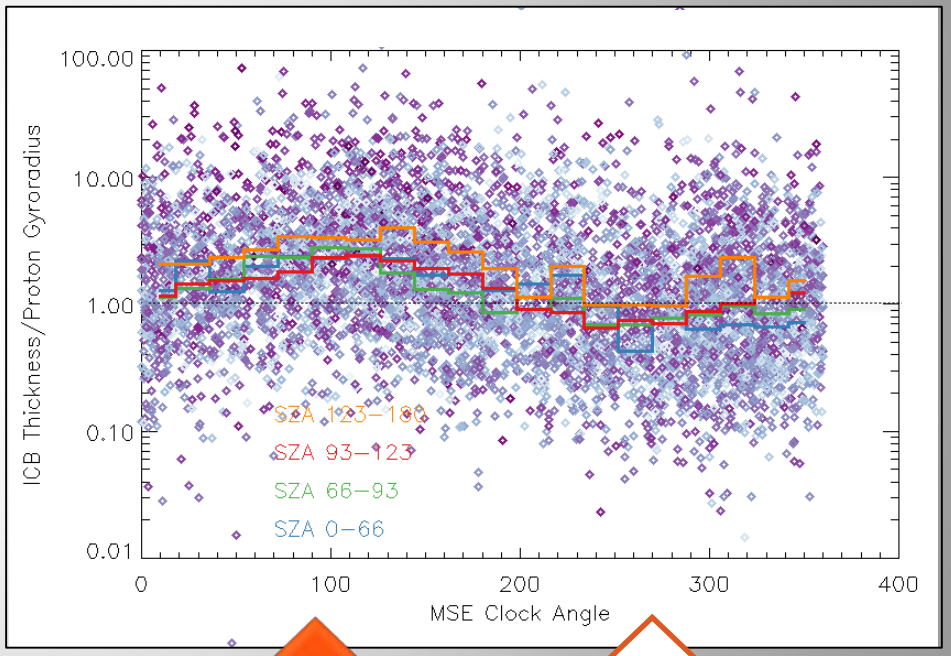


Boundary Layer Asymmetries

Boundary farther out in -E hemisphere

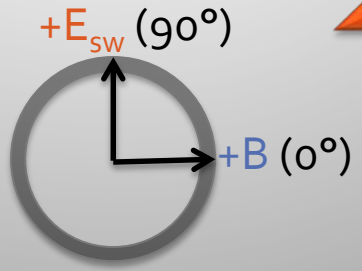


Boundary thicker in +E hemisphere



+E

-E

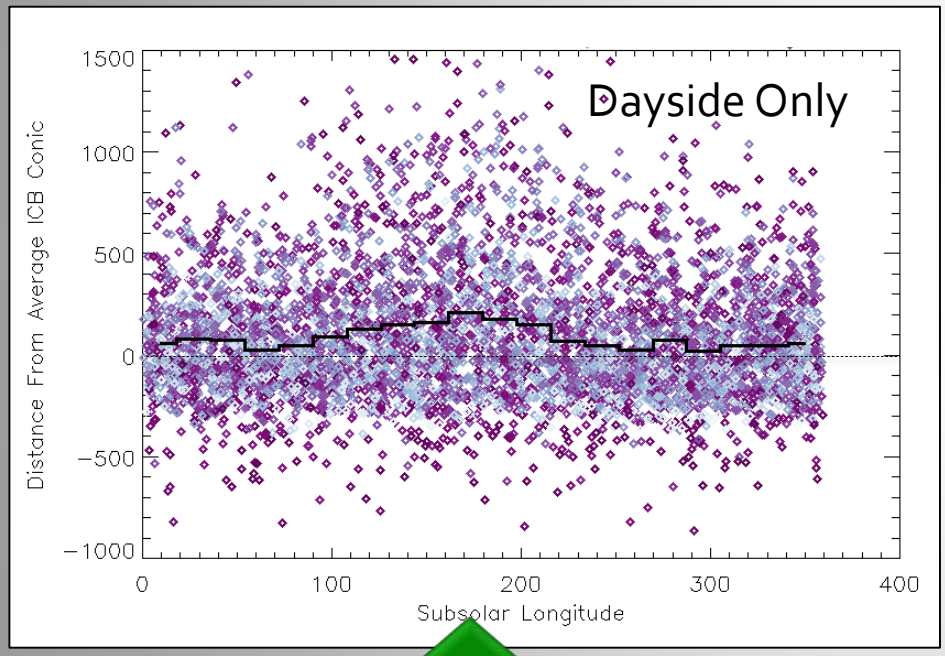


+E

-E

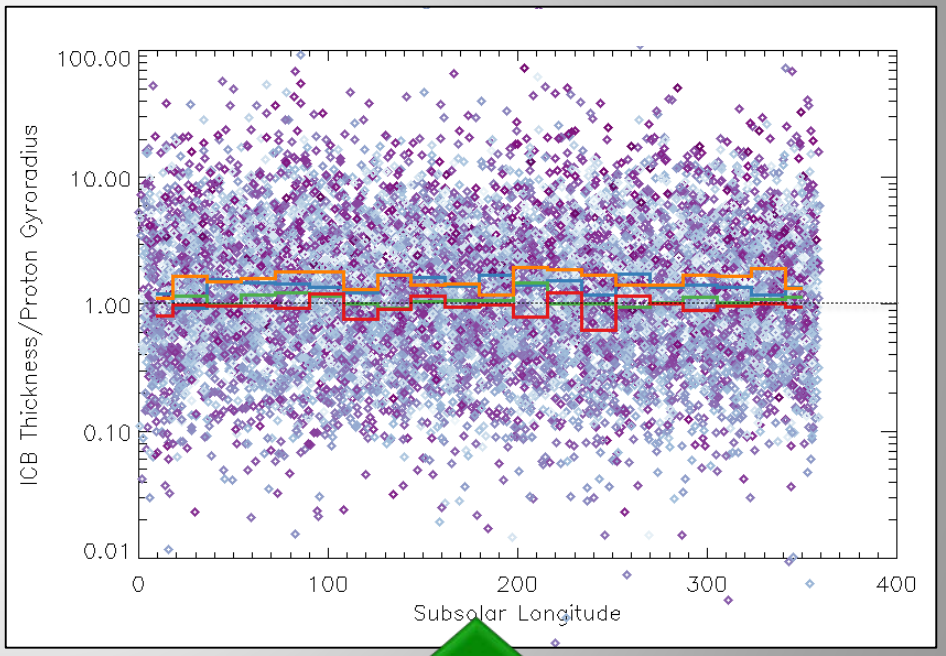
Boundary Layer Asymmetries II

Boundary farther out over crustal magnetic fields



Far Side

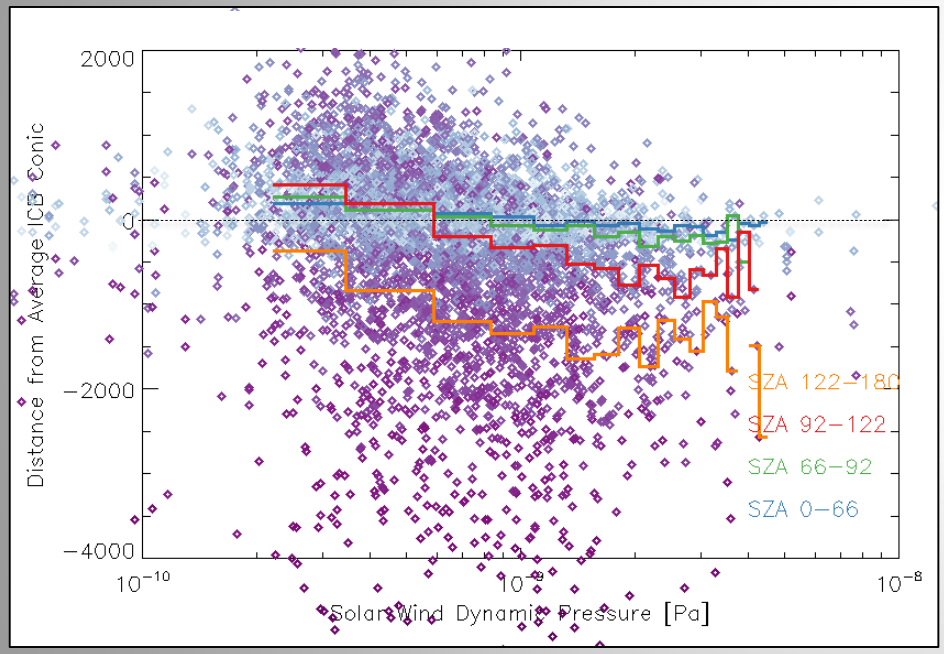
Boundary thickness unaffected by crustal magnetic fields



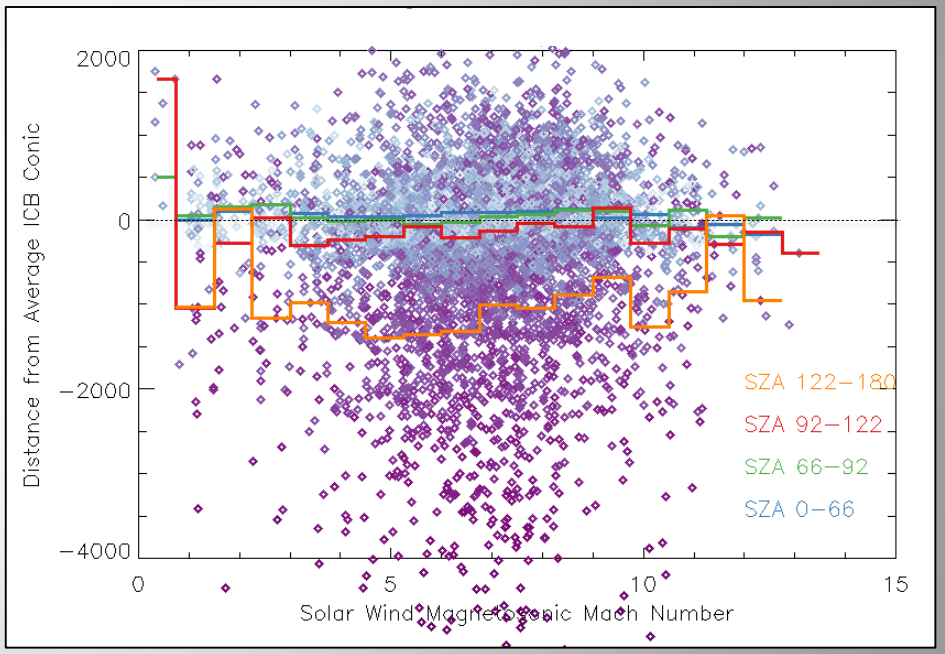
Far Side

Boundary Layer Solar Wind Dependence

Boundary compressed by solar wind ram pressure

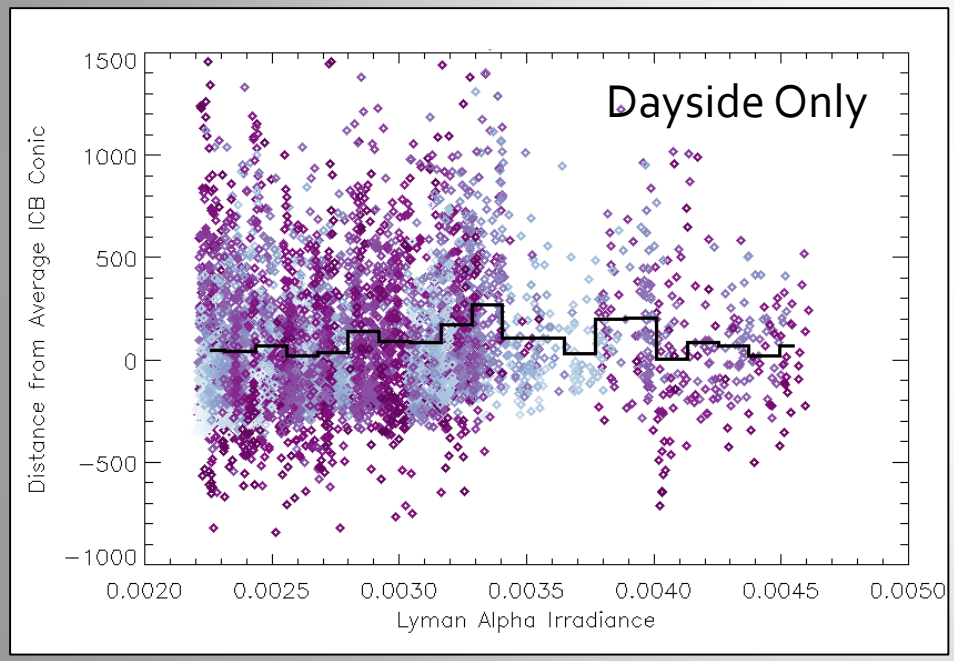


Boundary insensitive to solar wind Mach number

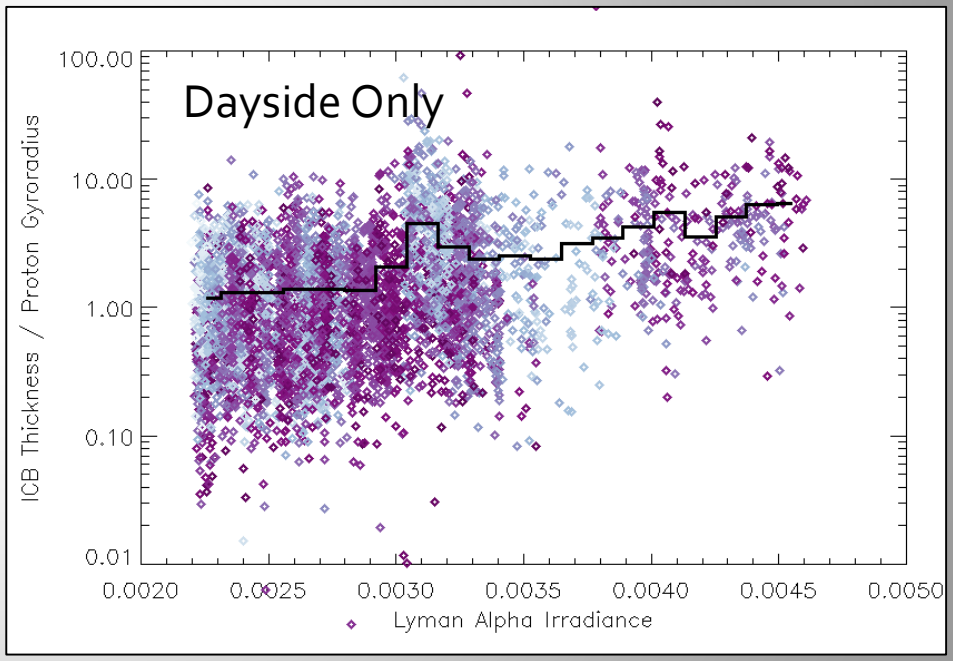


Boundary Layer EUV Dependence

Boundary position doesn't depend on EUV…

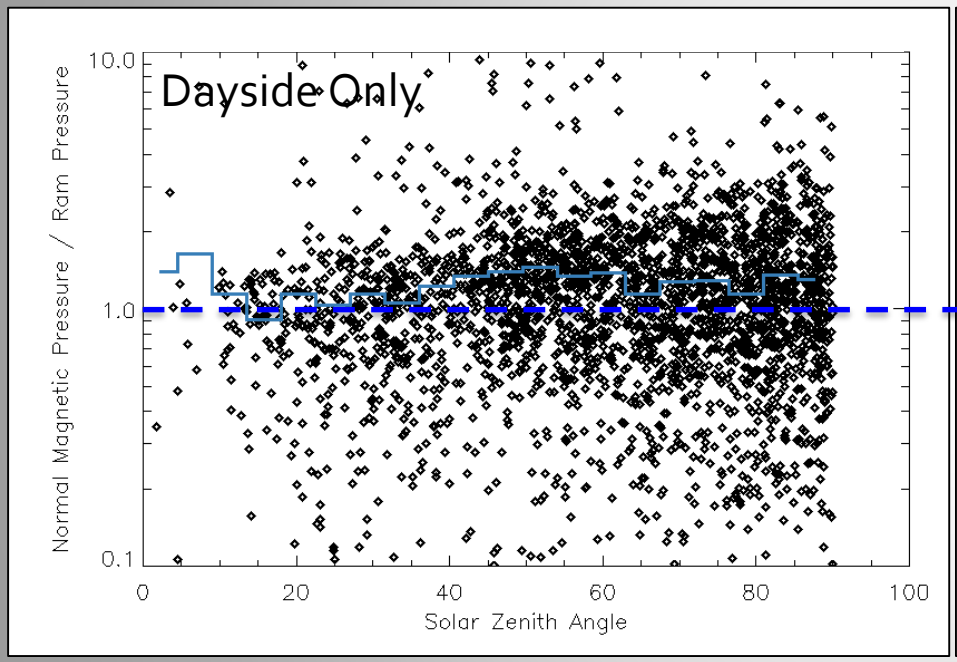


But boundary thickness does!

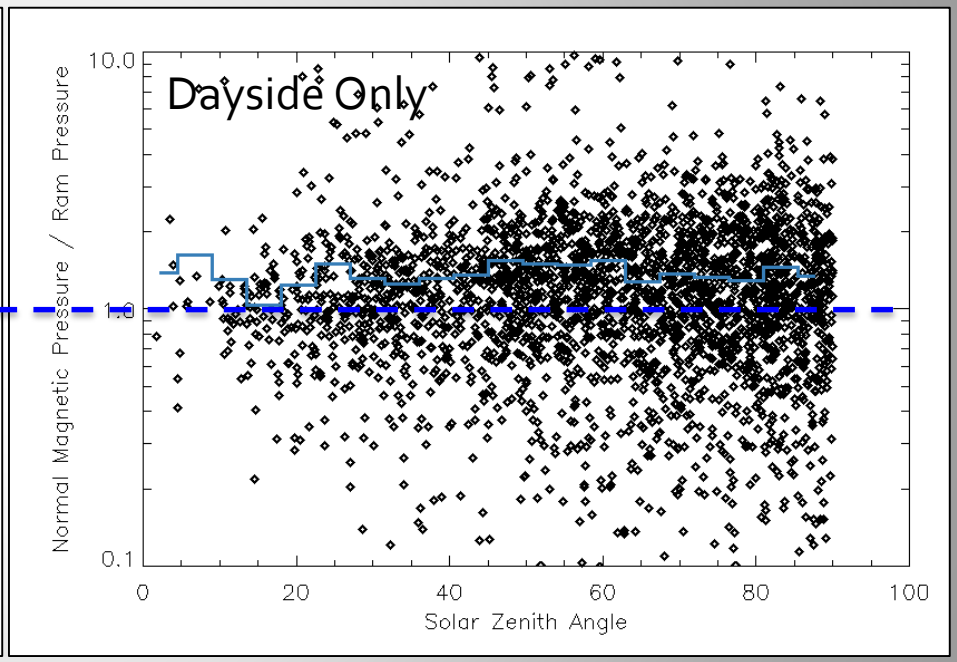


Pressure Balance at Boundary Layer

Outer ion composition boundary layer

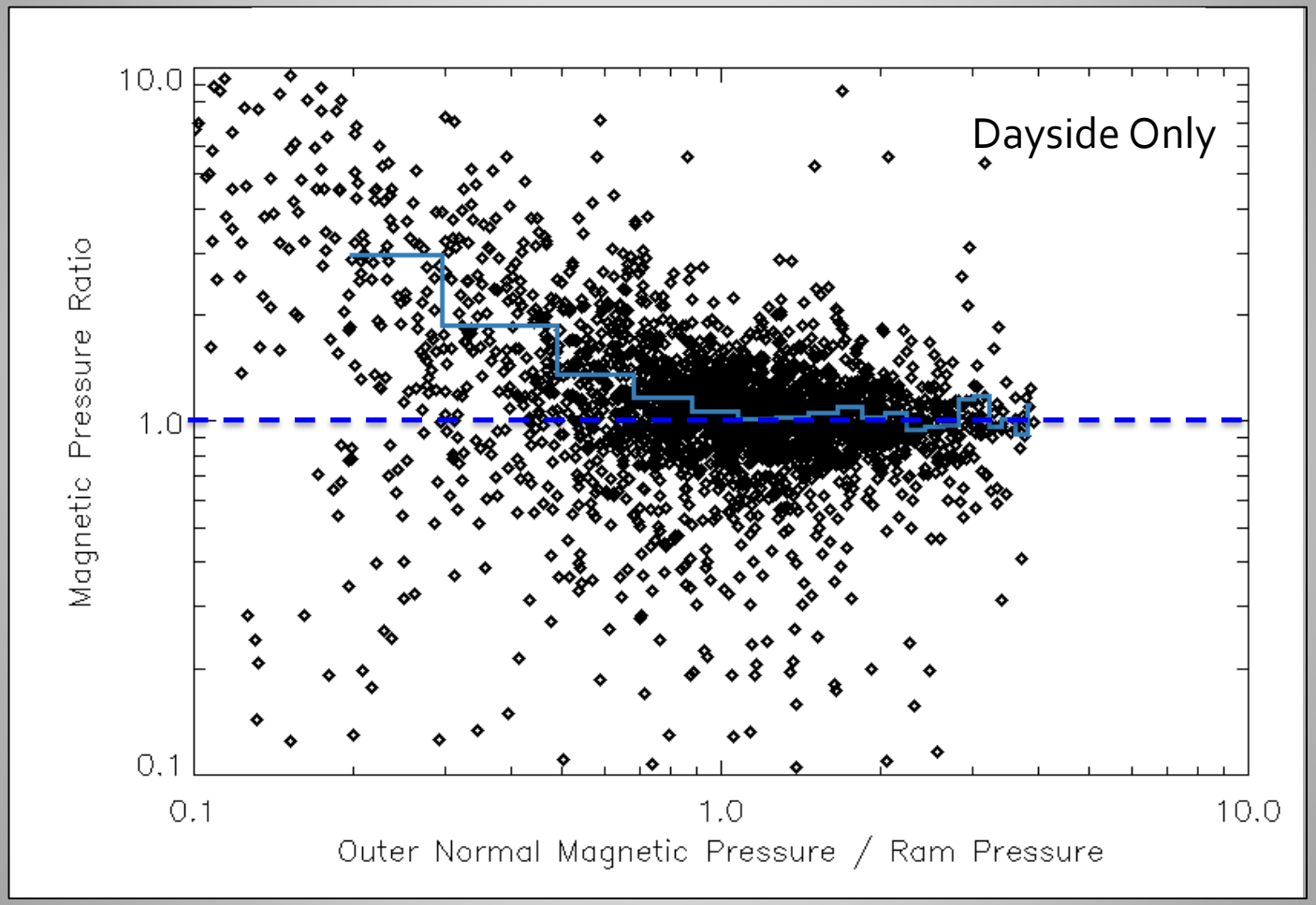


Inner ion composition boundary layer



- Tangential magnetic field balances normal component of solar wind ram pressure
- Pressure balance already established by the outer edge of the composition boundary
- Excess of magnetic pressure – result of crustal magnetic fields?

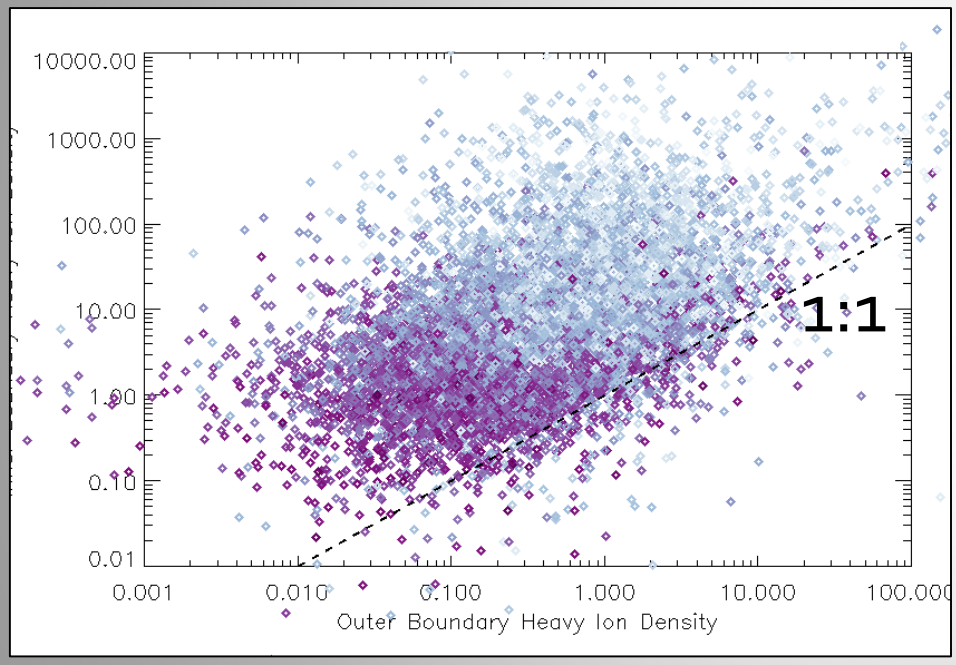
Magnetic Field Jump



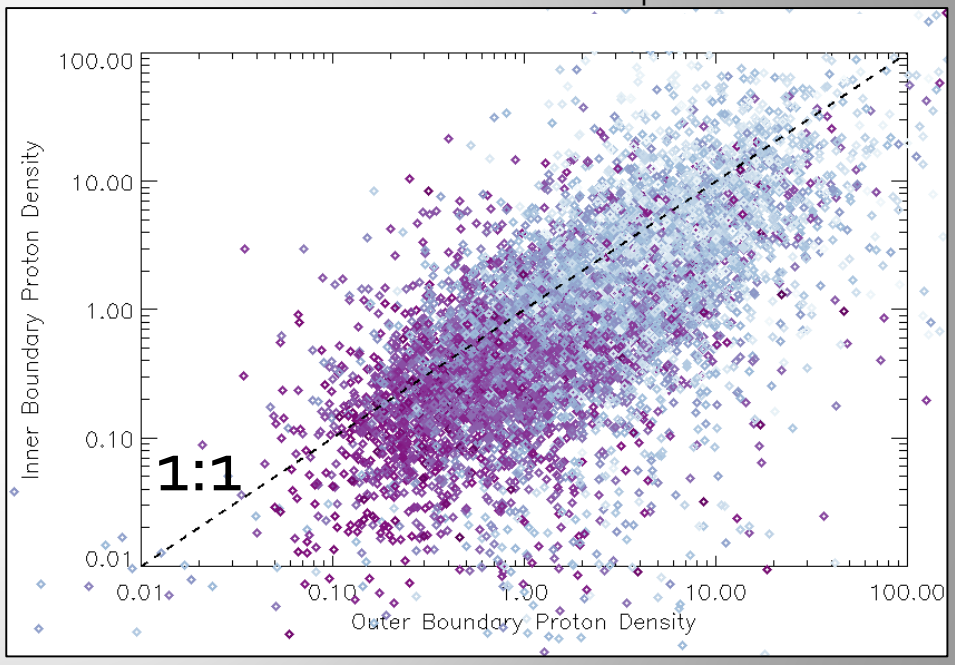
- Magnetic field and pressure jump across boundary usually moderate
- ICB ≠ MPB (at least not the same thickness!)

Density Jump

Heavy Ion Density n_h



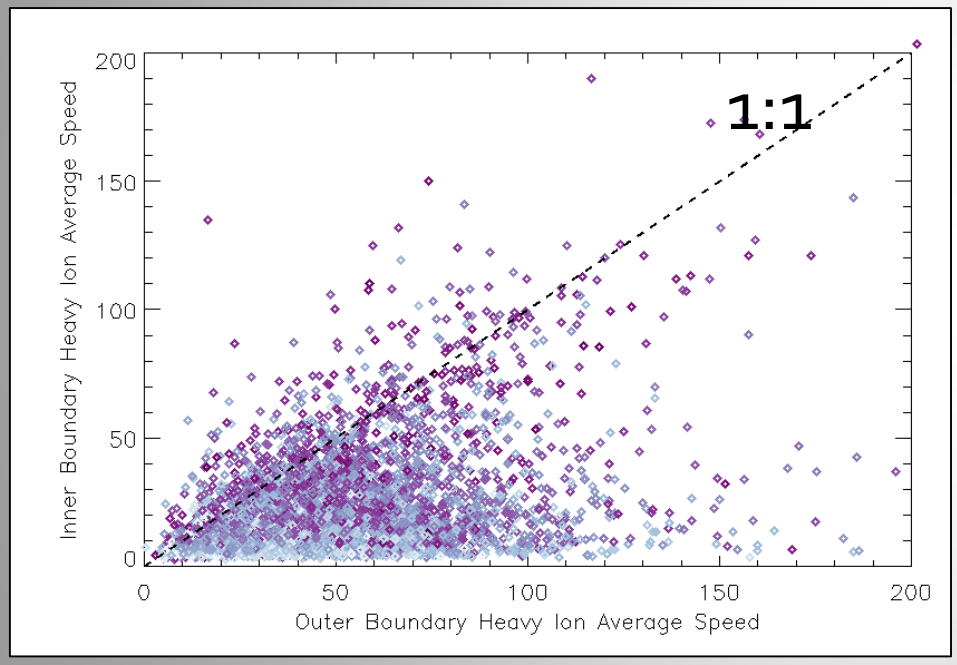
Proton Density n_p



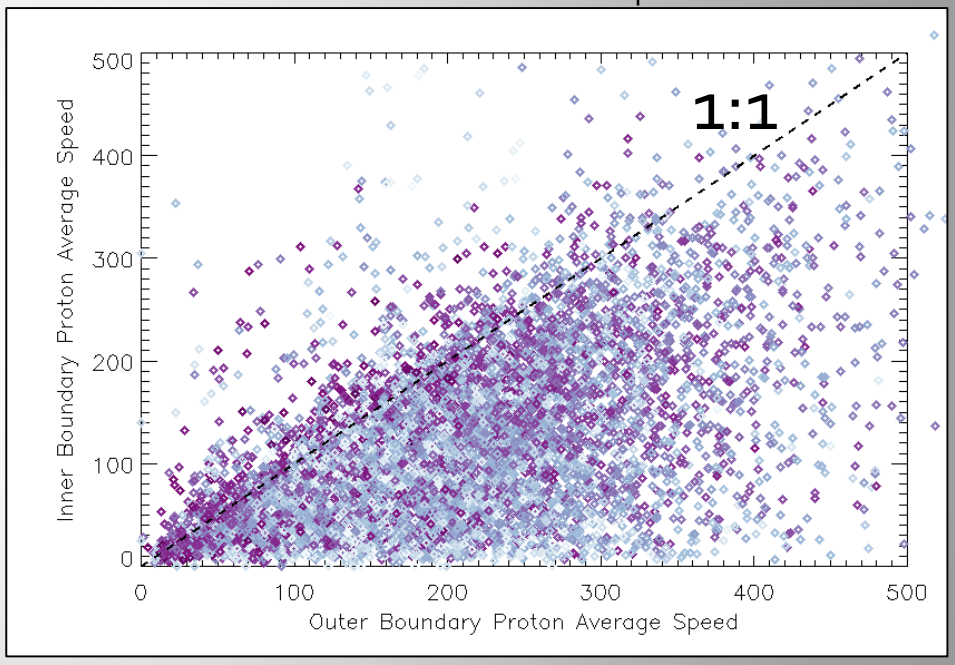
- Heavy ion density increases across boundary
- Proton density usually drops across boundary

Speed Jump

Heavy Ion Speed <v_h>



Proton Speed <v_p>



- Both heavy ion and proton speed are lower inside the boundary

Conclusions

- The transition in composition between solar wind and planetary ions is part of a complex boundary layer
  - The ion composition boundary (ICB) is not (always) the same as either the MPB or the ionopause
  - The ICB has significant asymmetries in both location and thickness, ultimately resulting from the asymmetry of the Lorentz force