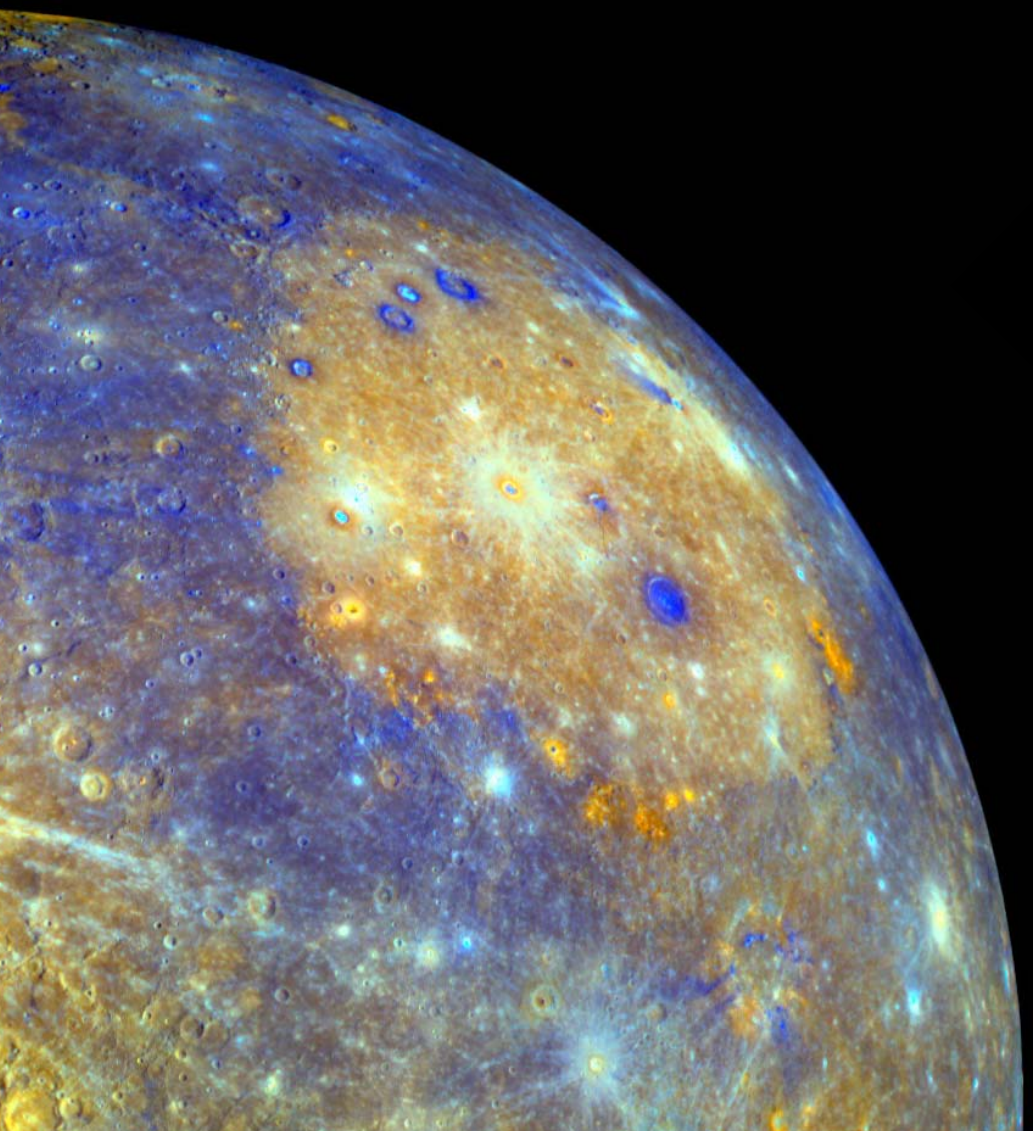
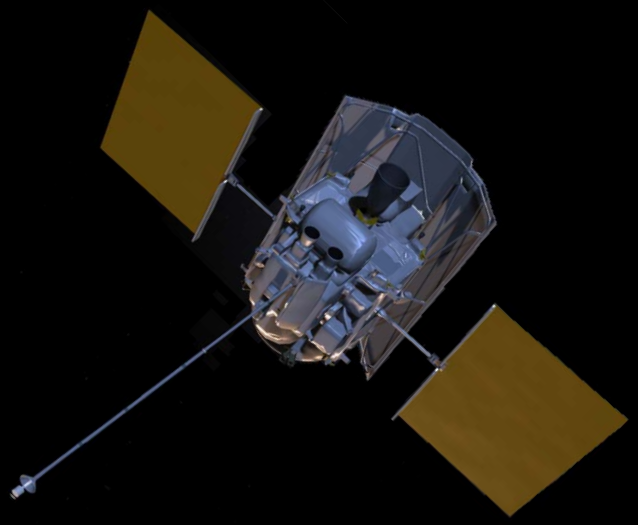
Global Simulations of Mercury's Magnetosphere





R. Winglee and A. Kidder

University of Washington

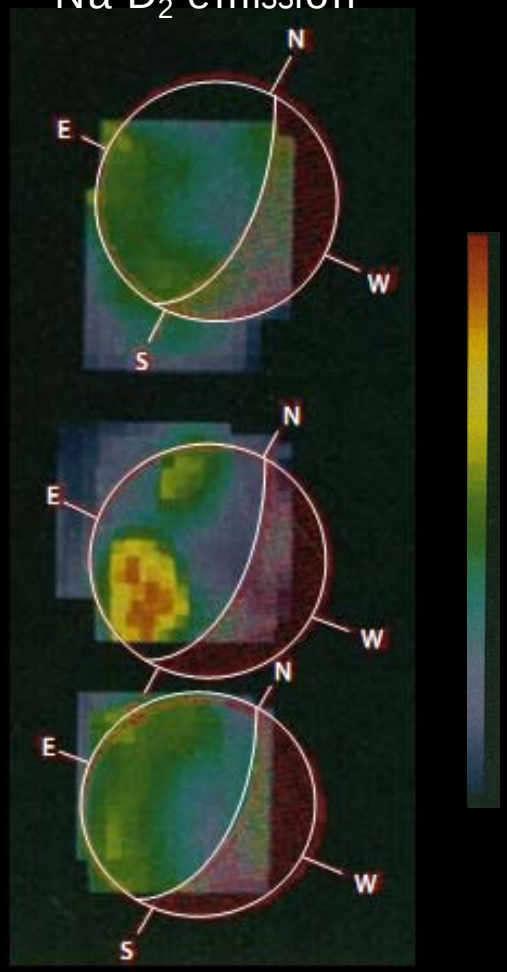
Outline

- Main observations detailing unique features of Mercury's Magnetosphere
- Compare and contrast workings of main models
  - MHD Hybrid Multi-Fluid
- Significant results from the various models
- What models can do in the future in concert with these missions

Exosphere: Ground-based observations

Sun

Na D_2 emission

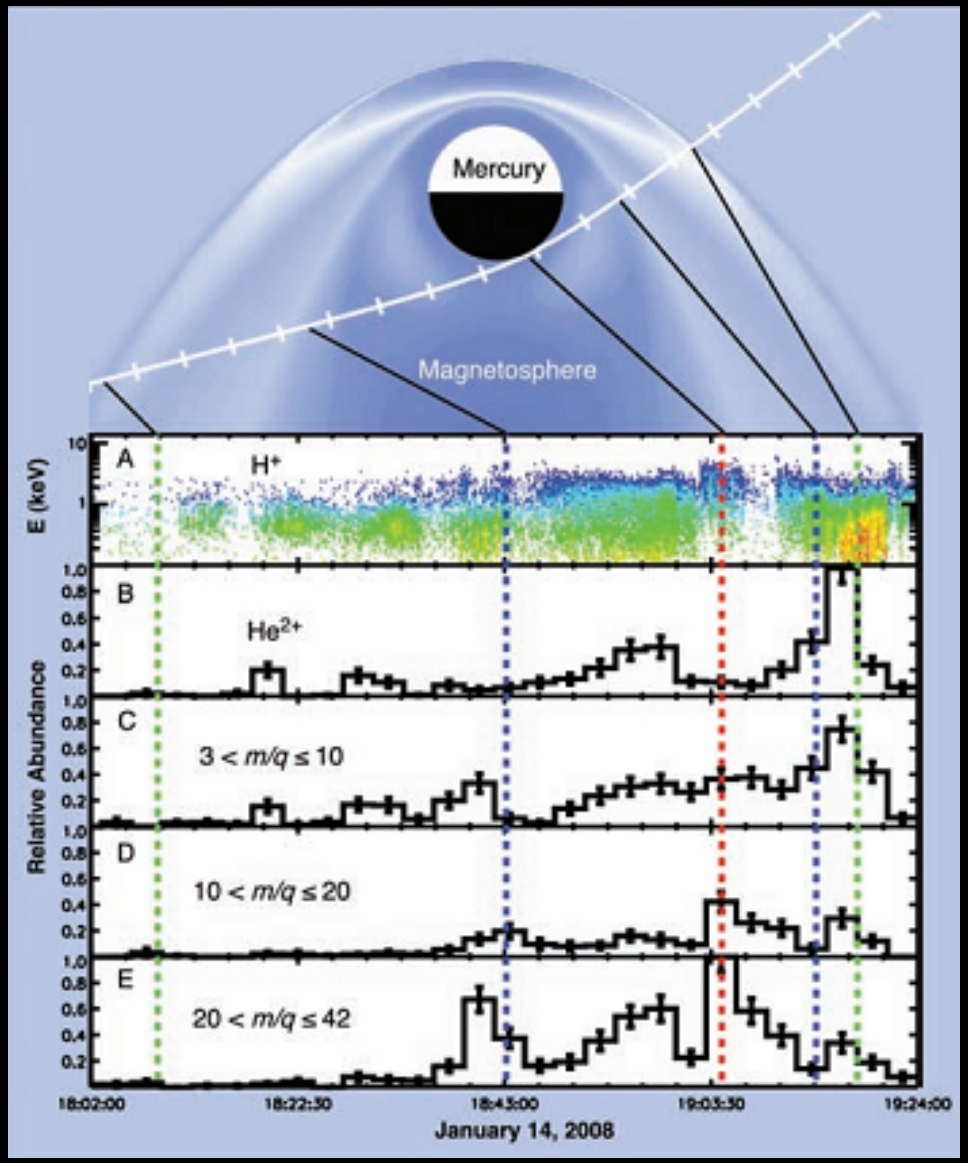


modified from
Potter & Morgan, 1990

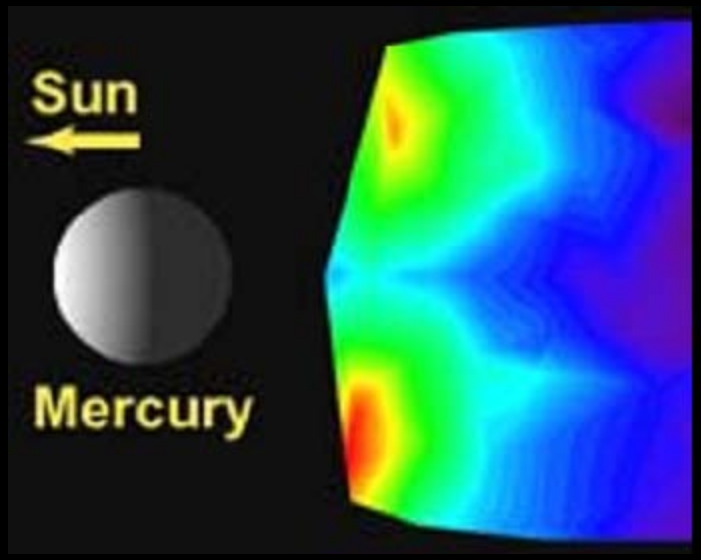
Discovery of:

- Sodium
- Potassium
- Calcium

Exosphere: MESSENGER Observations



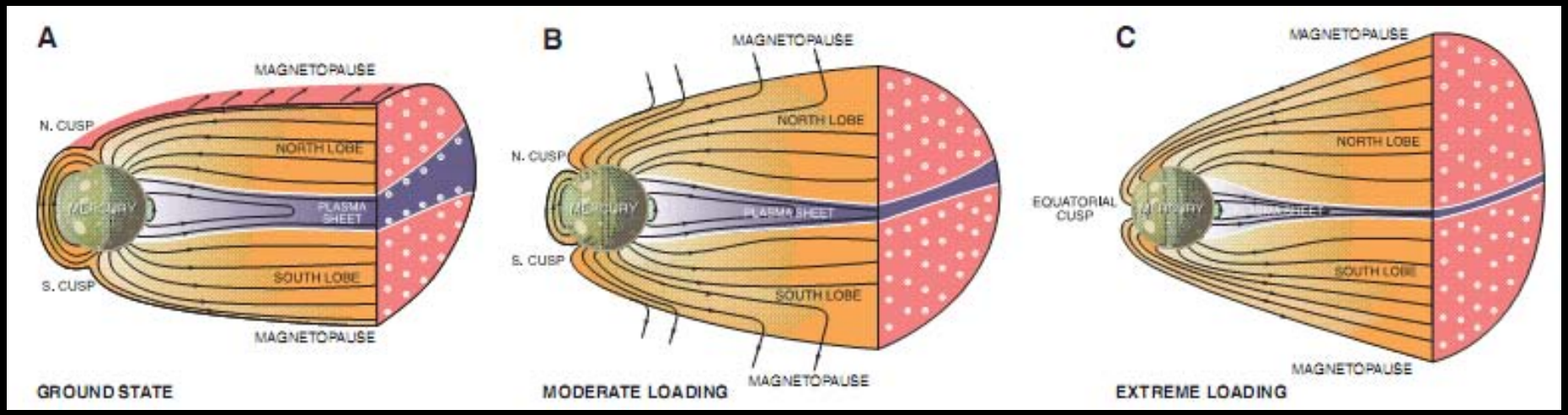
Zurbuchen et al., 2009



NASA

What controls the sodium on a day to day basis?

MESSENGER: Loading of the tail



Slavin et al., 2010

- Weak magnetic field
- Dominated by heavy ions
- Sparse ionosphere

- Ground State

  Bow Shock ~1.9 R_M

  Magnetopause ~ 1.4 R_M

Solar wind conditions can drive substantial deviations from the ground state – how, what &why?

Mercury's Magnetosphere

What things are going to be important in this regime?

- Heavy ions – varies in time and space
- Exospheric variations
- Gyroradius effects (weak magnetic field + heavy ions)
- Global system – substorm dynamics

Types of Models

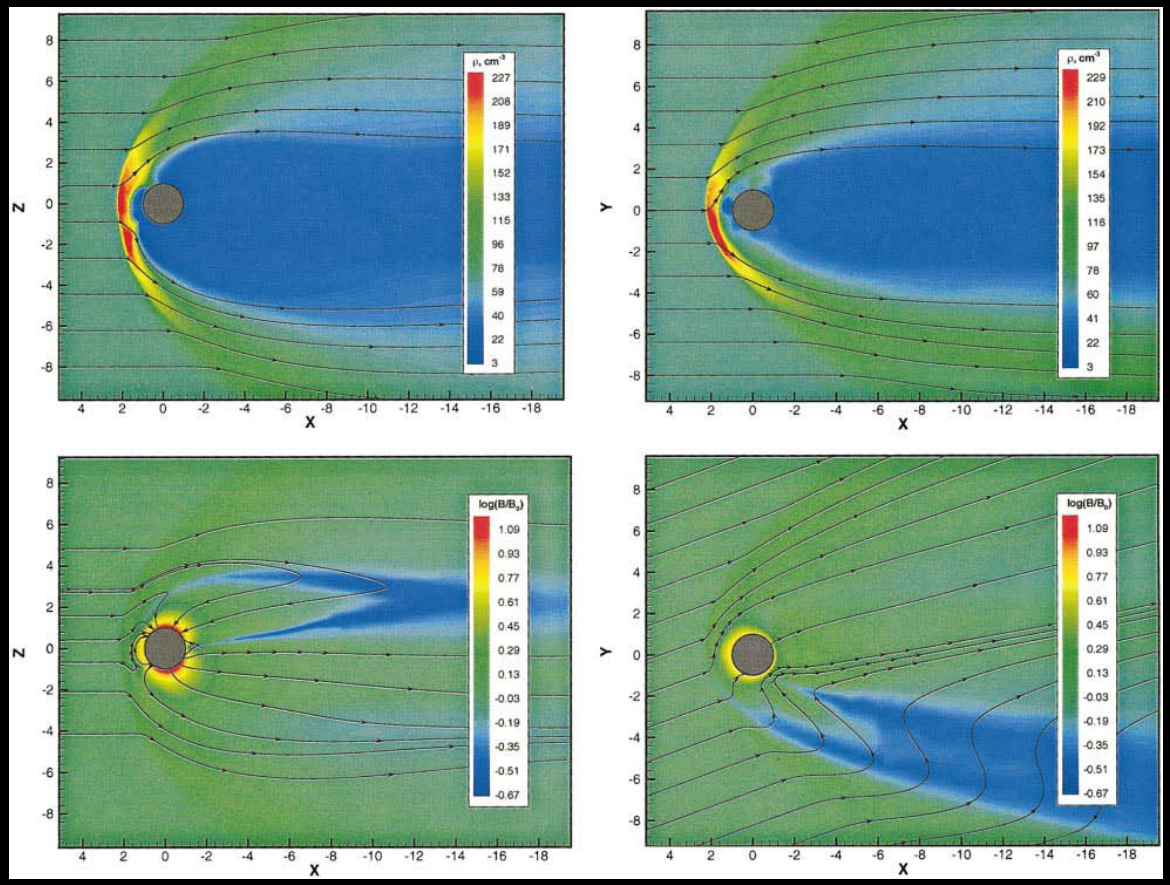
- MHD
  - single fluid
  - global scale
- Hybrid
  - particle ions, fluid electrons
  - smaller scale
- Multi-Fluid
  - three ion fluids, fluid electrons
  - global scale

Comparative features of various simulation techniques

Process	MHD	Multi-fluid	Hybrid
Ion Cyclotron/Ion Skin Depth Effects in Electrodynamics	Hall MHD	Yes	Yes
Ion Cyclotron in Momentum Equation	No	Yes	Yes
Light/Heavy Ion Interactions	No	Yes	Yes
Temperature Anisotropies	No	No	Yes
High Energy Tails in Particle Distribution	No	No	Yes
Global Magnetosphere	Yes	Yes	No
Time Scale	min to hrs	min to hrs	Mins
Resolution	~300 km	~120 km	~300 km
Substorm Processes	Yes	Yes	Limited
FTEs/Flux Ropes	No	Yes	Maybe
Multi-Component Plasmas	No	Yes	Yes
Solar wind energy input	Yes	Yes	Yes

MHD Models

Kabin et al. (2000)

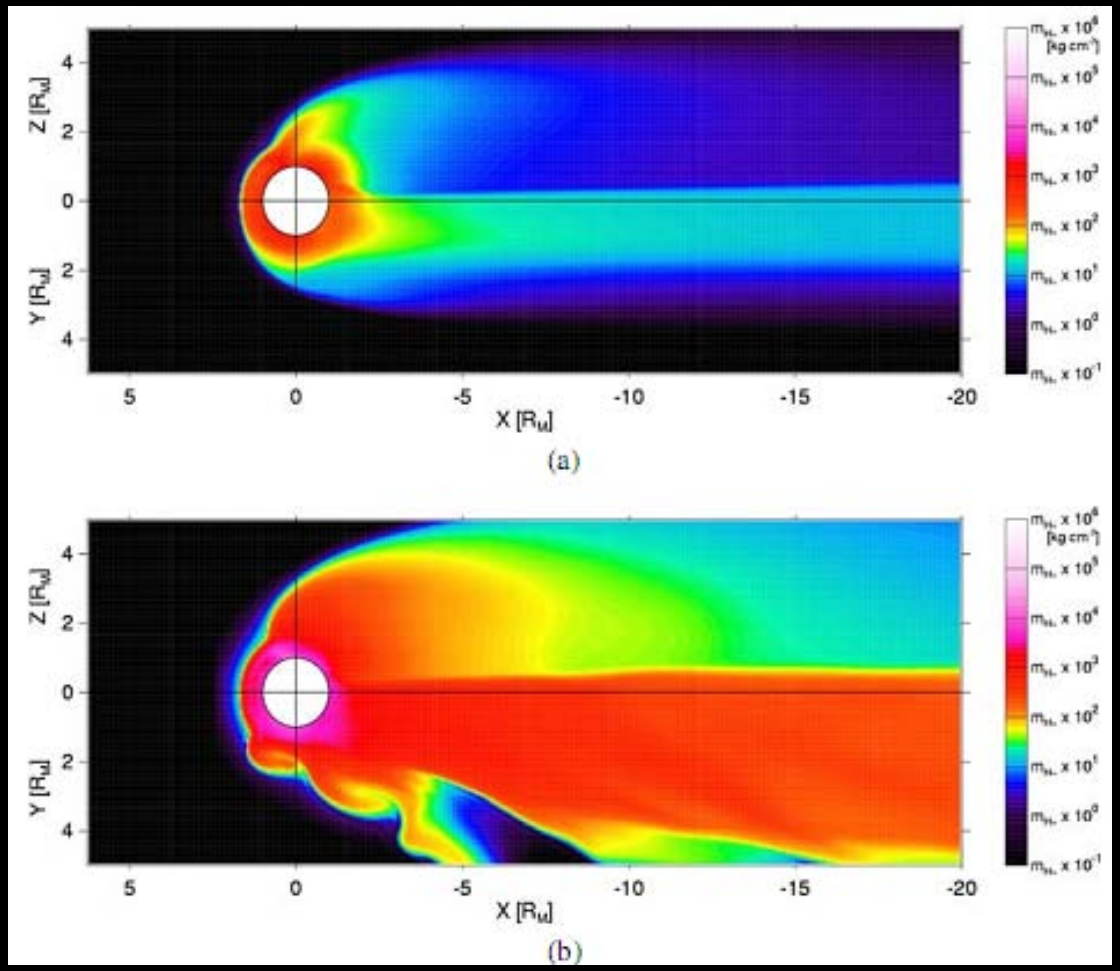


Noon-Midnight Meridian Equatorial Plane

- Ground state for Parker spiral conditions
- Subsolar point impact with solar wind conditions V_{SW}=1000 km/s, n=73/cm^3

MHD Models

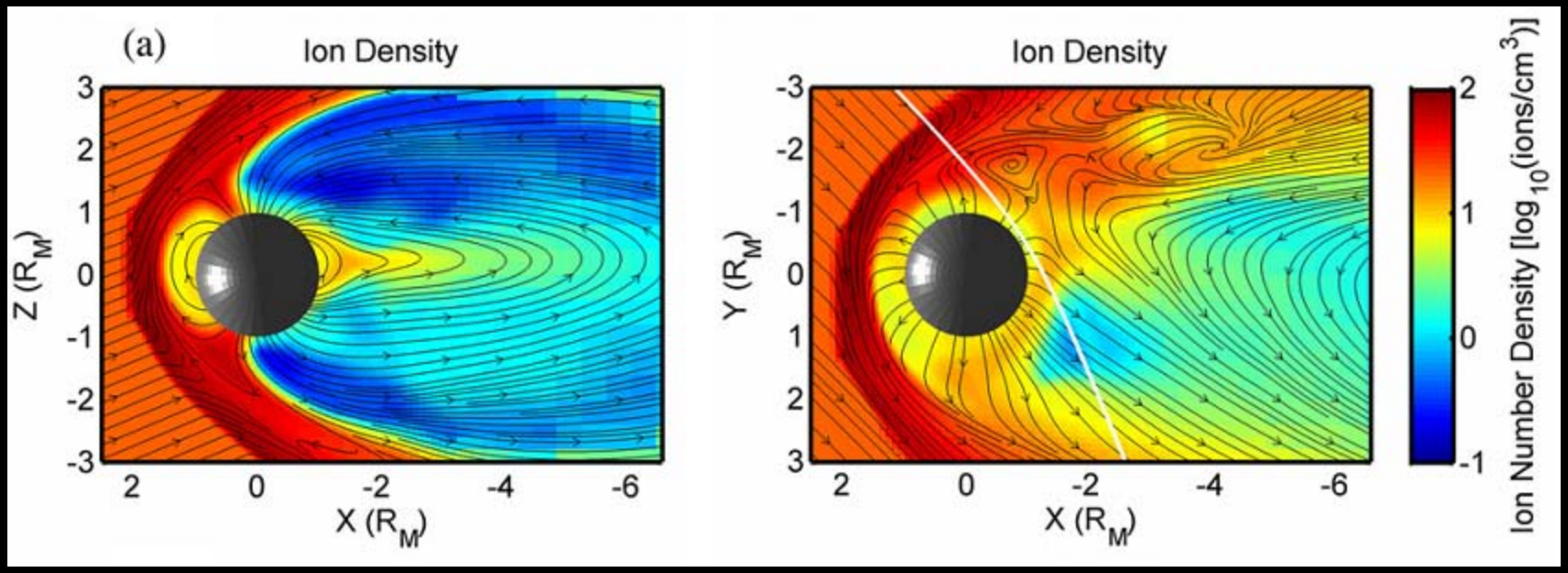
Fujimoto et al. (2007)



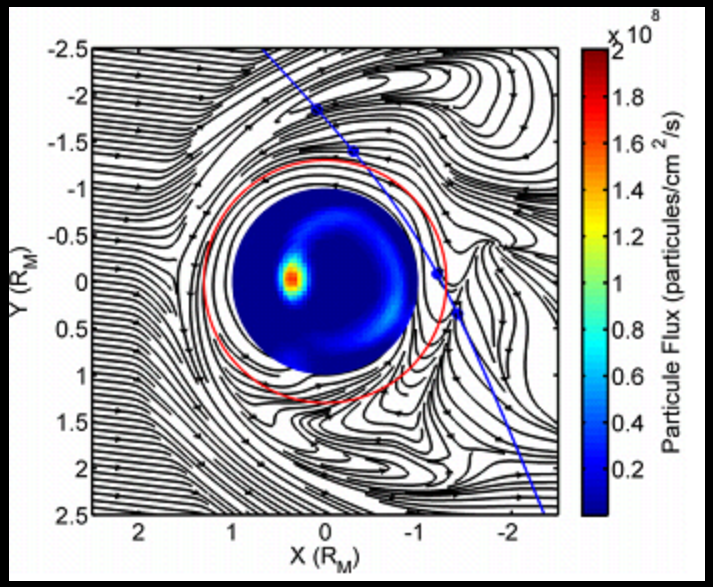
- Increase in planetary production rate (top vs. bottom)
- Kelvin-Helmholtz developing on the dusk side

MHD Models

Benna et al. (2010)



- New MHD model includes modified Ohm's law
- Flow from H^+ indicate a drift belt where sodium could potentially be quasi-trapped



Types of Models

MHD

- single fluid
- global scale

Hybrid

- particle ions, fluid electrons
- smaller scale

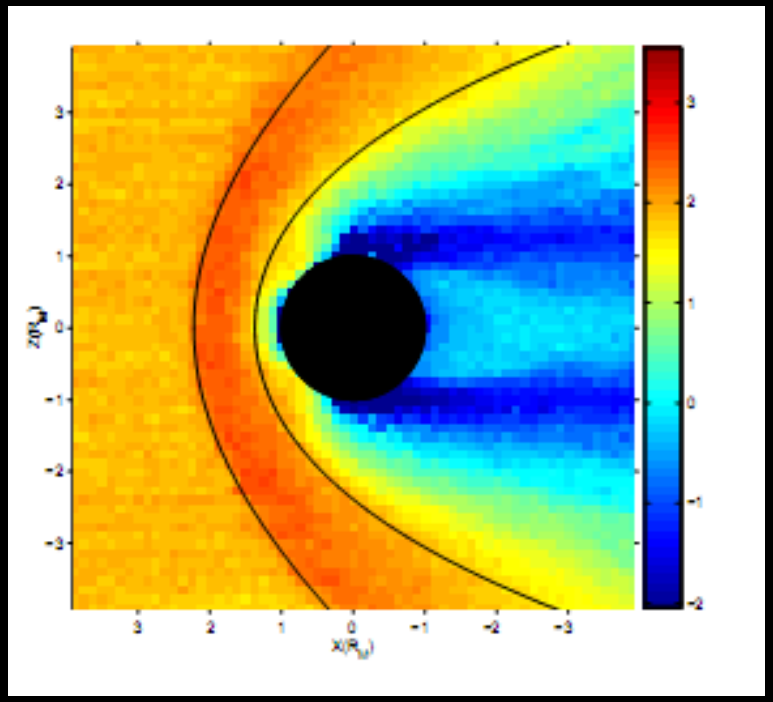
Multi-Fluid

- three ion fluids, fluid electrons
- global scale

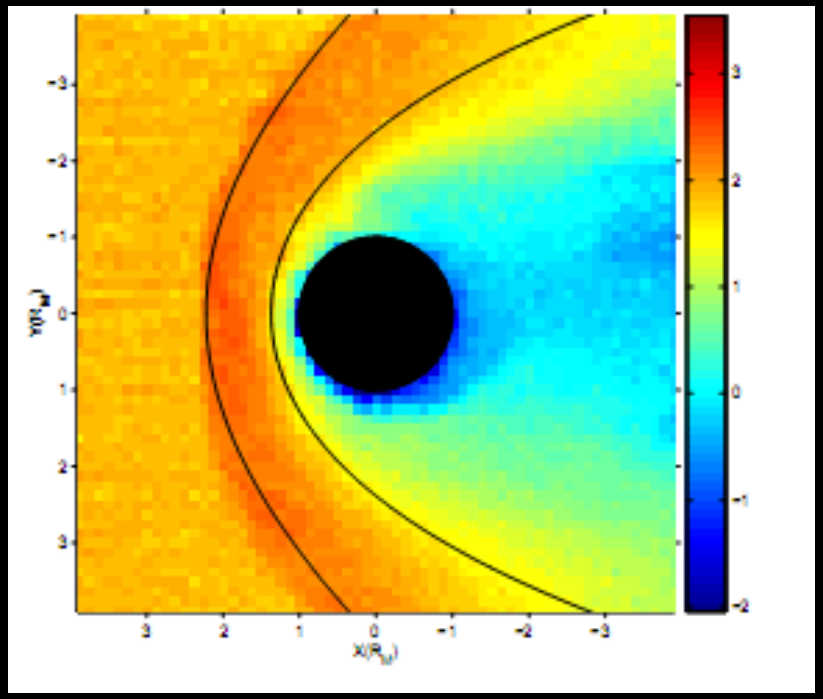
Hybrid Models

Kalio and Janhunen (2003)

Solar wind density (log scale)



XZ Plane



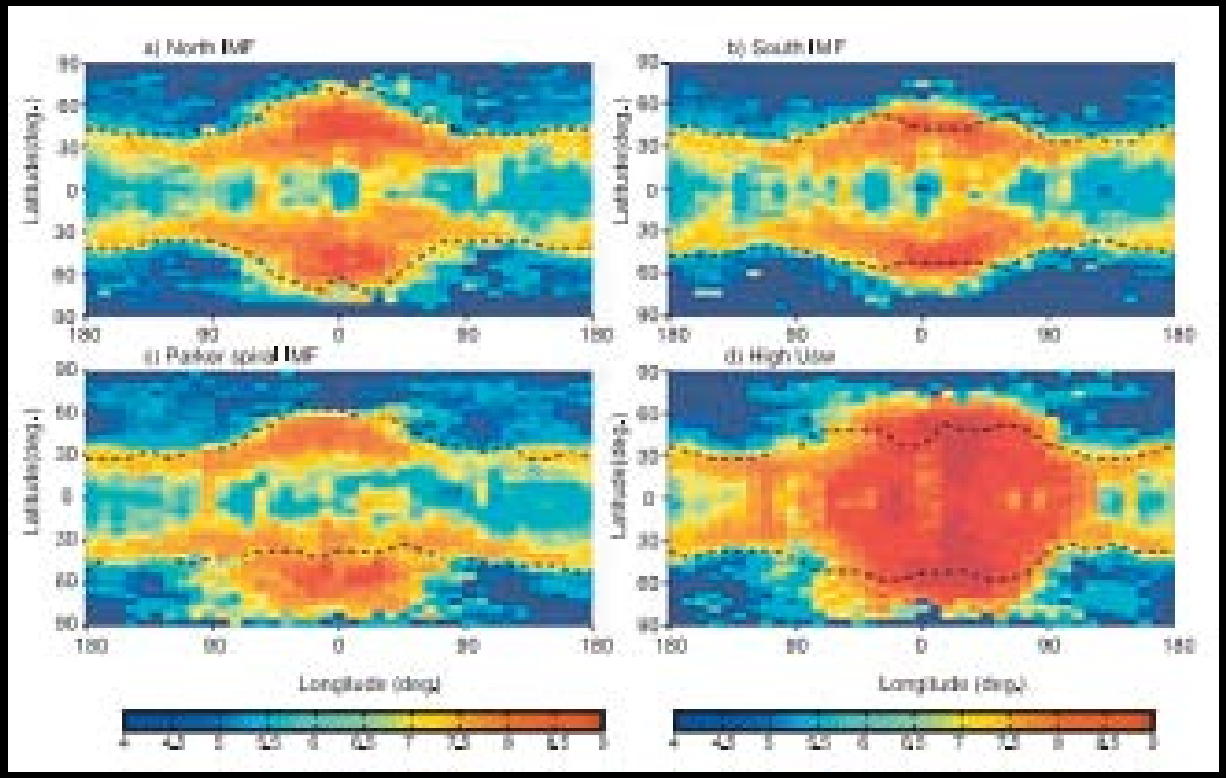
XY Plane

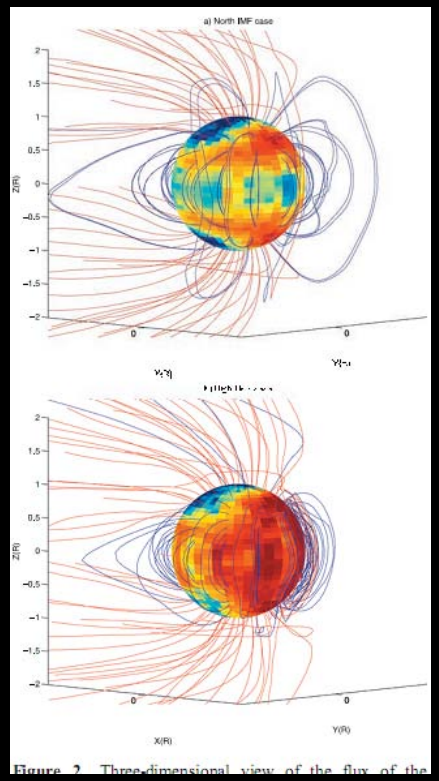
- Asymmetries in equatorial plane

Hybrid Models

Kalio and Janhunen (2003)

Northward IMF





Northward IMF

Southward IMF

Southward IMF

Parker Spiral

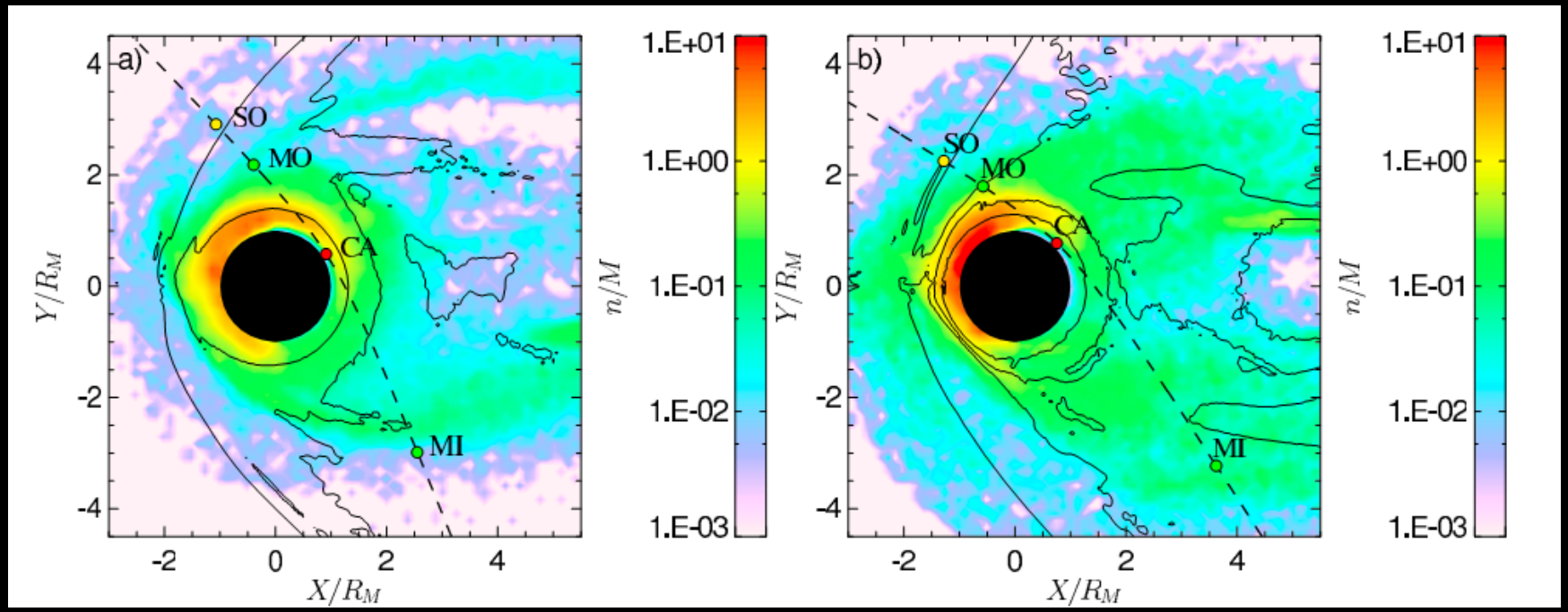
High Solar Wind

High Solar Wind

Hybrid Models

Paral and Tráveníčk (2010)

Na^+ Equatorial density M1 and M2 Encounters (log scale)



Northward IMF

Southward IMF

- Include temperature anisotropies
- Drift-driven plasma belt for Na^+
- Enhancement in pre-dawn sector

Types of Models

MHD

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Hybrid

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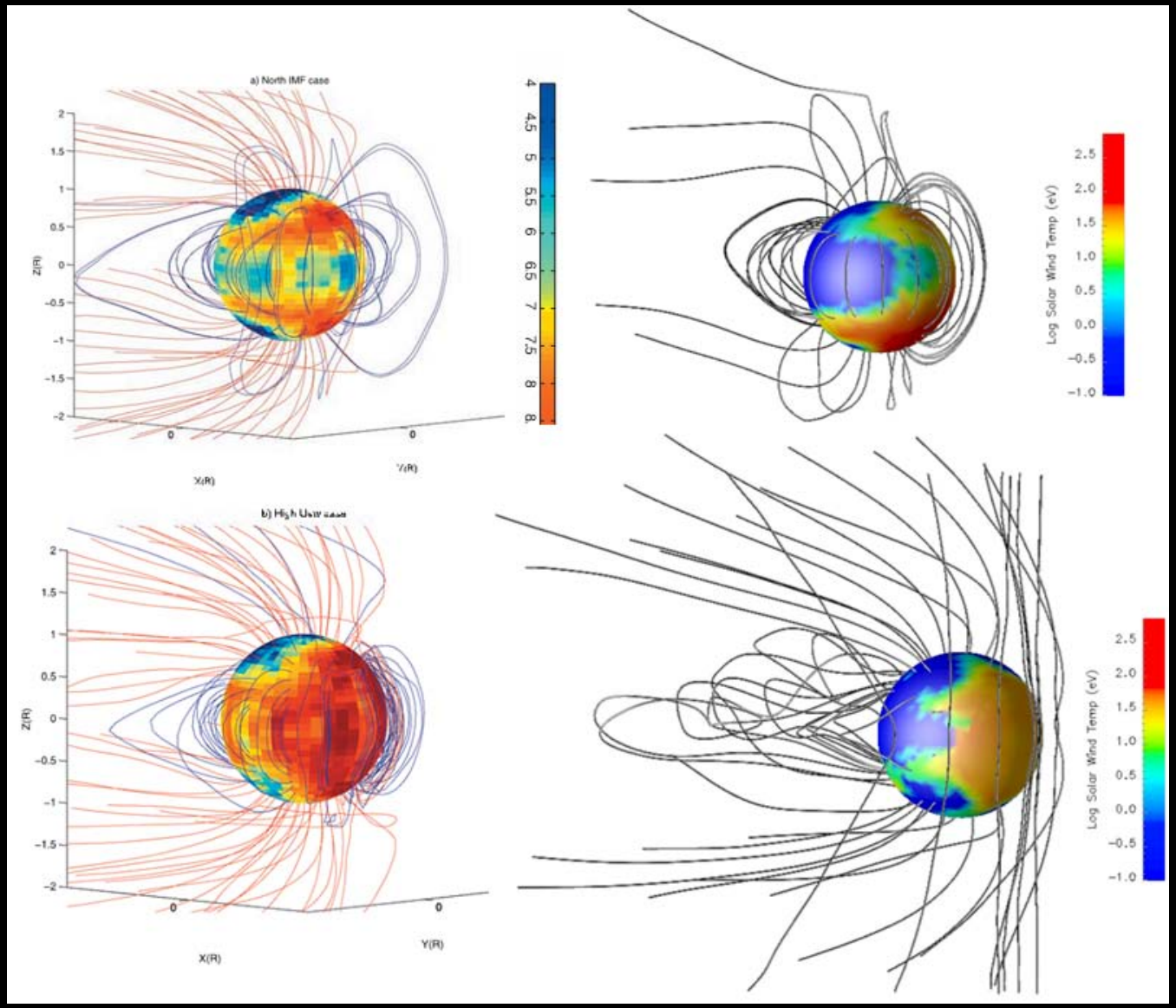
- smaller scale

Multi-Fluid

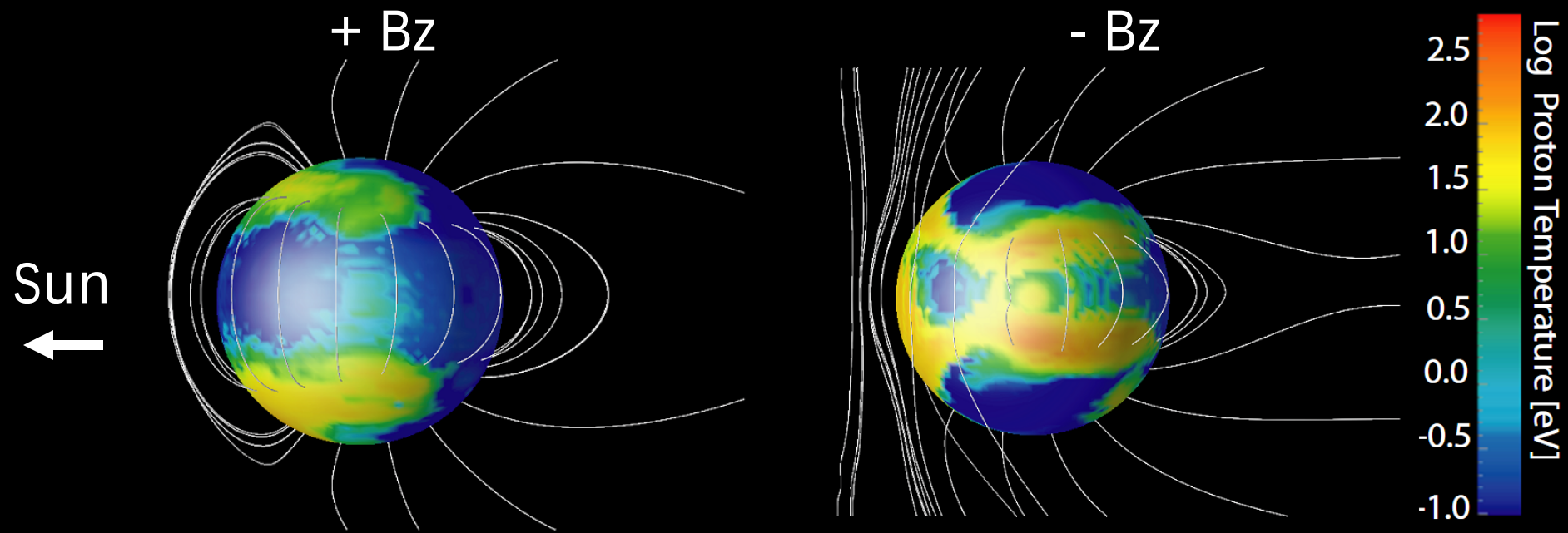
- three ion fluids, fluid electrons
- global scale

Hybrid: Kallio & Janhunen Multi-Fluid: Kidder & Winglee



- Good agreement for solar wind access to the planet

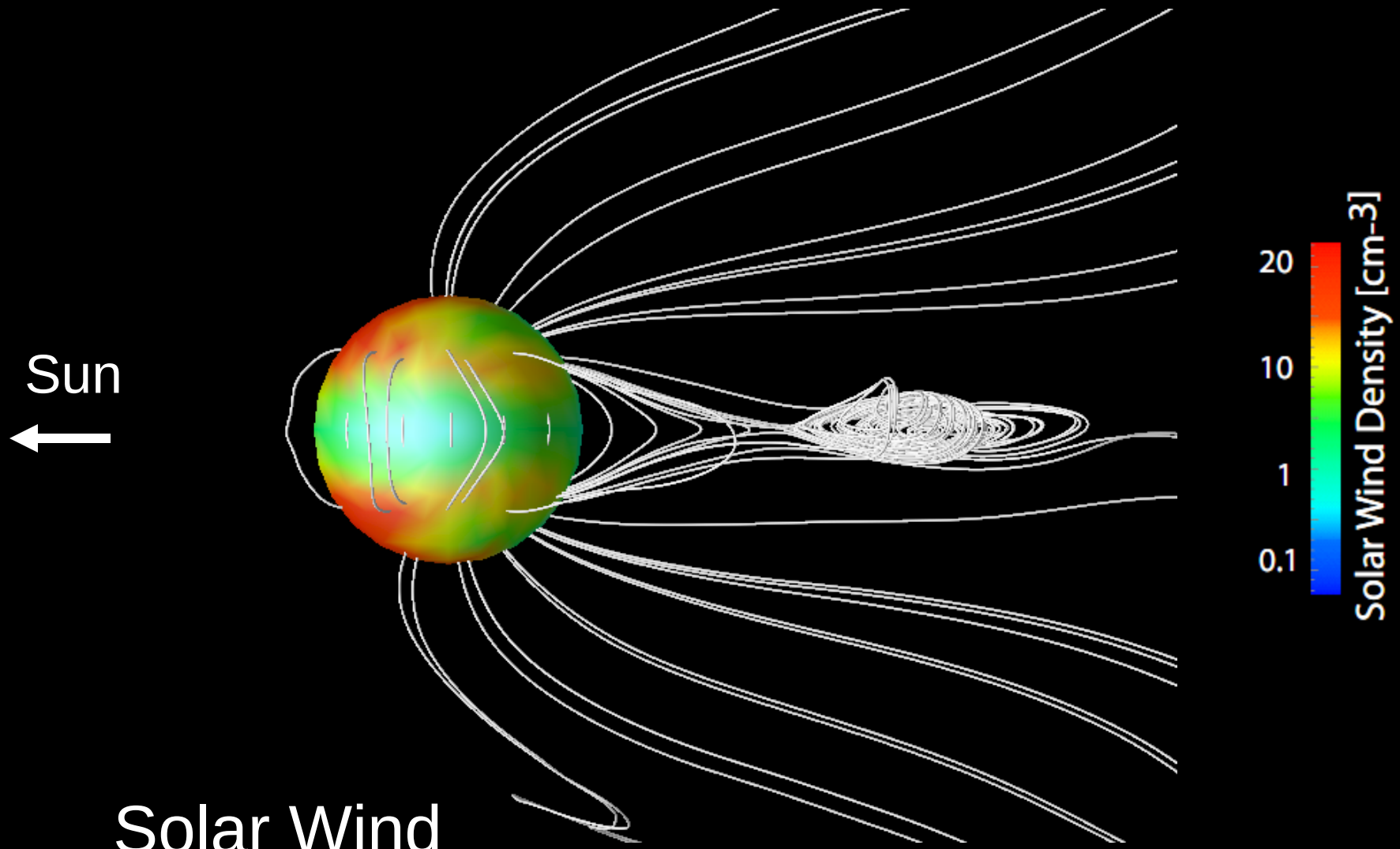
Multi-fluid Model (erosion of dayside magnetosphere)



Kidder et al., 2008

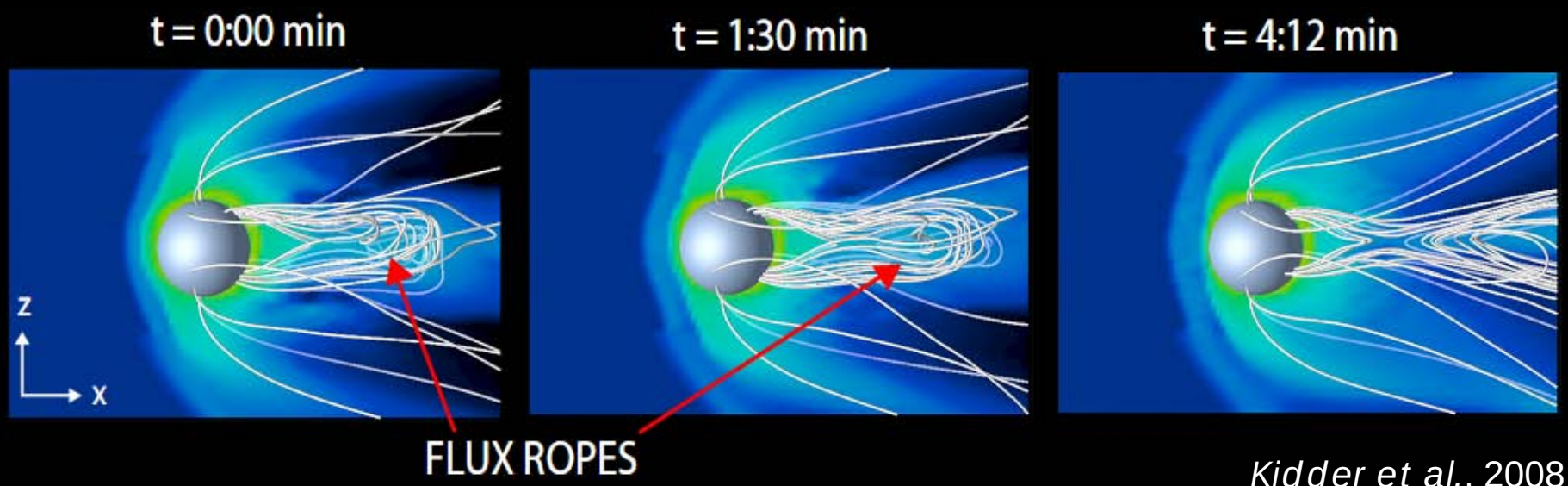
- Separatrix moves down in latitude (from 75° to 65°)
- Bow shock ($+B_z$=1.8 R_M, -Bz=1.3 R_M)
- Magnetopause ($+B_z$=1.4 R_M, $-B_z$ = 1.1 R_M)

Multi-Fluid Model



Solar Wind
Precipitation

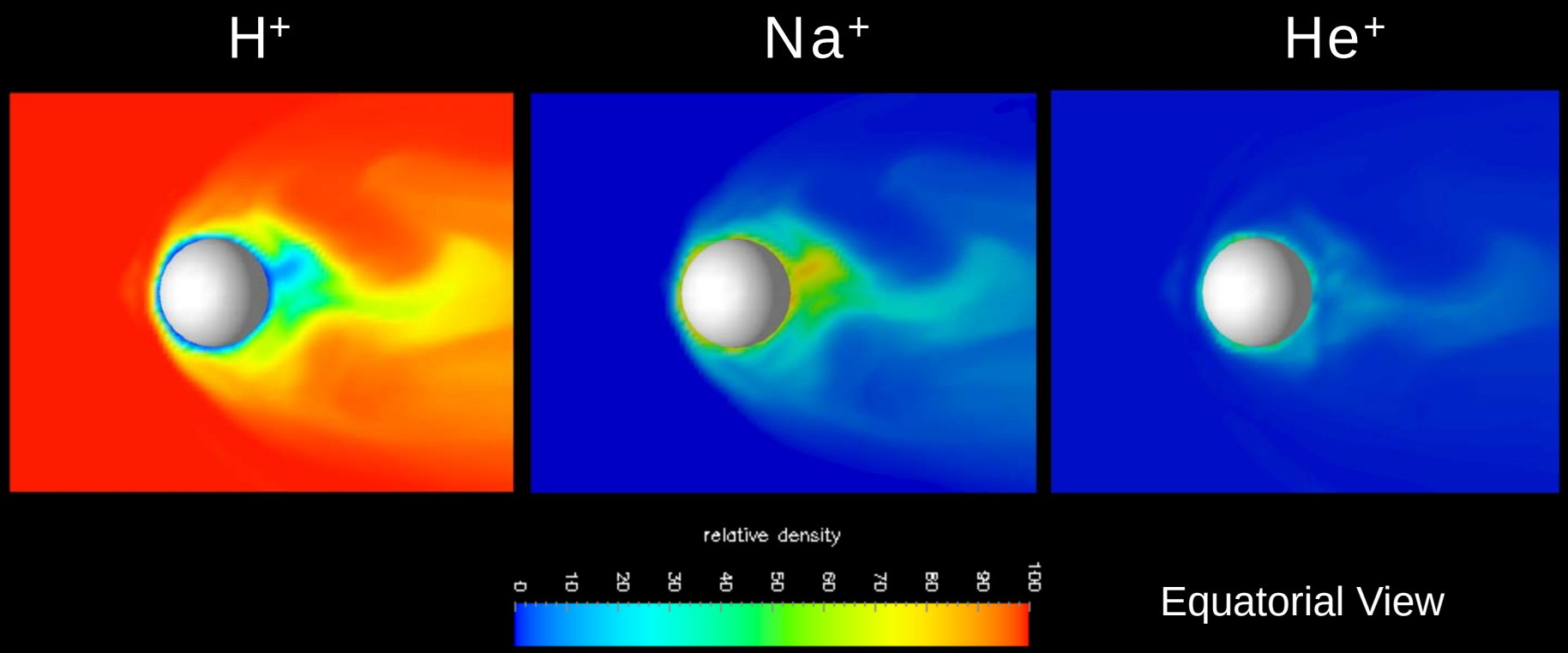
Flux ropes form on short time scales



Kidder et al., 2008

3rd flyby: Loading and unloading of magnetic flux

Relative Densities During Reconnection



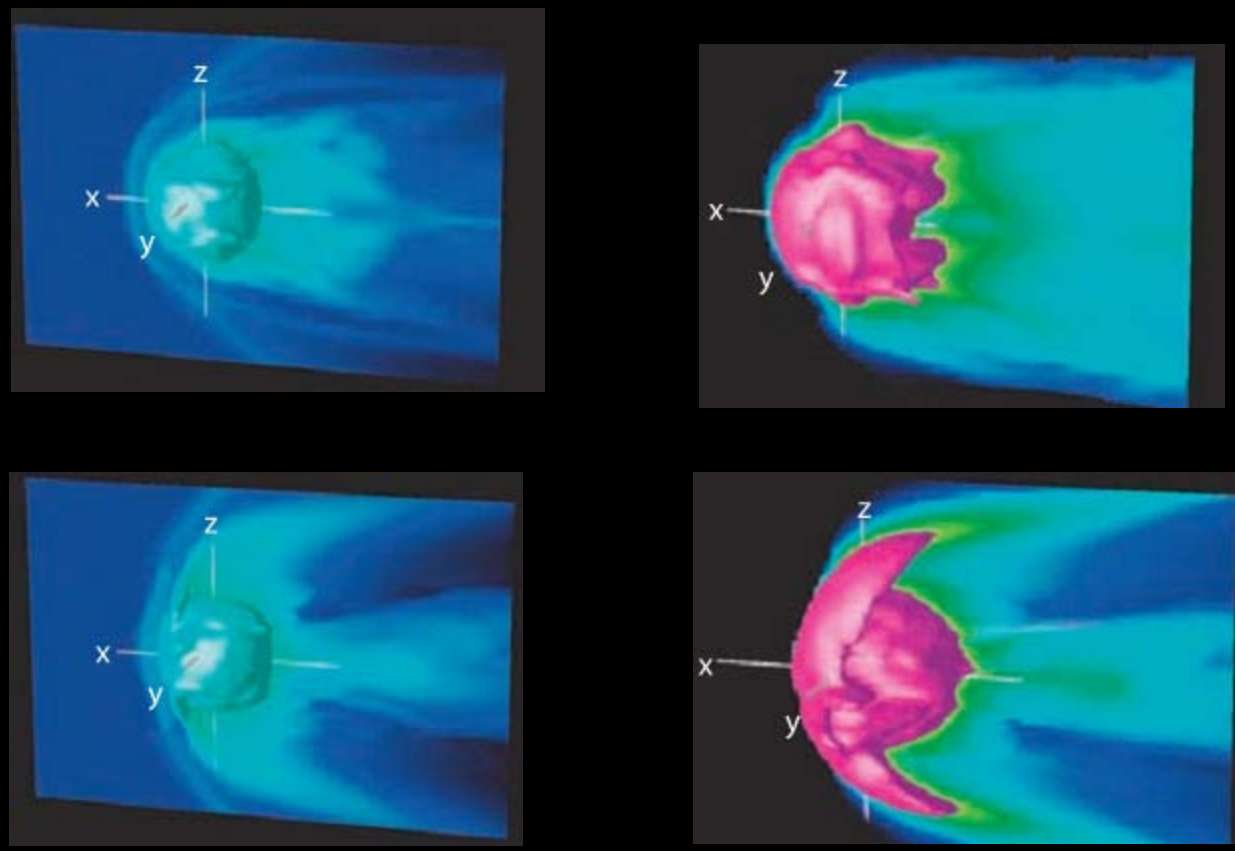
Equatorial View

Local Regions dominated by Solar Wind H^+ -
IMF and Time dependent

Na^+ outflows on short time scales

$+B_Z$ $-B_Z$

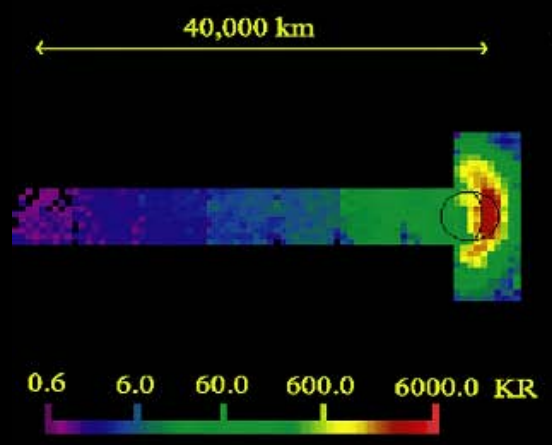
Sun



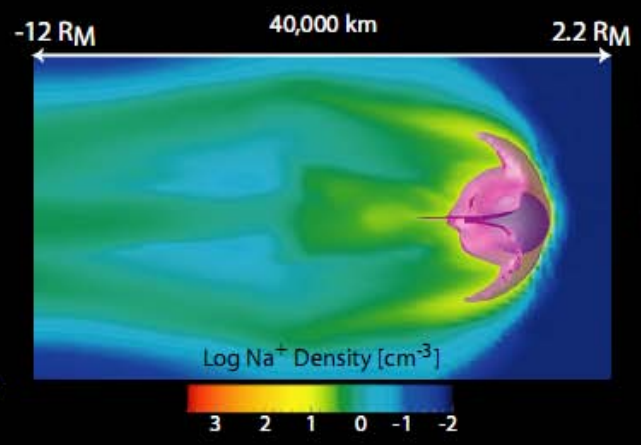
= He^+ isosurface = Na^+ isosurface

Kidder et al., 2008

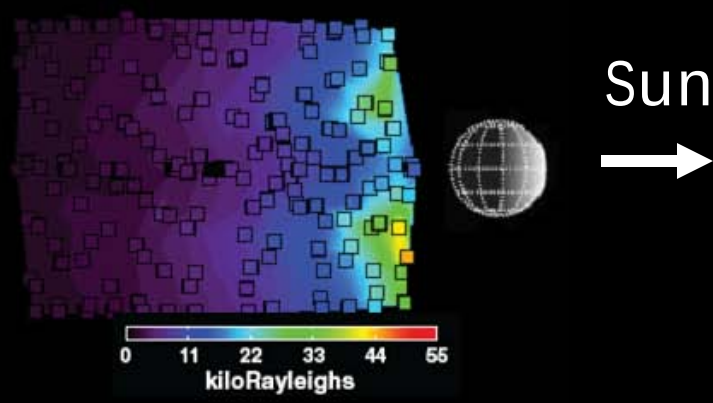
Na^+ outflows on short time scales



Ground-Based Obs.



Multi-Fluid Model



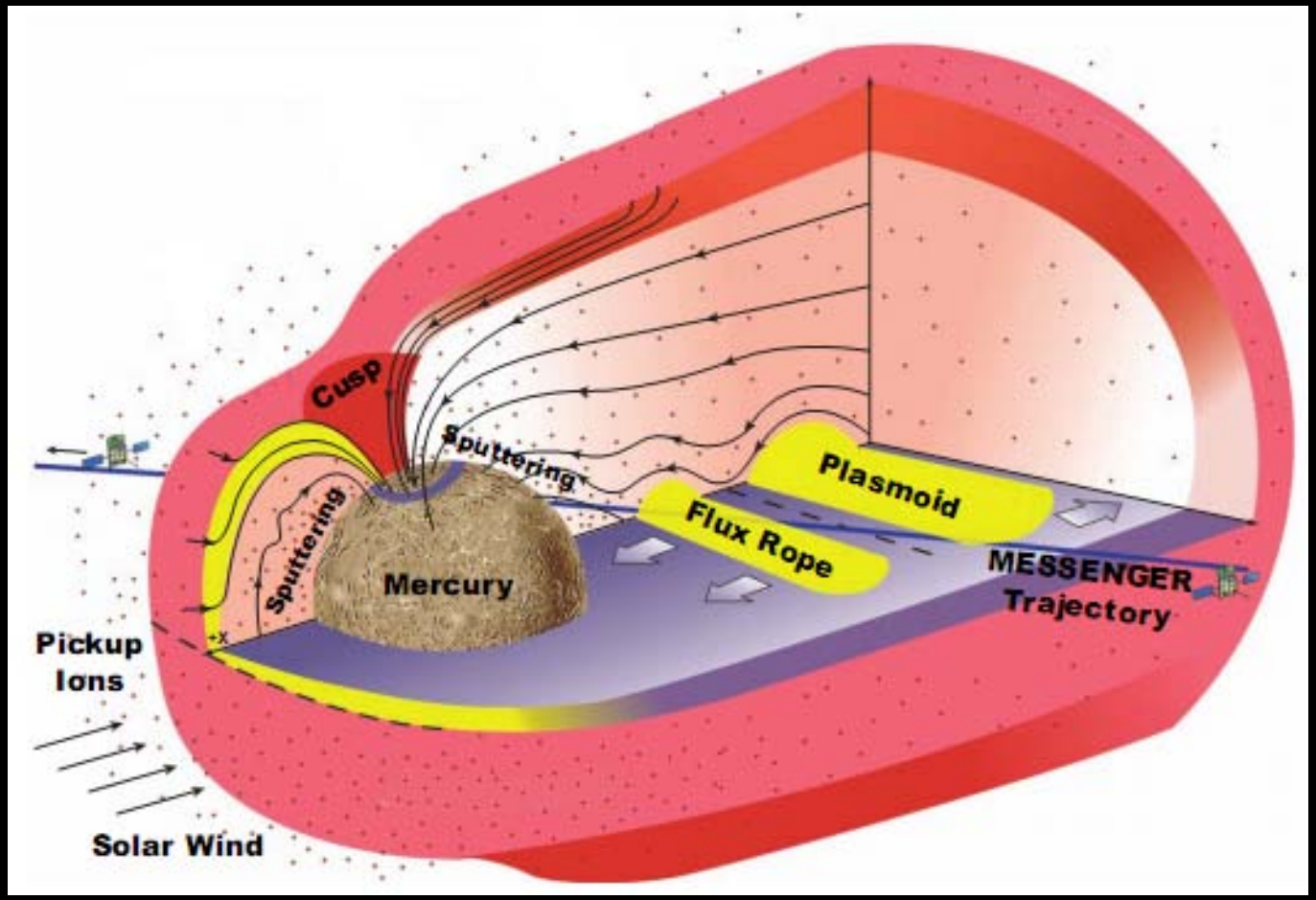
MESSENGER

Variation and asymmetry of the Na^+ outflow is an IMF influenced magnetospheric effect.

Future Work for Global Modeling

- Solar wind conditions from flybys + comparisons
- Extreme Loading and Unloading of Slavin et al.
- Mass dependent acceleration effects – Including Morphology of sodium ions under various upstream conditions
- Explanation of Flux Rope size and structures
- Substorms and current systems

Mercury's Magnetosphere



Slavin et al., 2009

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