3D MHD Modeling of Mercury's Magnetosphere During ICMEs

A. Glocer, M. Sarantos, J. Slavin

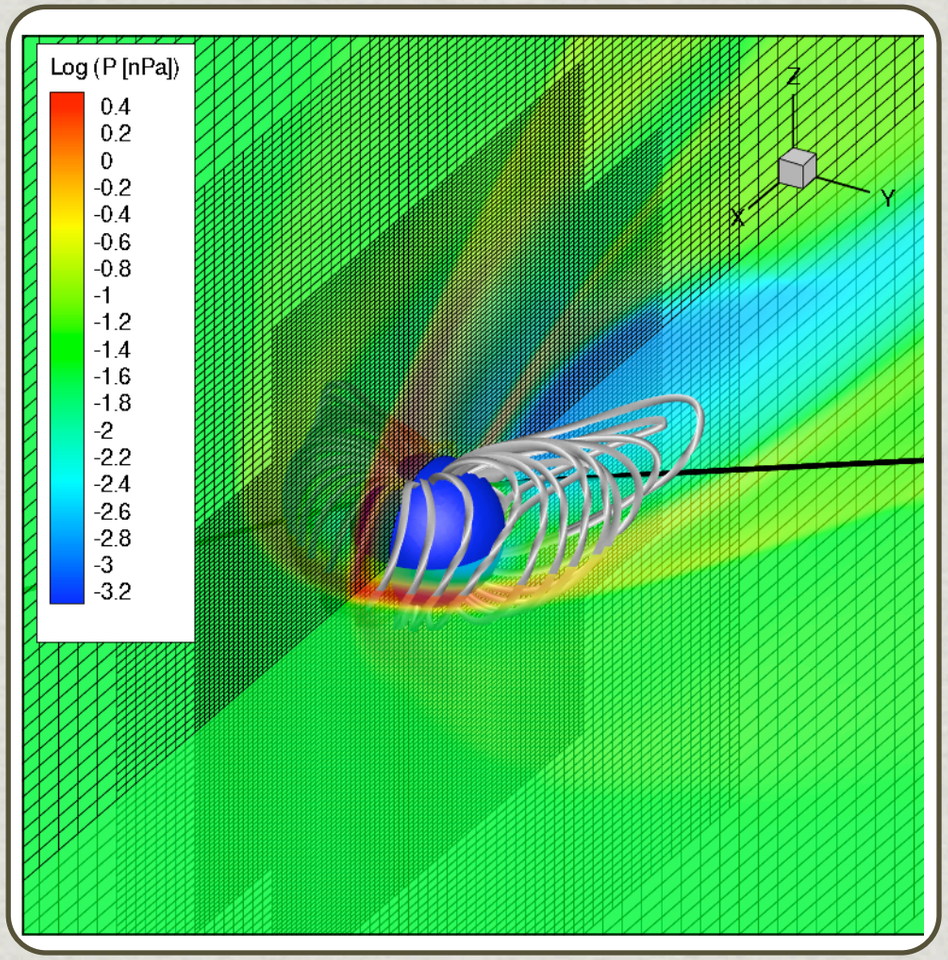
Outline

- Model description.
- Validation
  - Three boundary choices are considered:
    1. Floating
    2. Float ρ and p and $v_{||}$ pointing inward, reflect $v_{\perp}$ and $v_{||}$ pointing outward
    3. Float ρ, p, v_{Θ}, v_{Φ}, and $v_r<0$, reflect $v_r>0$
  - Use M1 and M2 as validation cases
- Mercury During ICMEs
  - Simulation of low M_A case
  - Simulation of Mercury interacting with an ICME

BATS-R-US

BLOCK ADAPTIVE TREE SOLAR-WIND ROE UPWIND SCHEME

- Conservative finite-volume discretization
- Shock-capturing TVD schemes
  - Rusanov, HLL/AW, Roe, HLLD
- Parallel block-adaptive grid
- Cartesian and generalized coordinates
- Explicit and implicit time stepping
- Classical, semi-relativistic and Hall MHD
- Multi-species and multi-fluid MHD
- Splitting the magnetic field into B0 + B1
- Various methods to control divergence B
- Nearly perfect scaling to more than 1000 processors



MAGNETOSPHERE DOMAIN:
INNER BOUNDARY LOCATION: 1.0 R_M
OUTER BOUNDARY: 32 R_M UPSTREAM AND 224 R_M DOWNSTREAM

Boundary

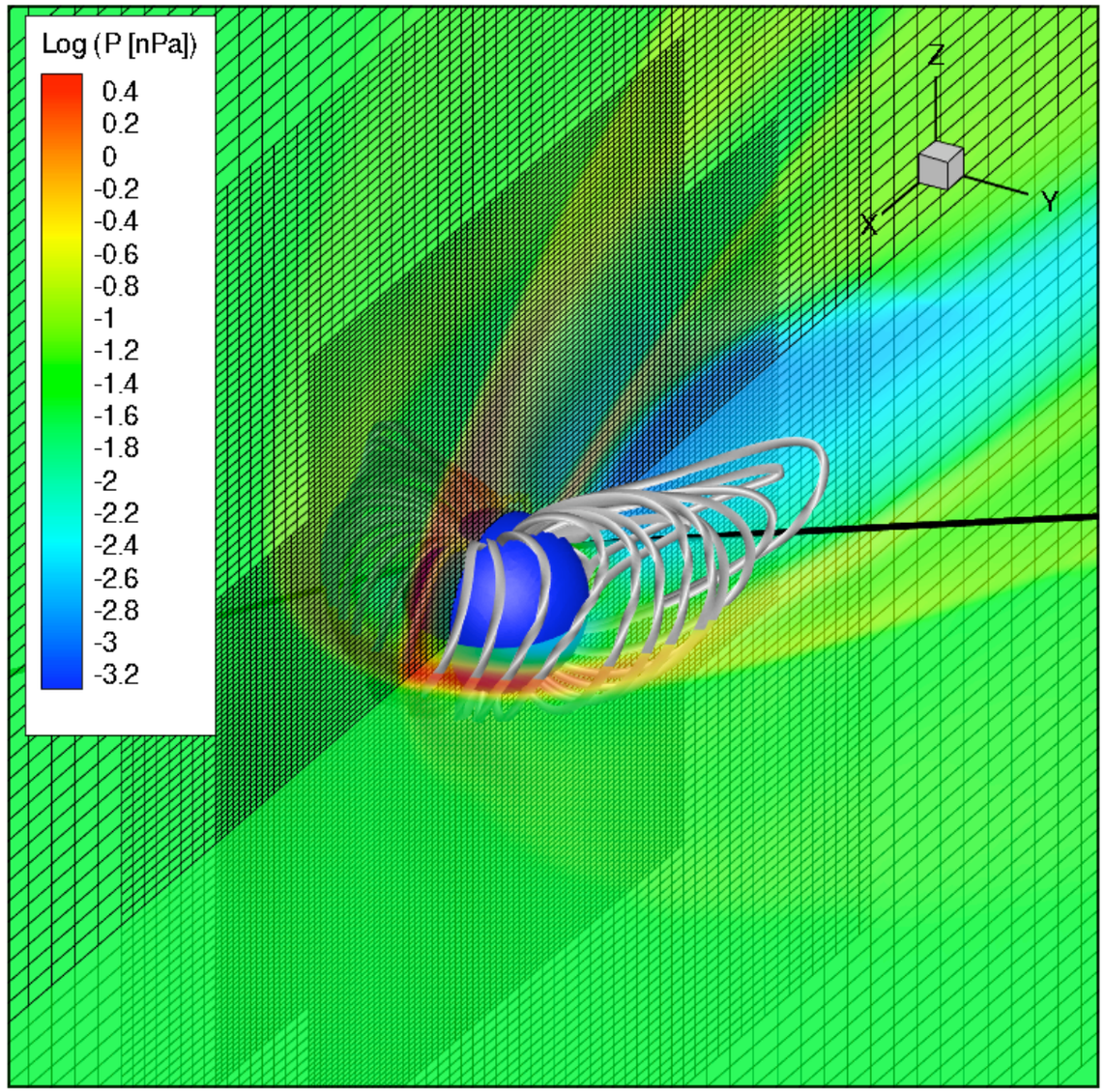
- The inner boundary condition has a huge effect on the solution.
- It is not immediately clear what the proper choice is.
- Several possibilities include:
  - Fixed BCs
  - Floating BCs
  - Float, B_1 ρ and p and $v_{||}$ pointing inward, reflect $v_{\perp}$ and $v_{||}$ pointing outward
  - Float, B_1 ρ, p, v_{Θ}, v_{Φ}, and $v_r<0$, reflect $v_r>0$
- Other questions: Conductance, FACs

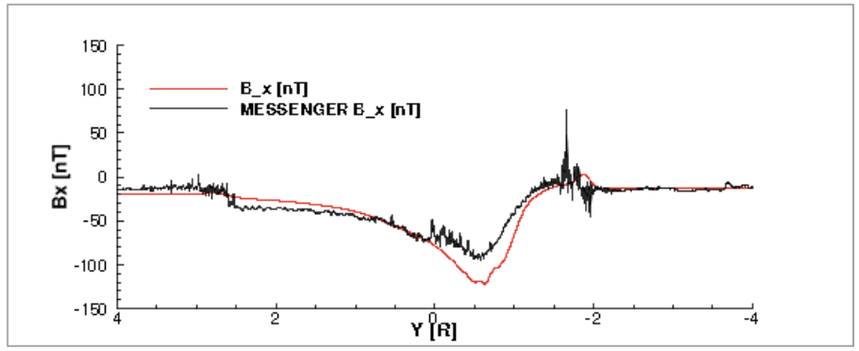
Boundary Testing Strategy

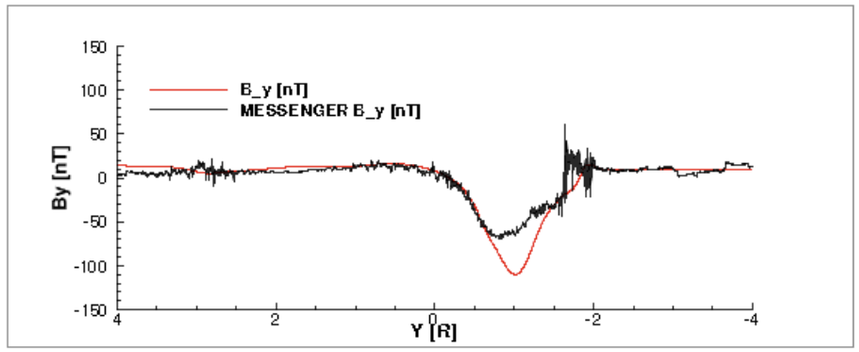
- To test the effect of the inner boundary we simulate the M1 and M2 flybys
- The solution is extracted along the MESSENGER trajectory and directly compared to MAG data
- These runs are also used to test dipole strength and displacement (final choice ~200 nT, displaced .18 northward)
- Compare the effect of boundary on closed field line region, precipitating flux

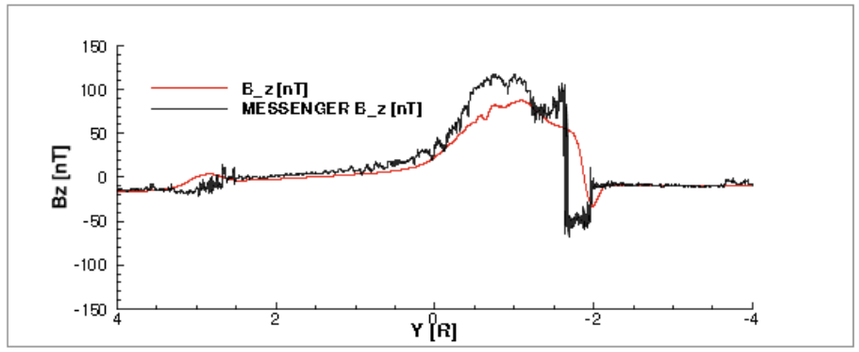
BC1

Mercury During MESSENGER's Second Flyby



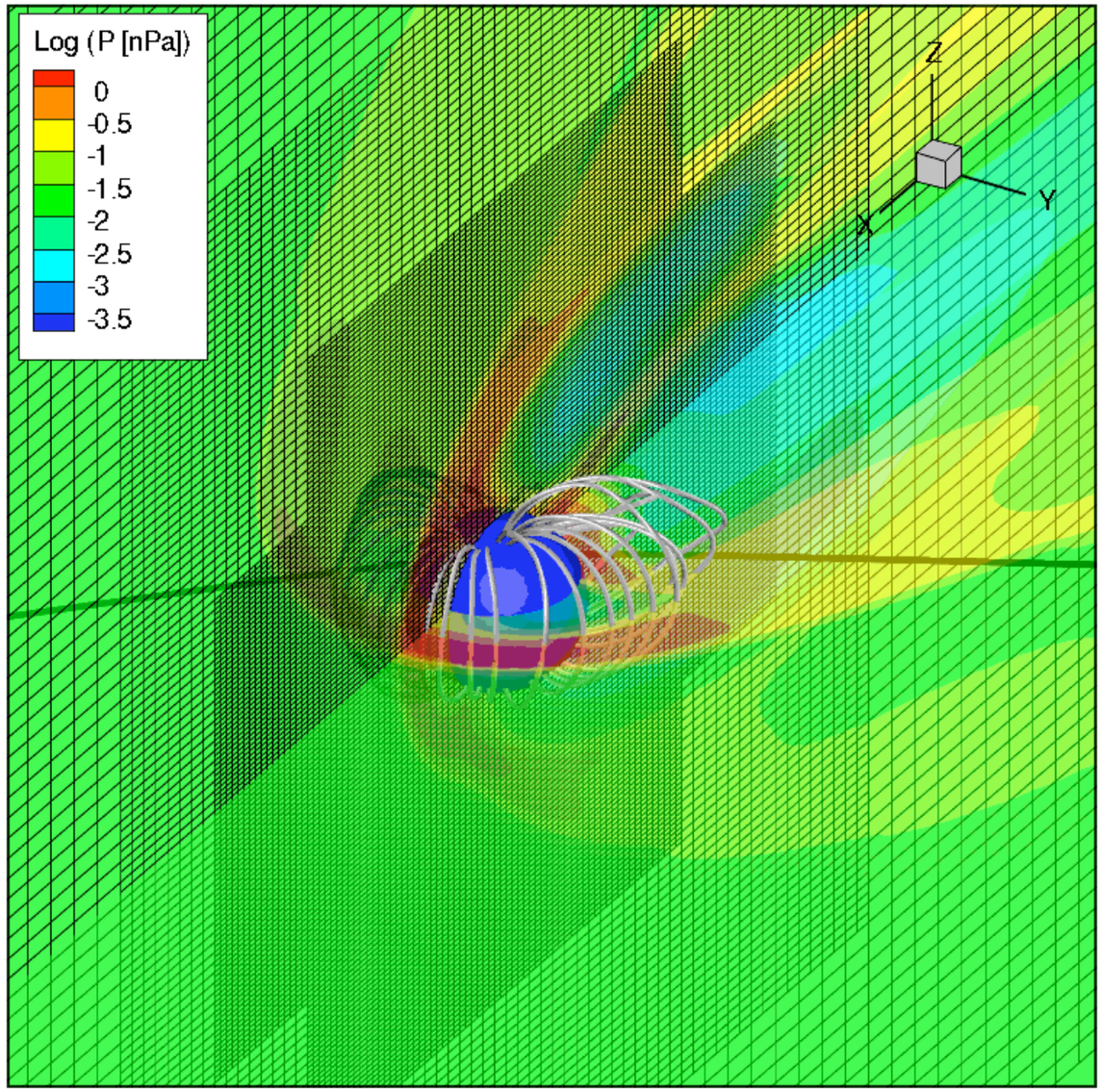


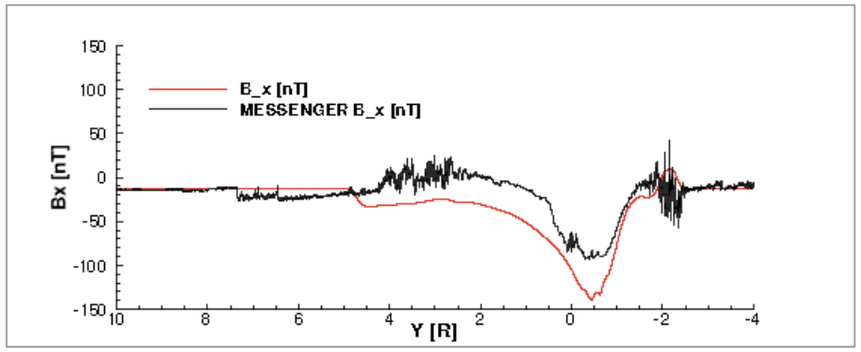


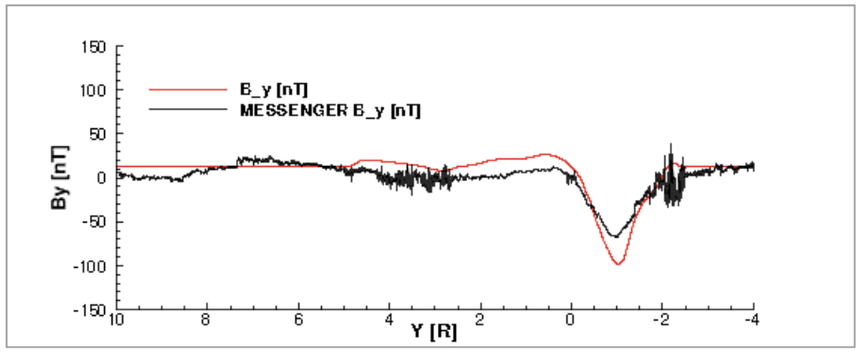


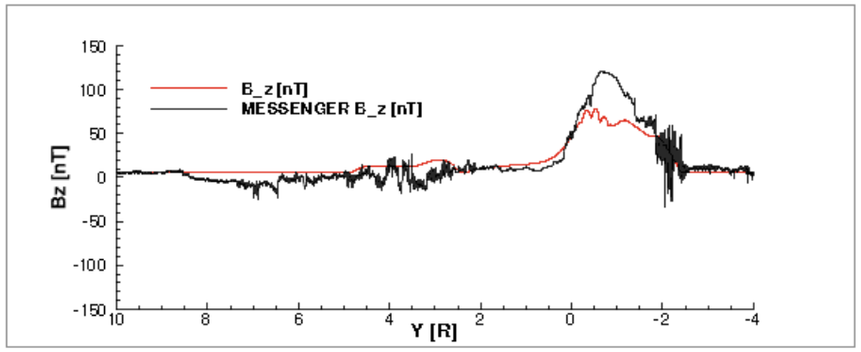
BC1

Mercury During MESSENGER's First Flyby



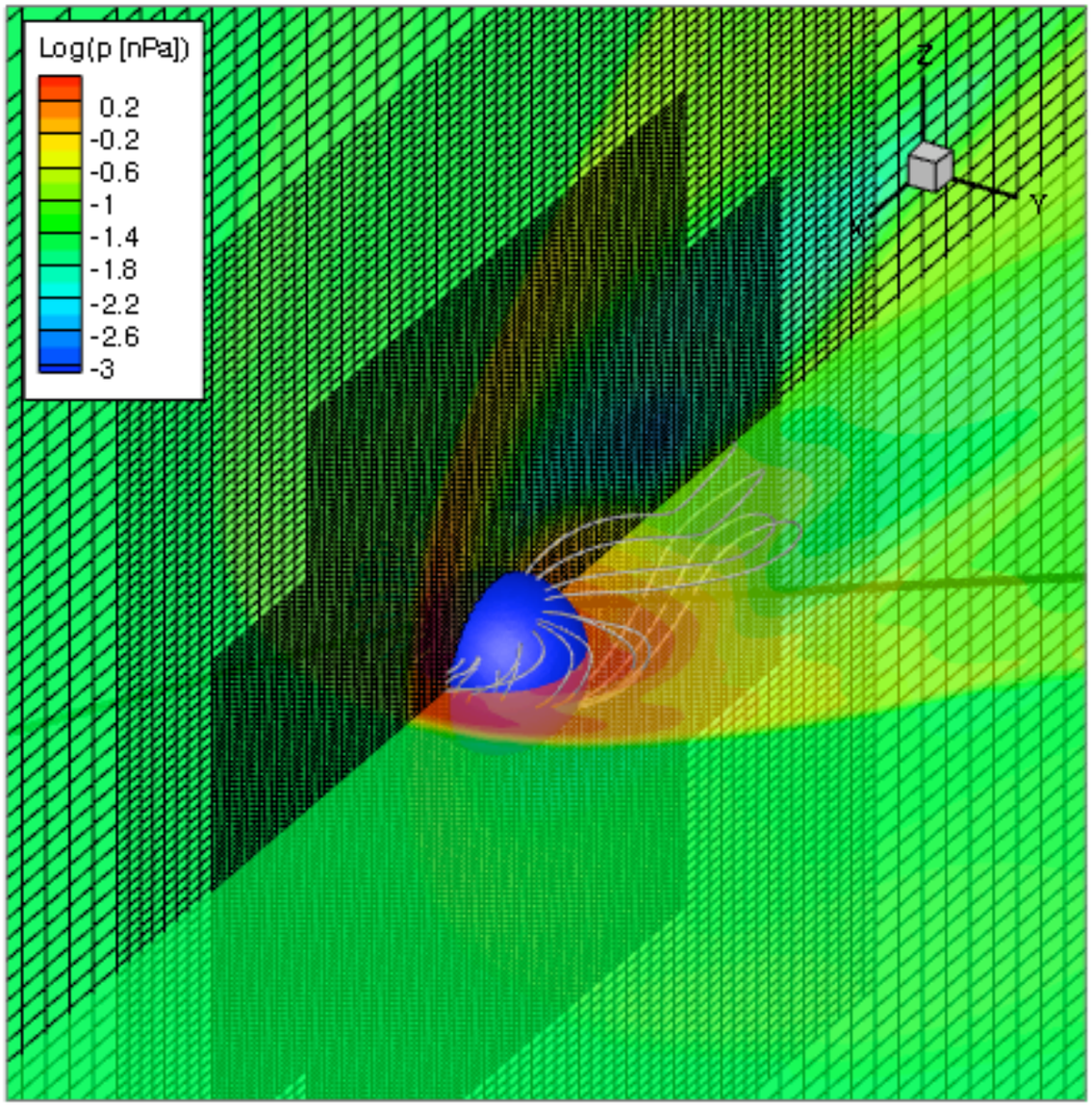


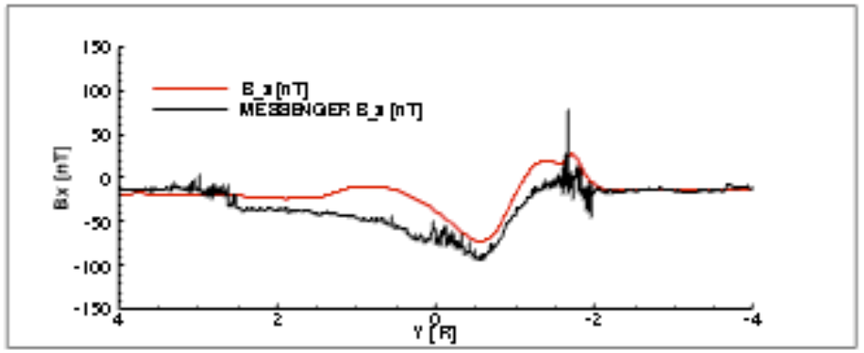


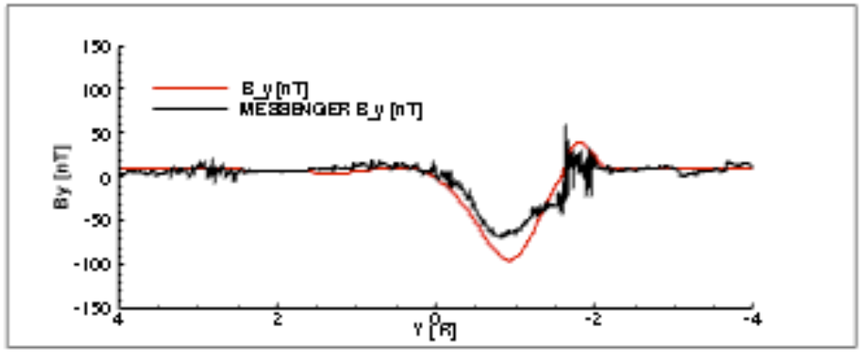


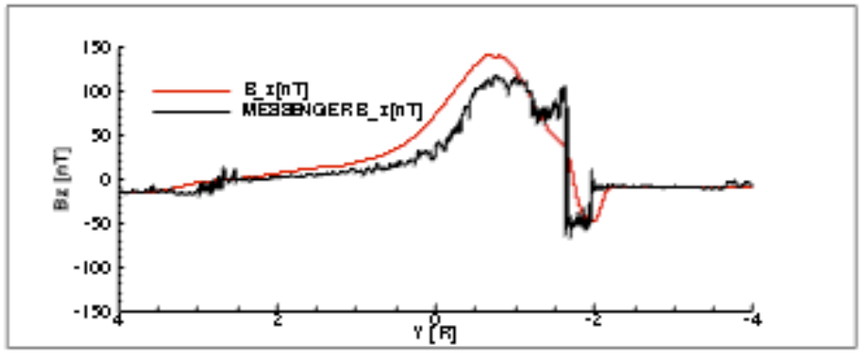
BC2

Mercury During MESSENGER's Second Flyby



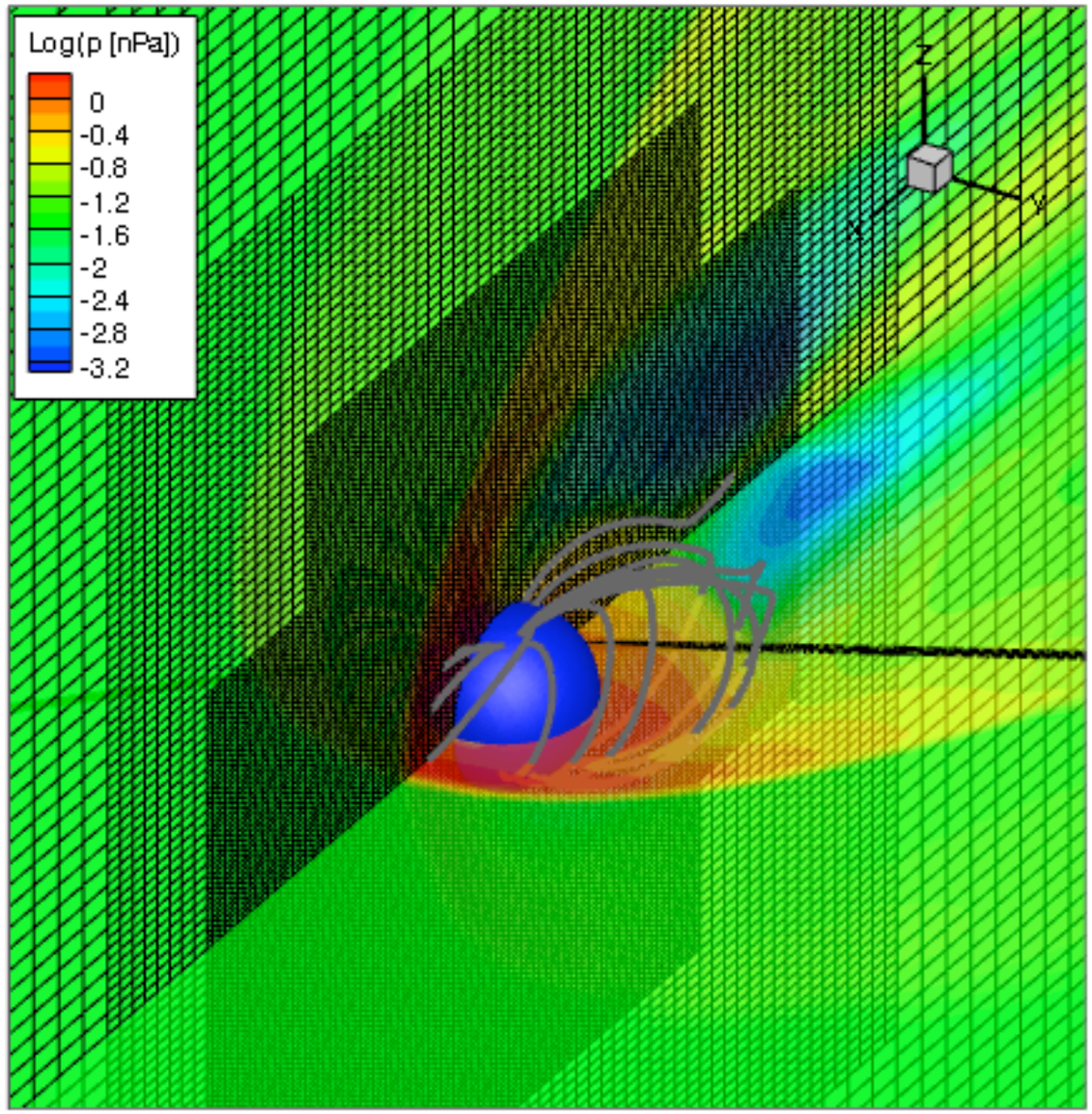


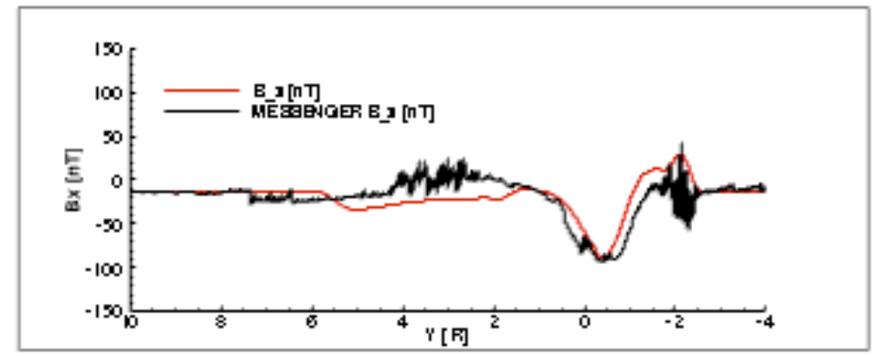


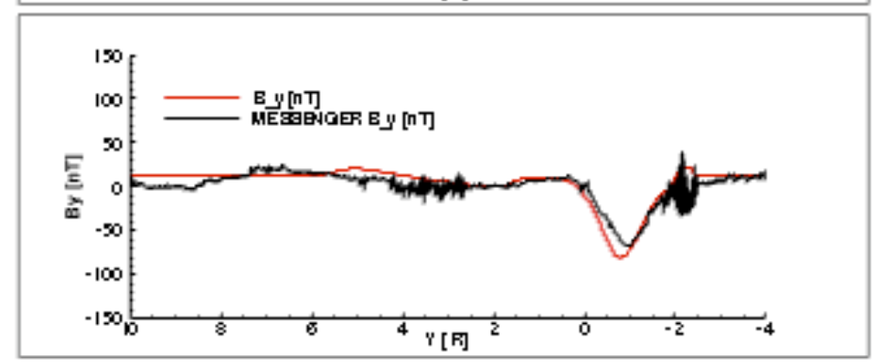


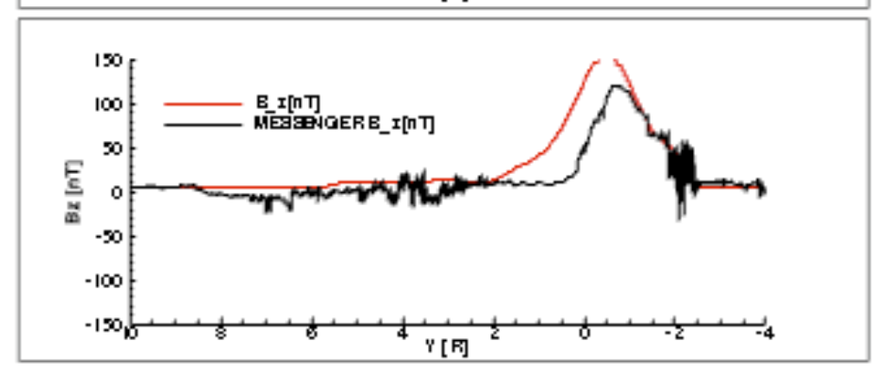
BC2

Mercury During MESSENGER's First Flyby



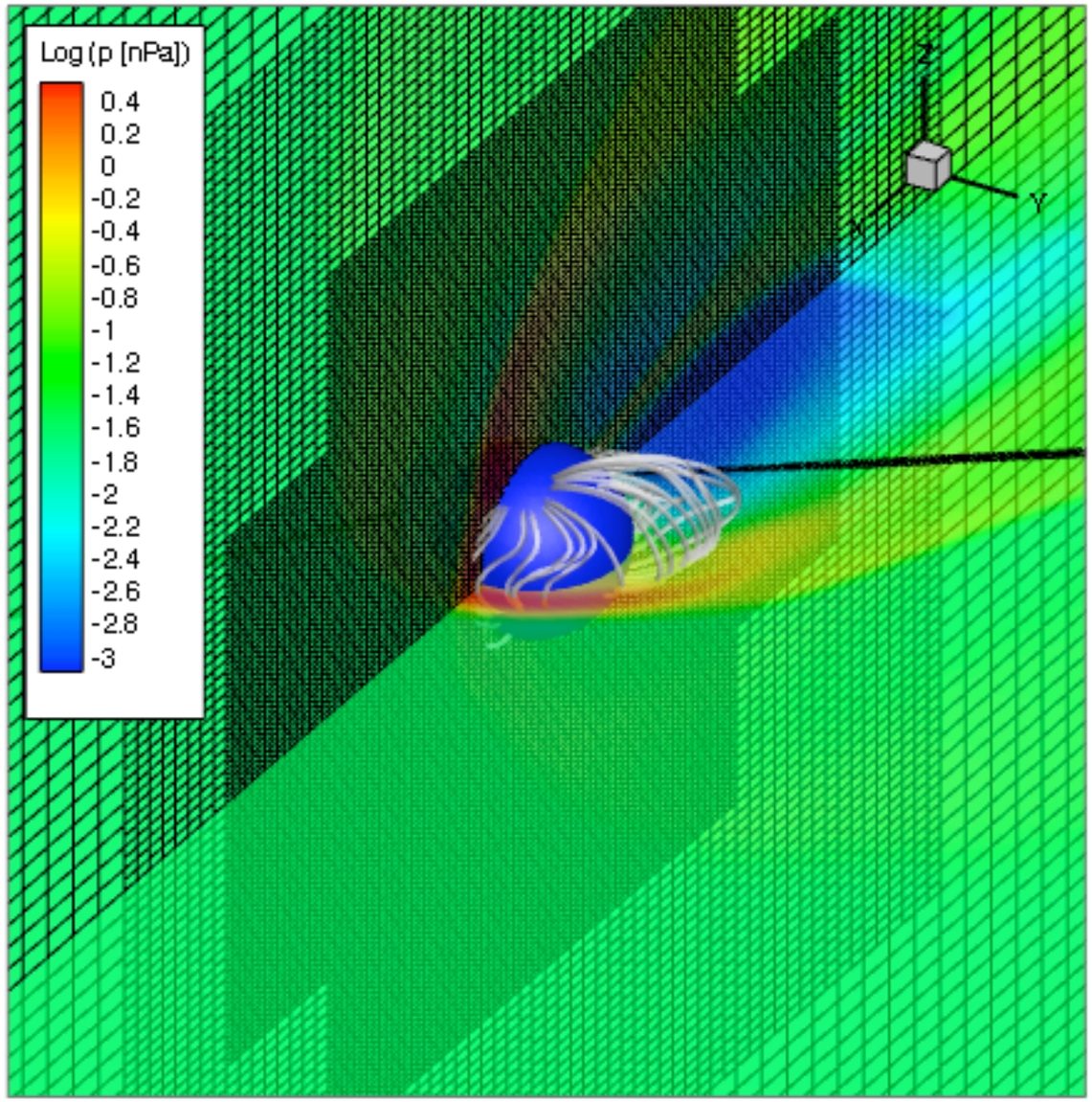


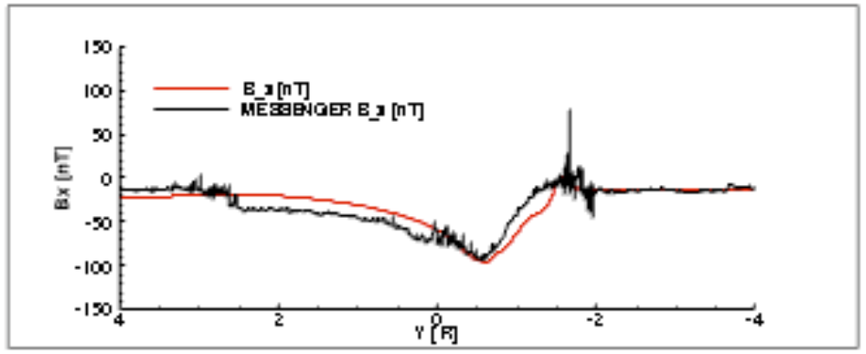


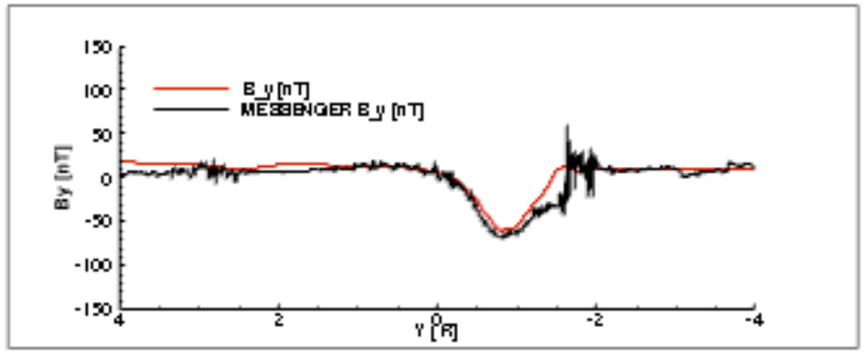


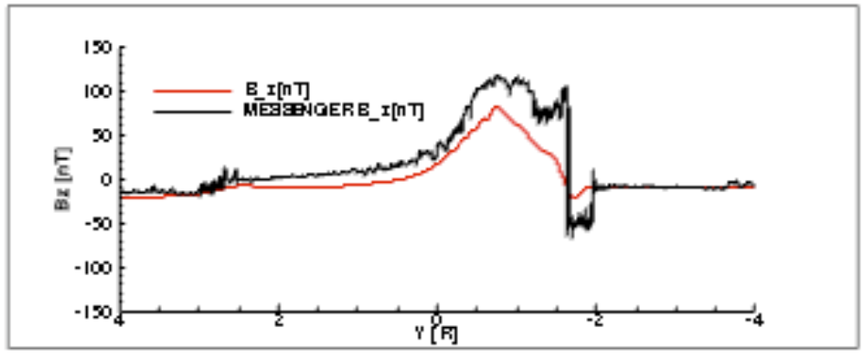
BC3

Mercury During MESSENGER's Second Flyby



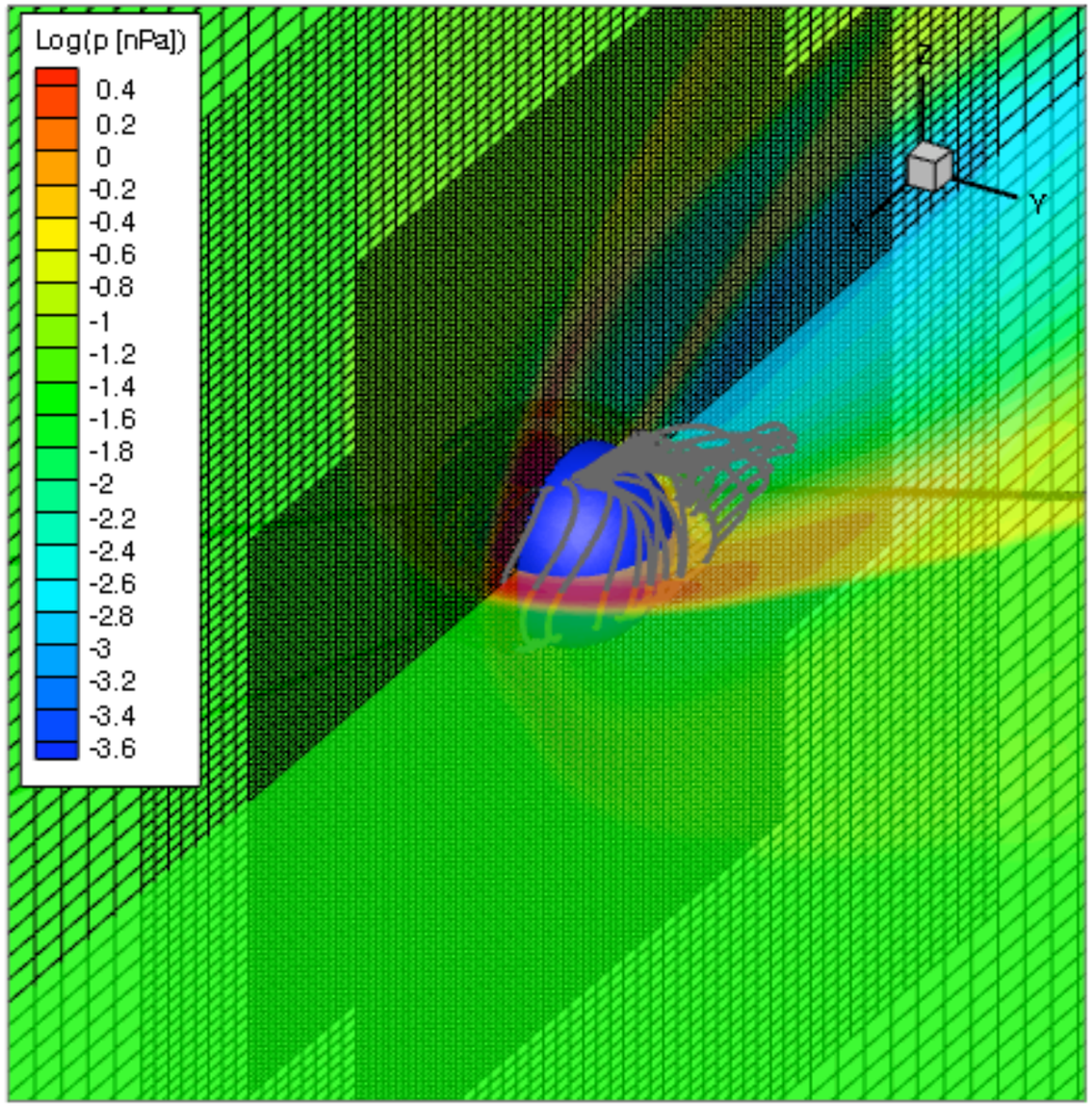


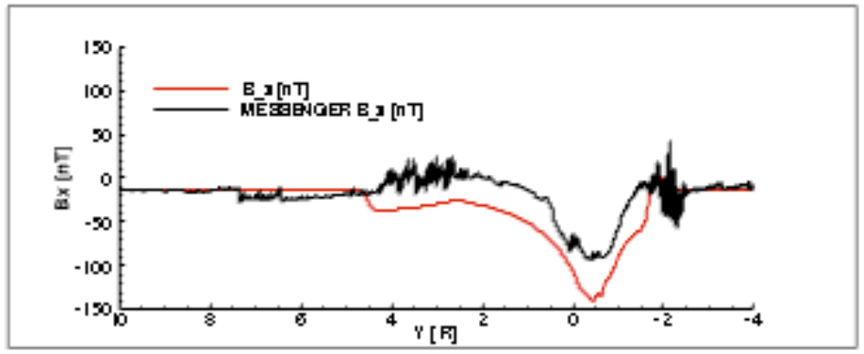


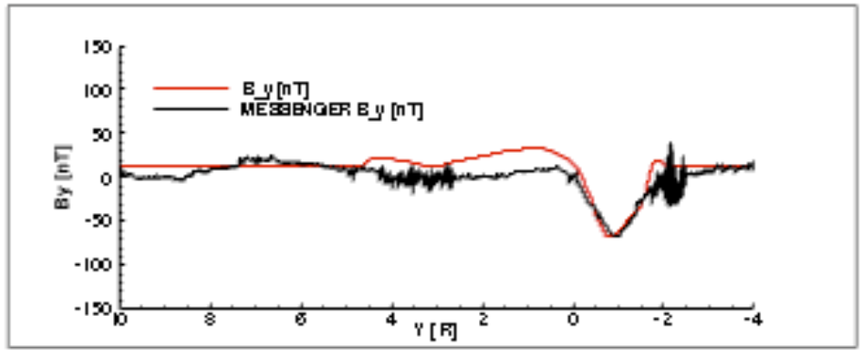


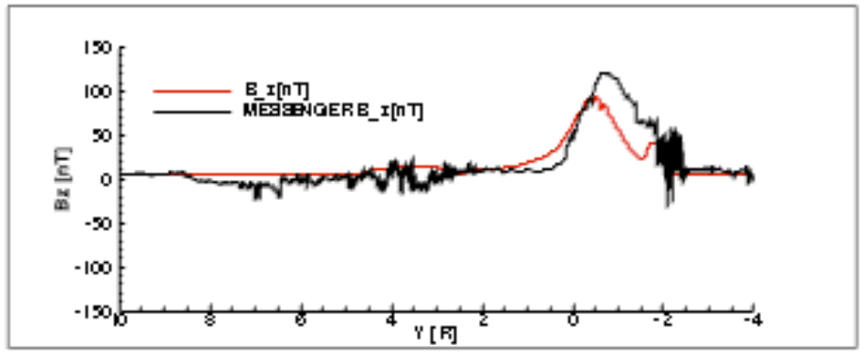
BC3

Mercury During MESSENGER's First Flyby





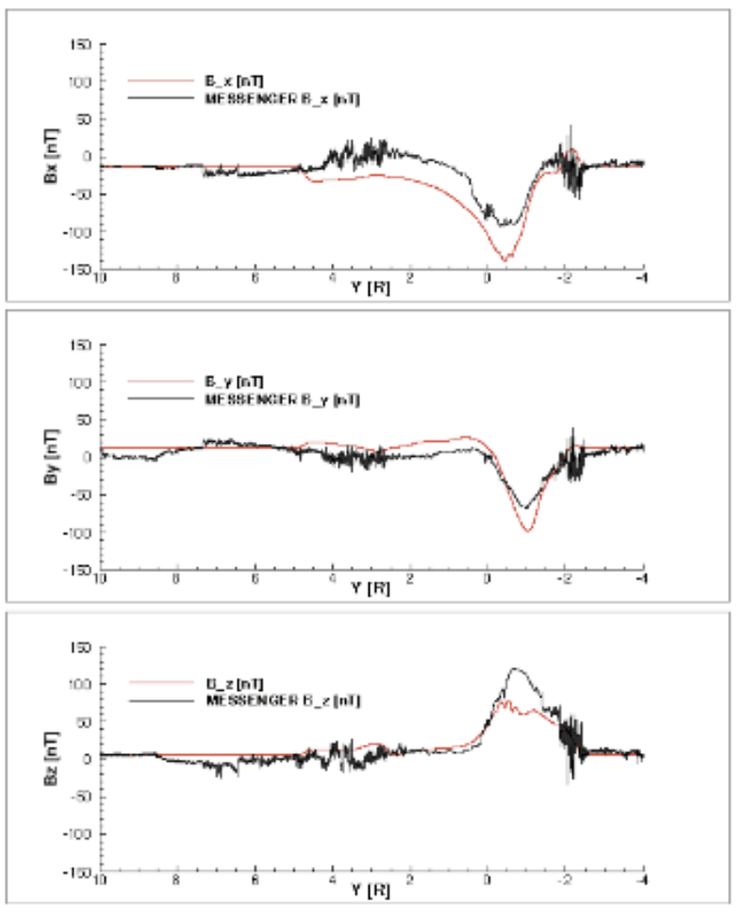




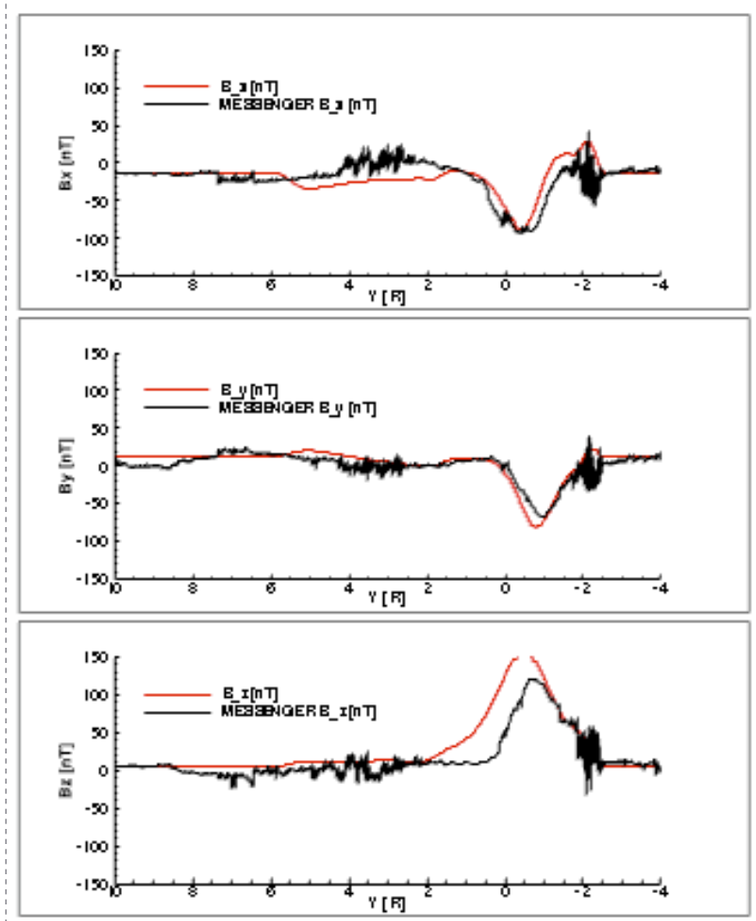
Boundary Comparison

M1 Flyby

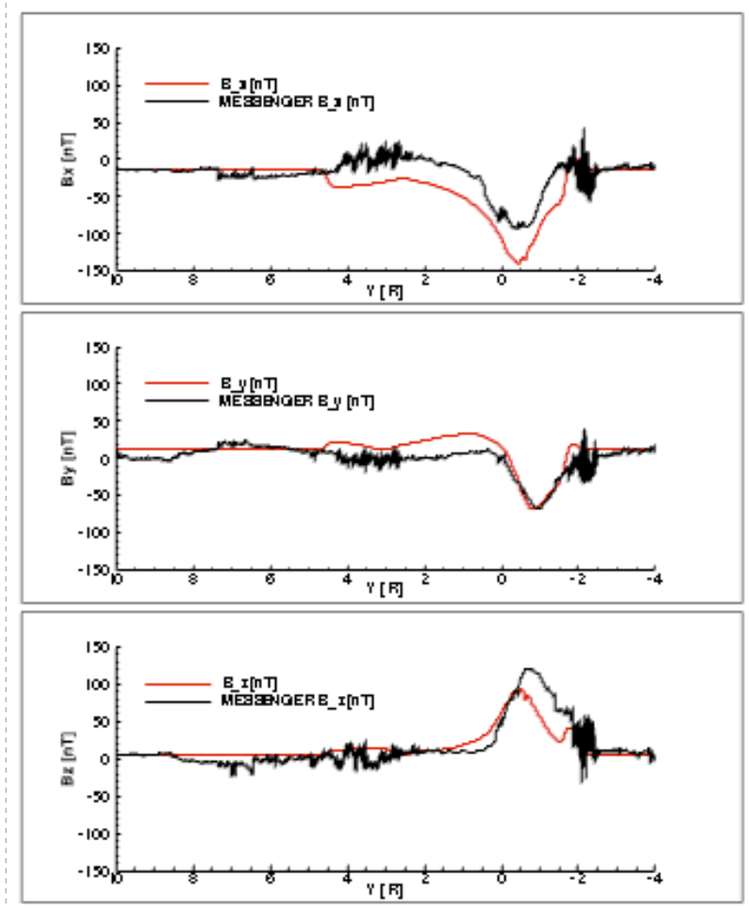
BC-1



BC-2



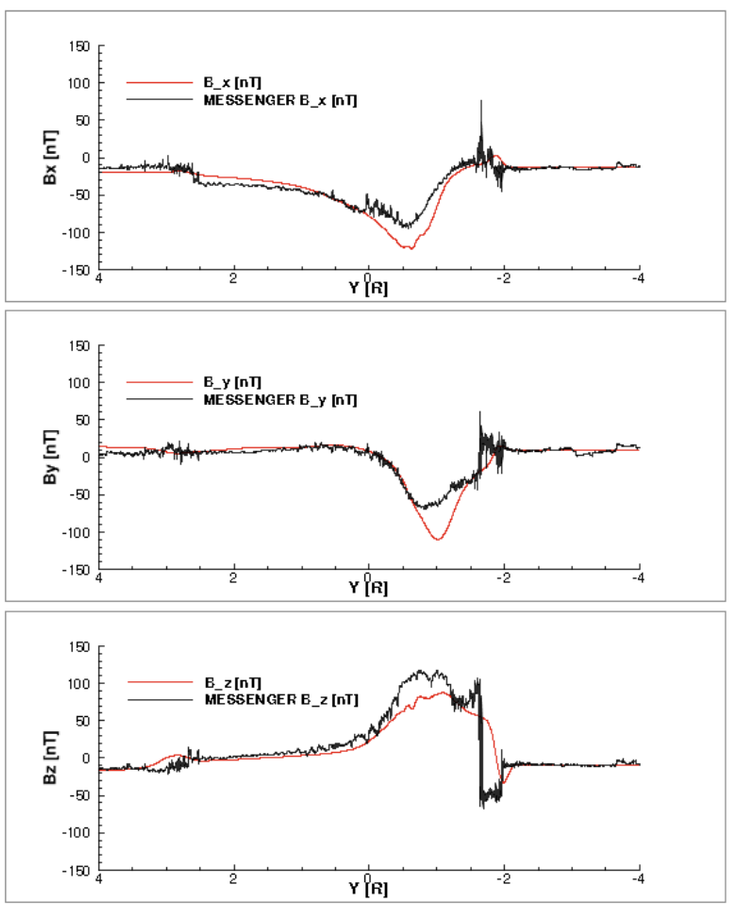
BC-3



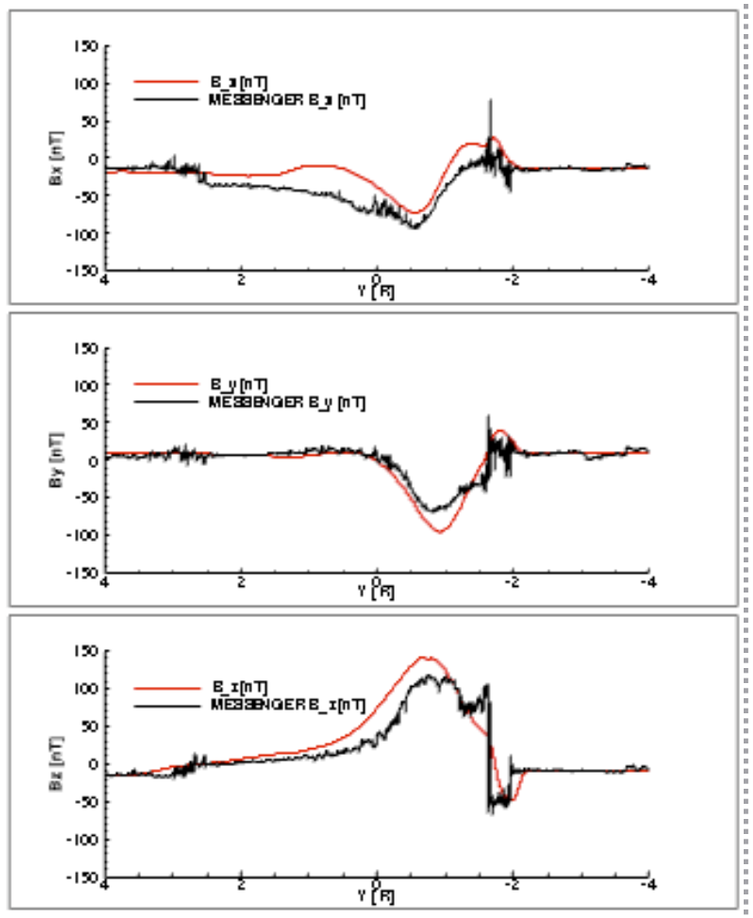
Boundary Comparison

M2 Flyby

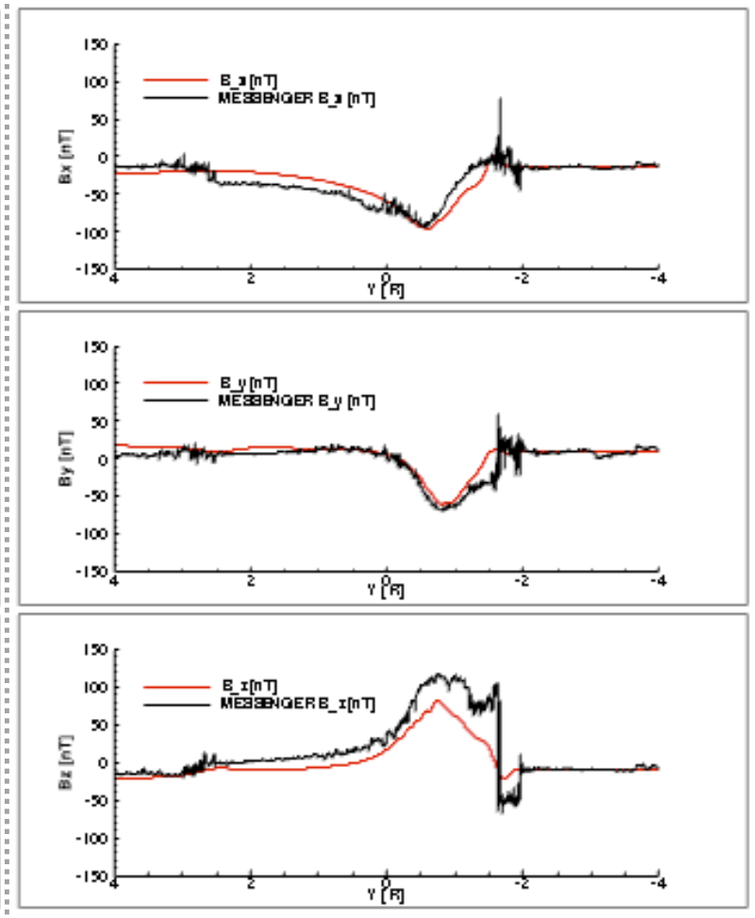
BC-1



BC-2

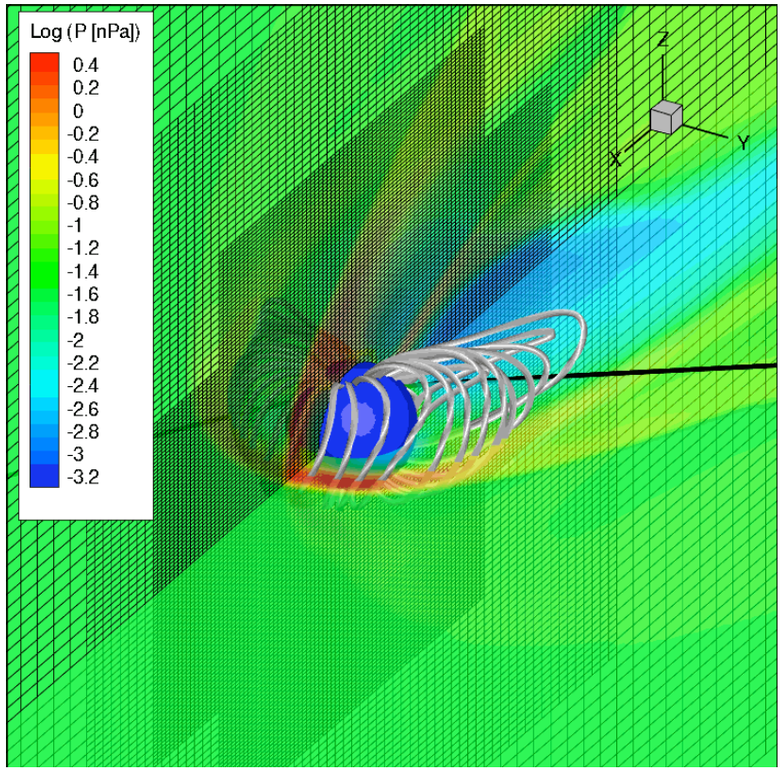


BC-3

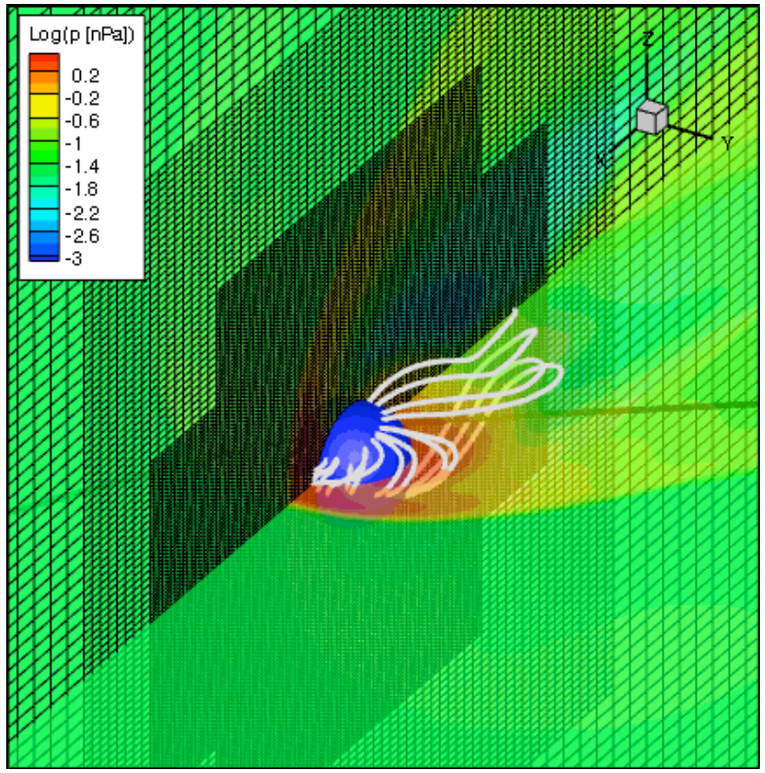


Boundary Comparison
Closed B-Field During M2

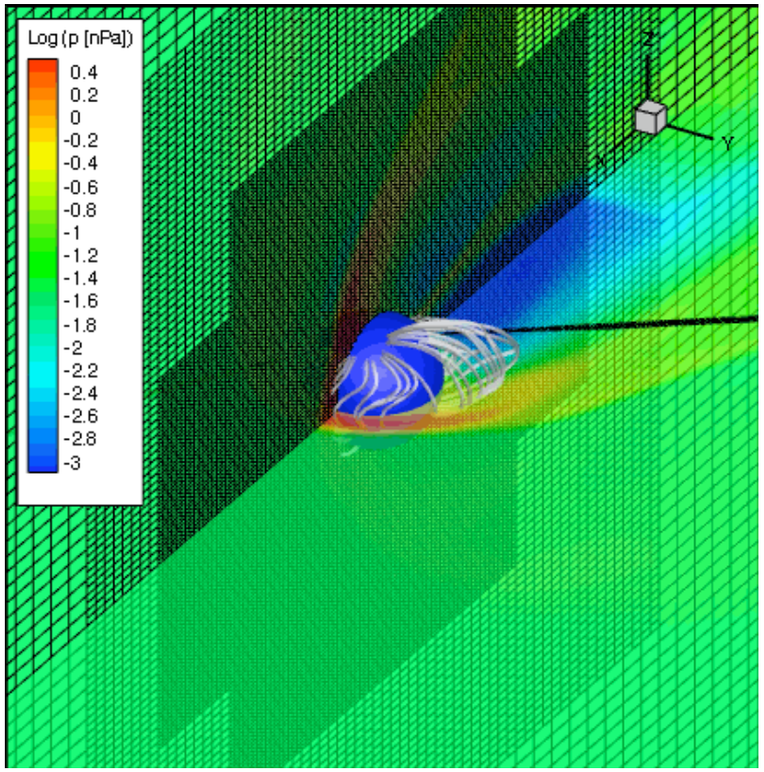
BC-1



BC-2

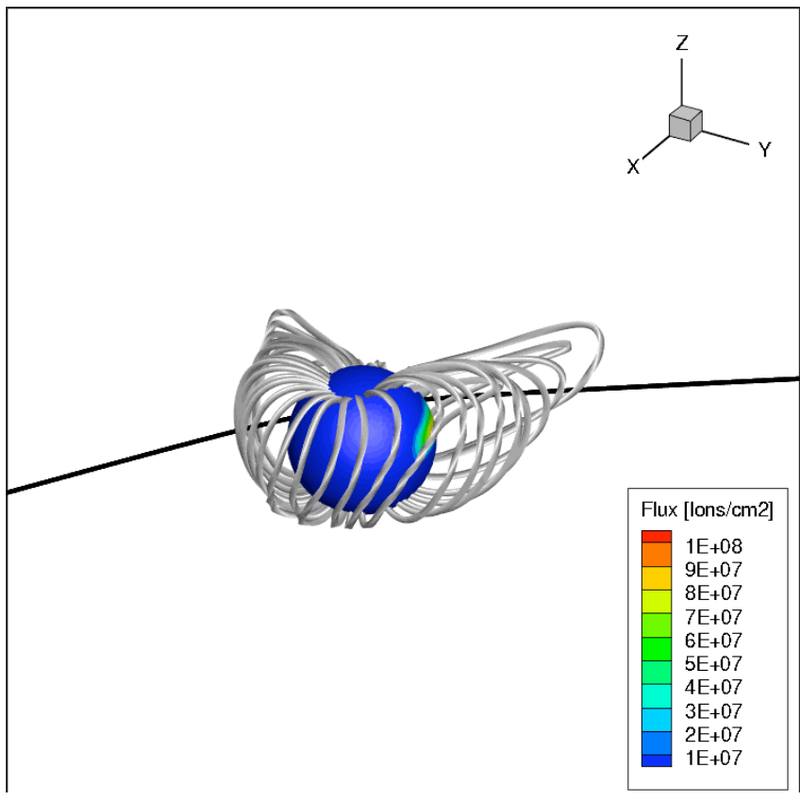


BC-3

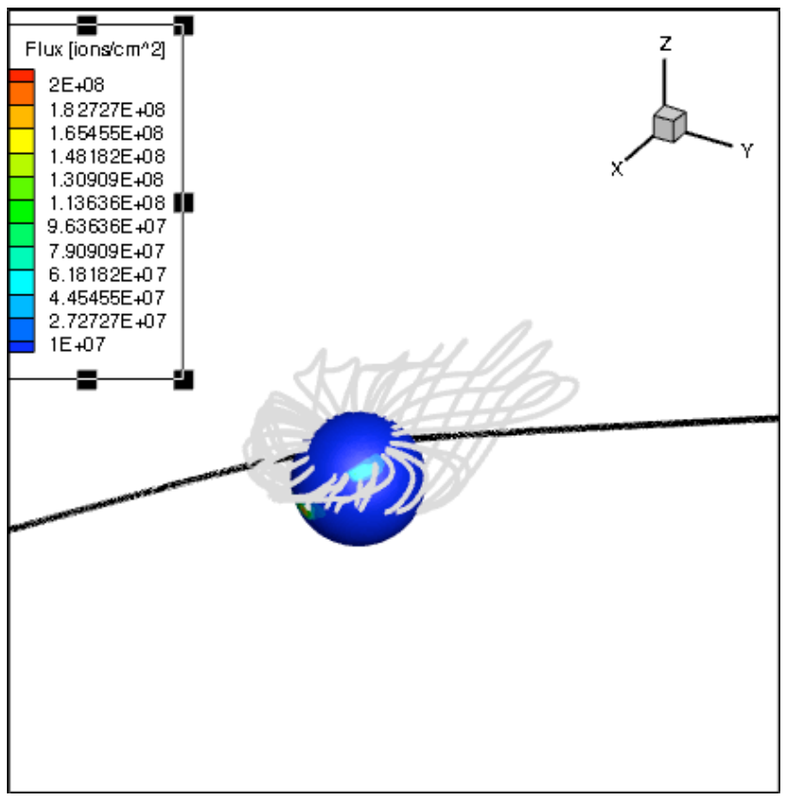


Boundary Comparison
Precipitating Flux During M2

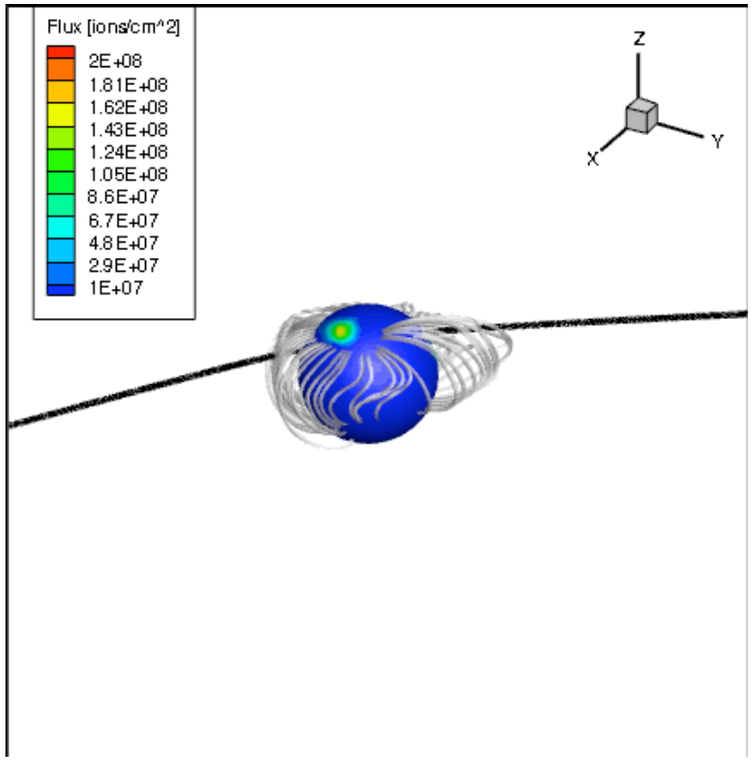
BC-1



BC-2



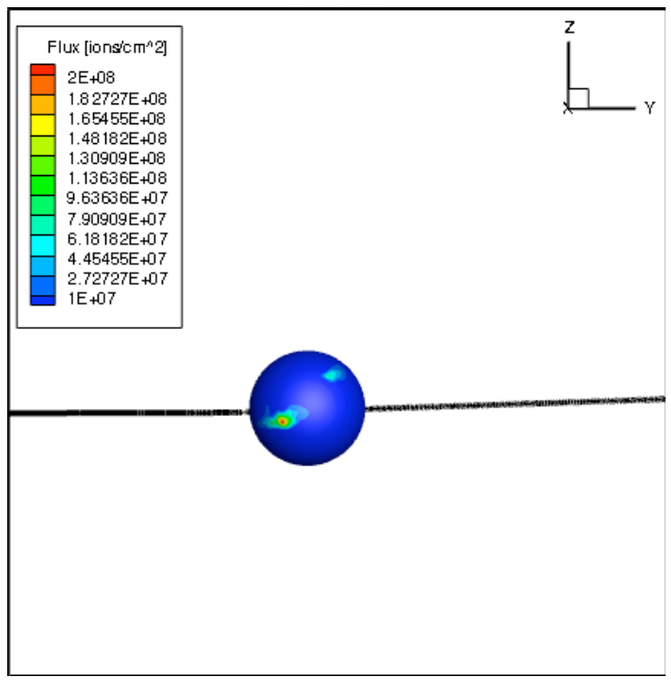
BC-3



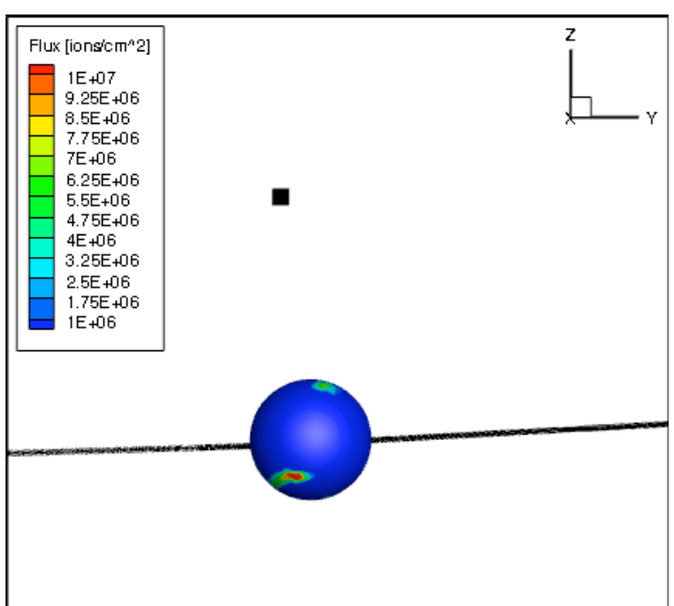
Boundary Comparison
Precipitating Flux Comparison

BC2

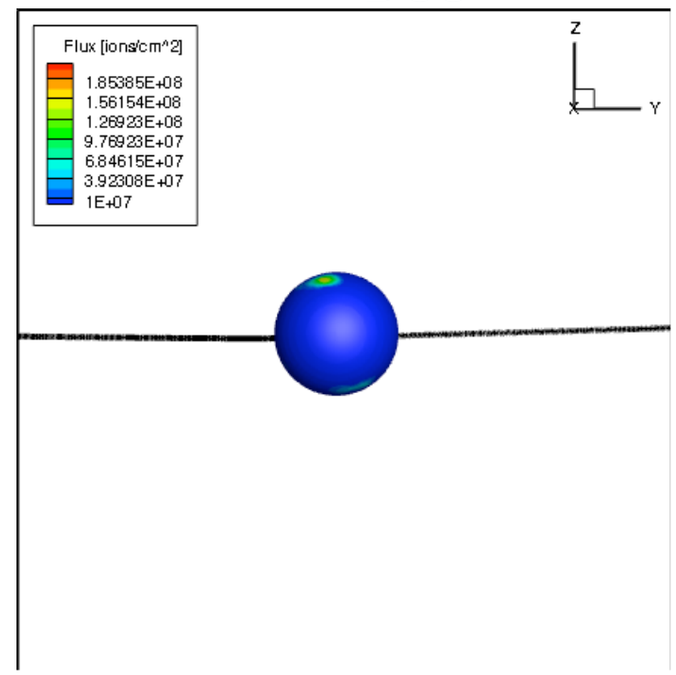
M2

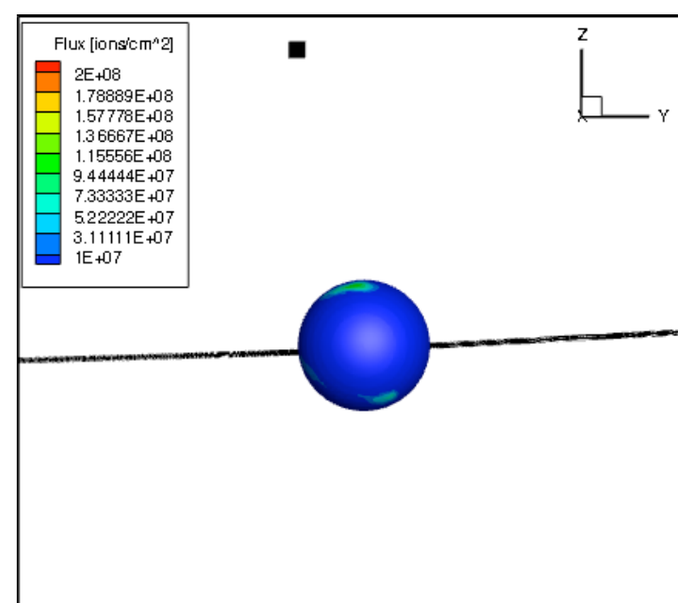


M1



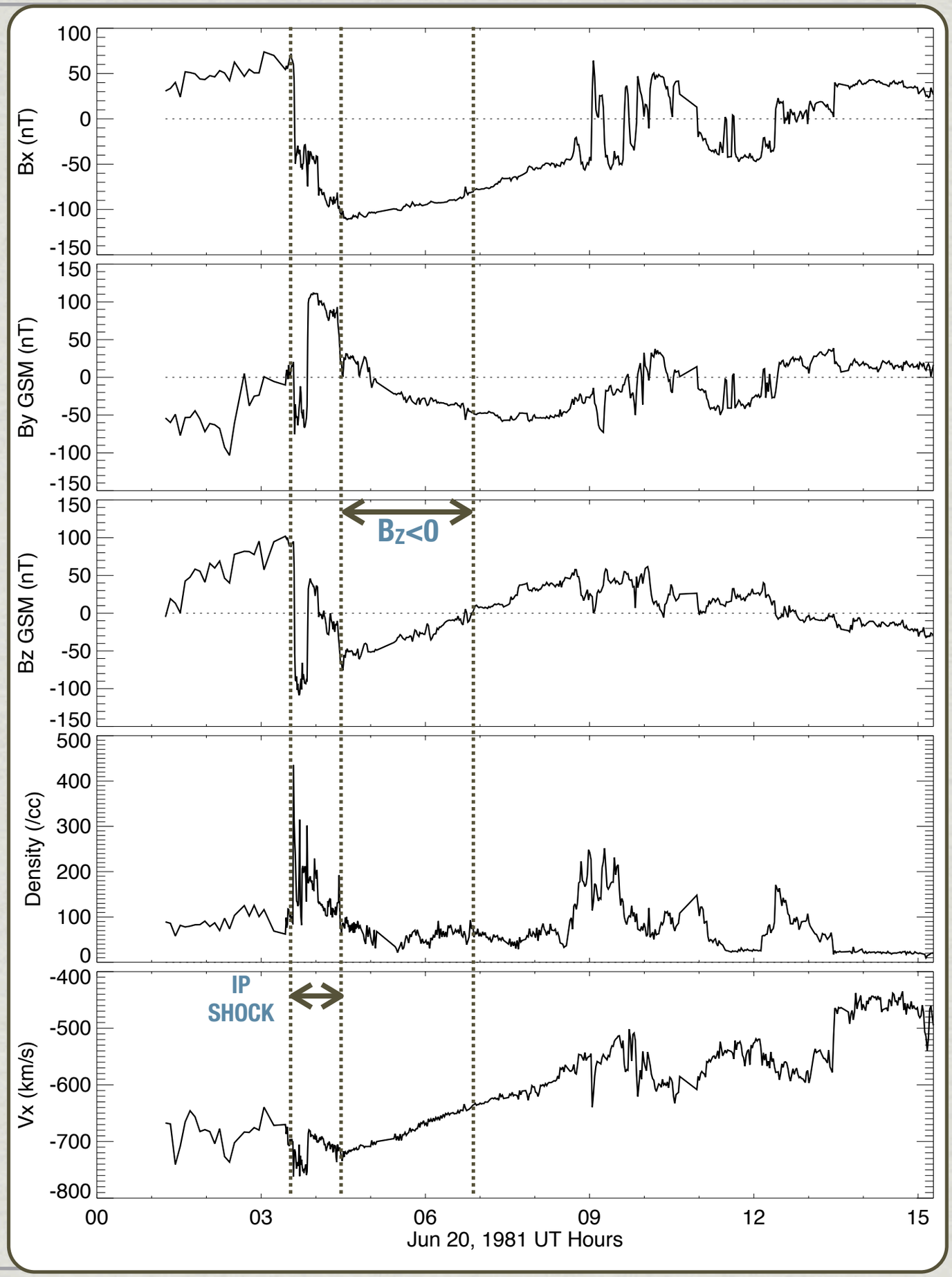
BC3



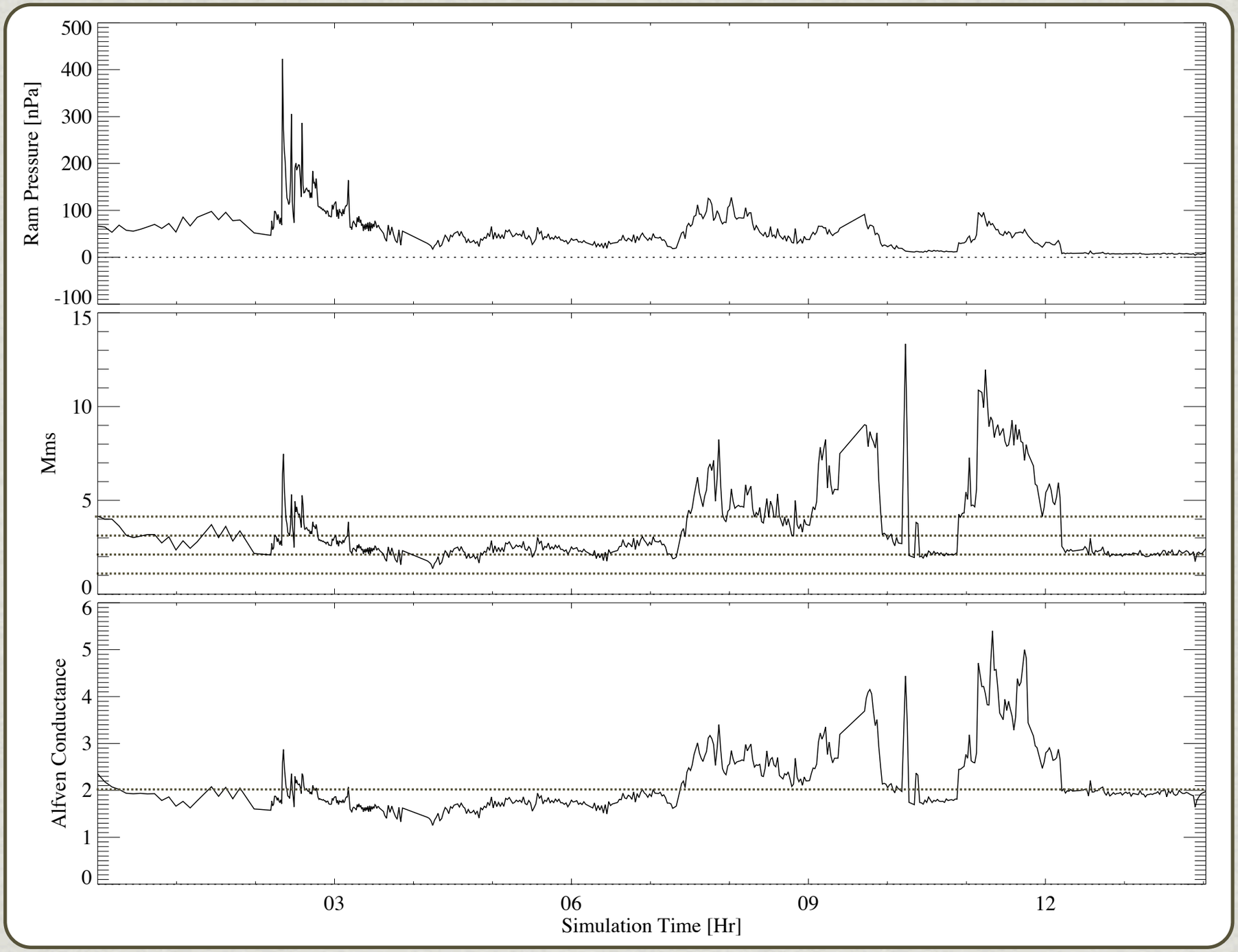


Disturbed Solar Wind At Mercury

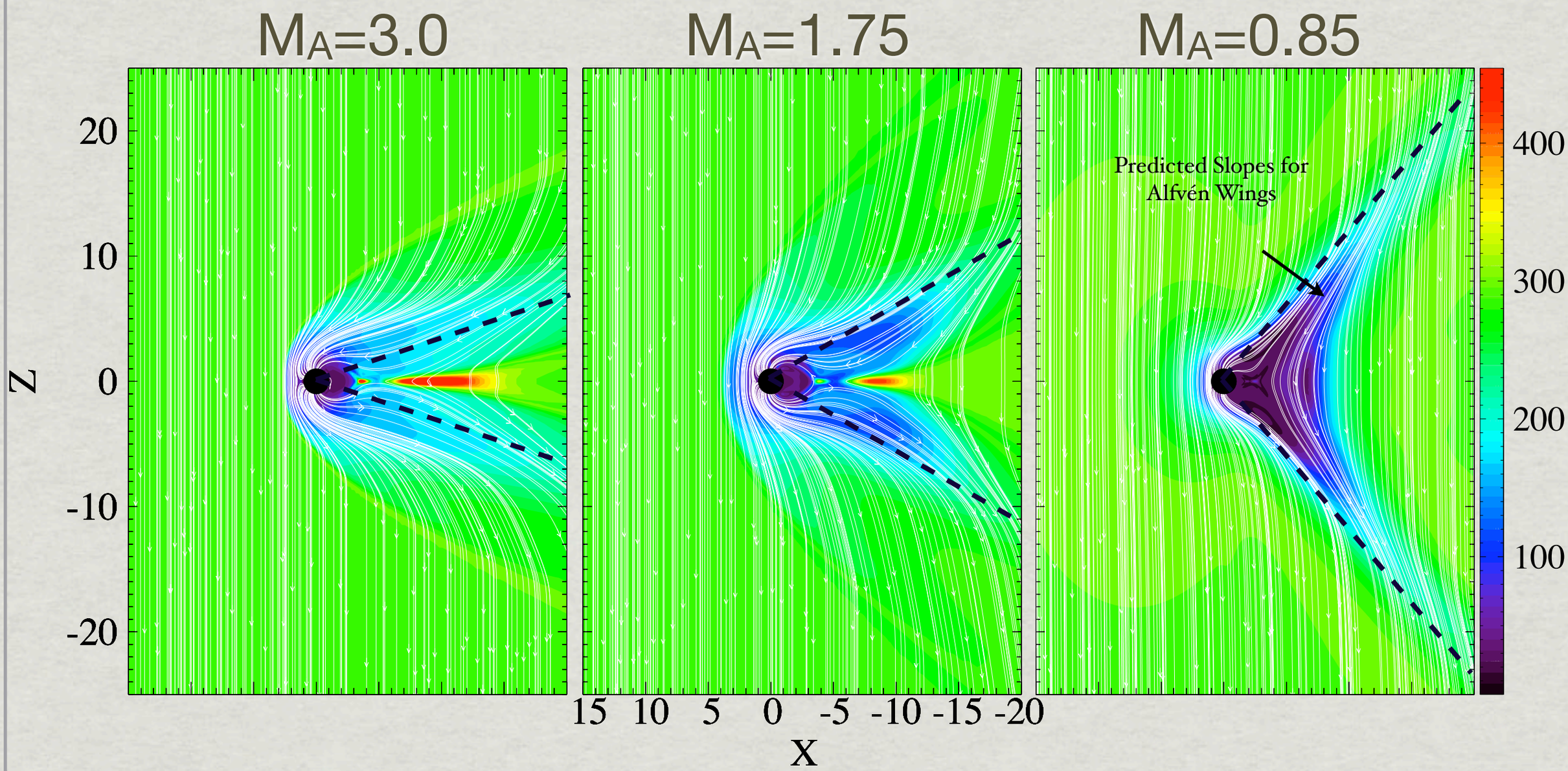
- MESSENGER enters orbit during solar max
- Low Alfvénic Mach numbers are seen particularly during ICMEs where |**B**| ≥ 100nT
- To the right, an ICME from Helios 1 measurements.
- These data were taken at 0.34AU.
- During ICMEs we can see extremely low Mach numbers



Solar Wind Ram Pressure, M_A, and Σ_A



Low M_A Case



- We systematically decrease the Alfvén Mach number (M_A) by dropping the solar wind B_z while holding other quantities constant.
- As the M_A is reduced, the lobes begin to separate and the shock front weakens.

Idealized High Ram Pressure

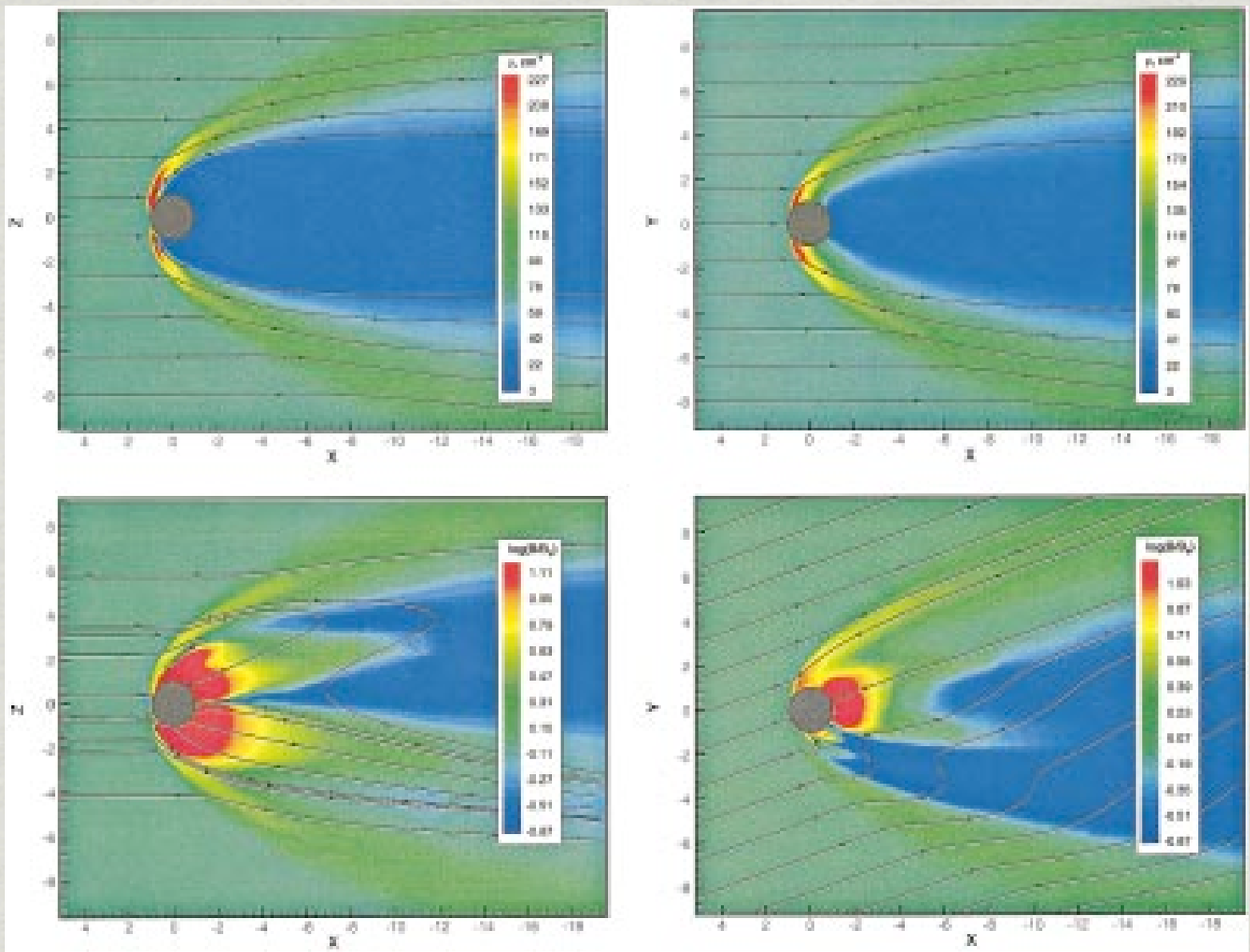
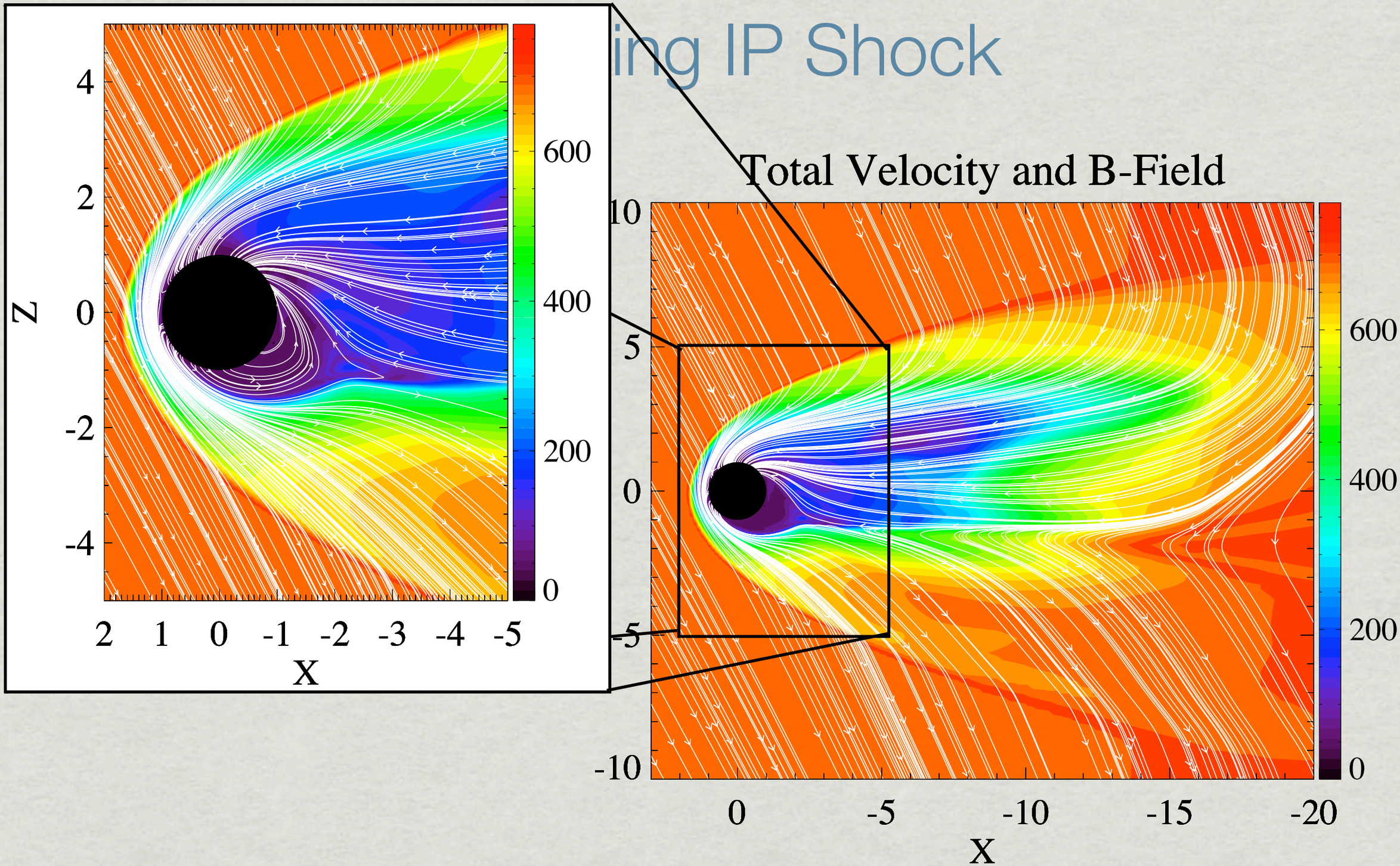


FIG. 7. Same as Fig. 1 for the Parker spiral with high speed and pressure of the solar wind, allowing it to penetrate to the surface.

Actual ICME Simulation

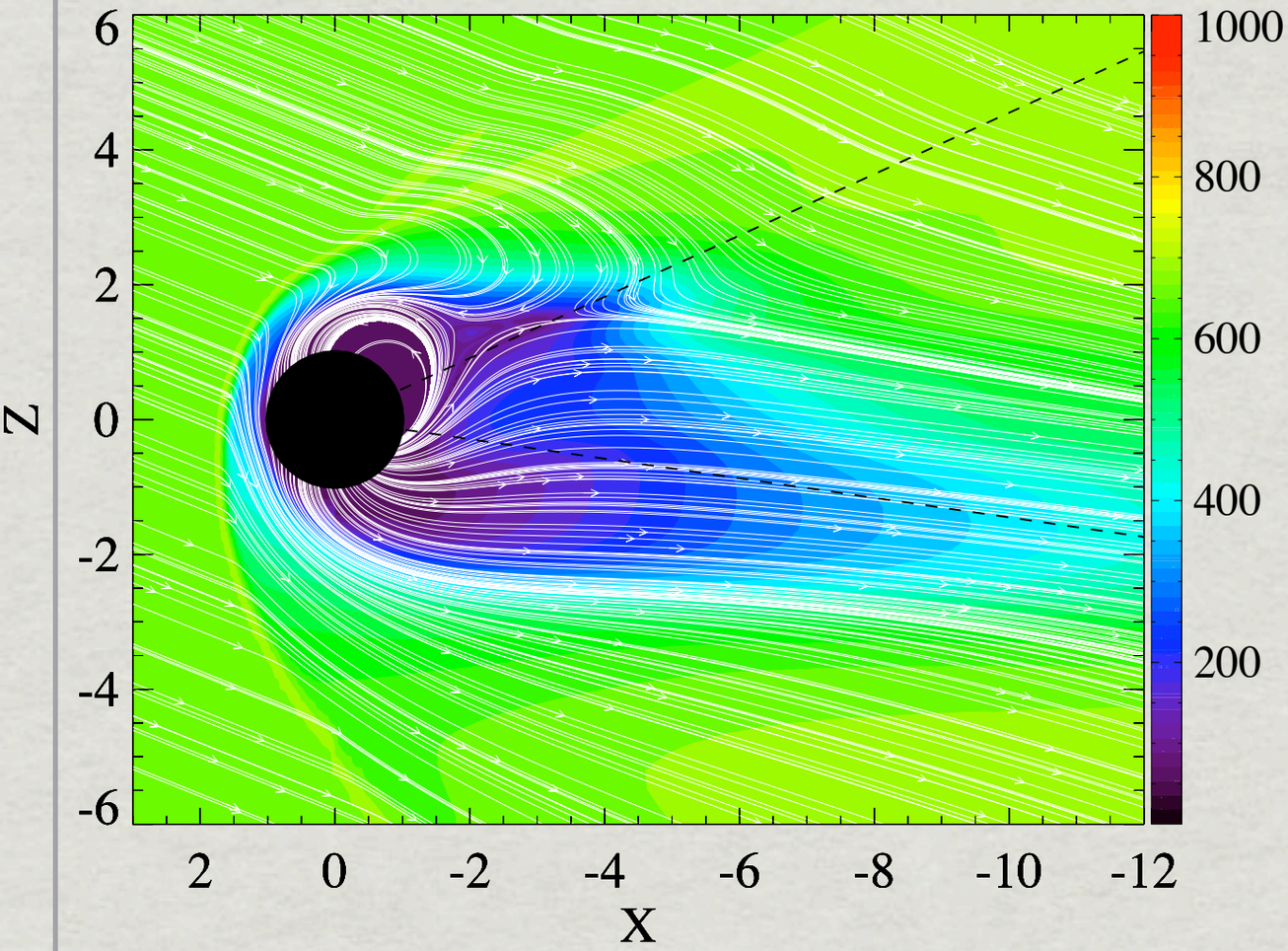
ing IP Shock



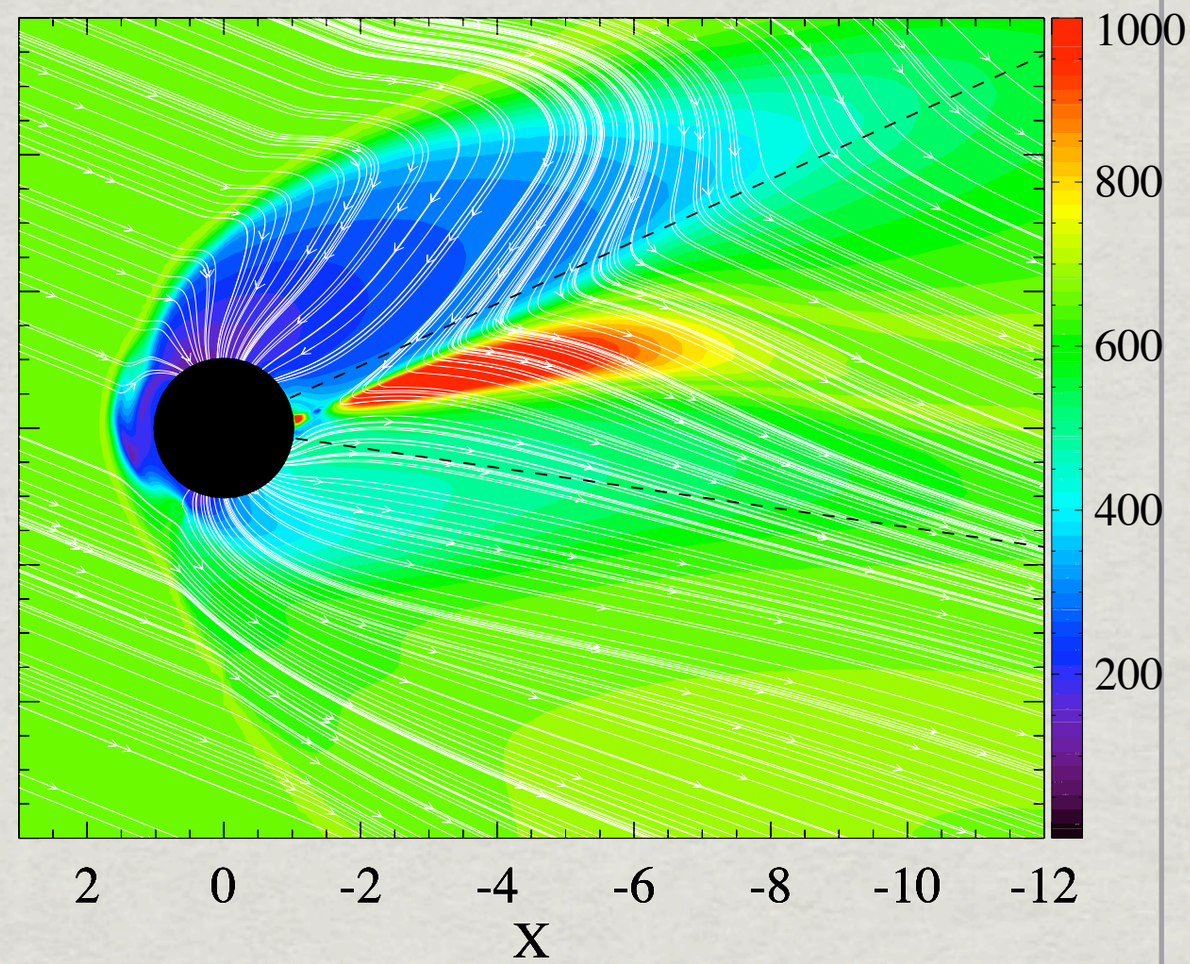
Actual ICME Simulation

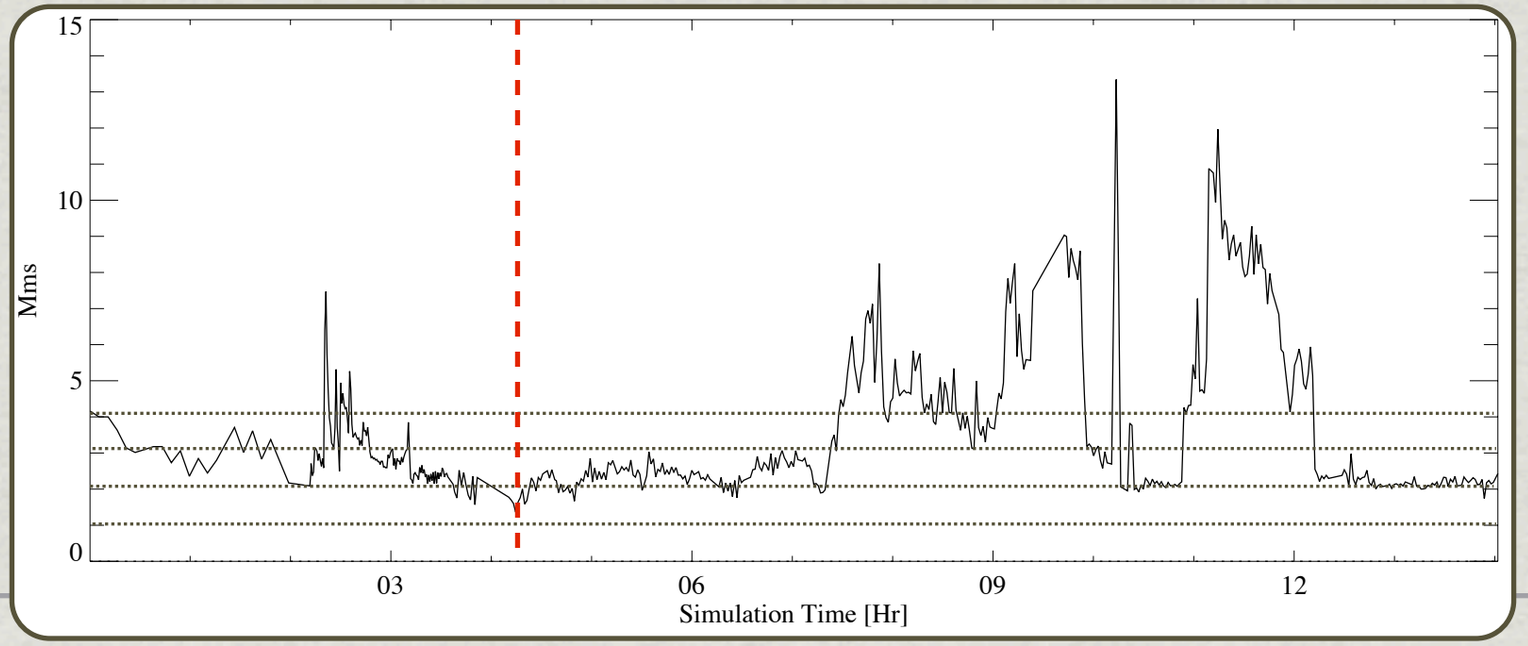
During Minimum M_A

BC2



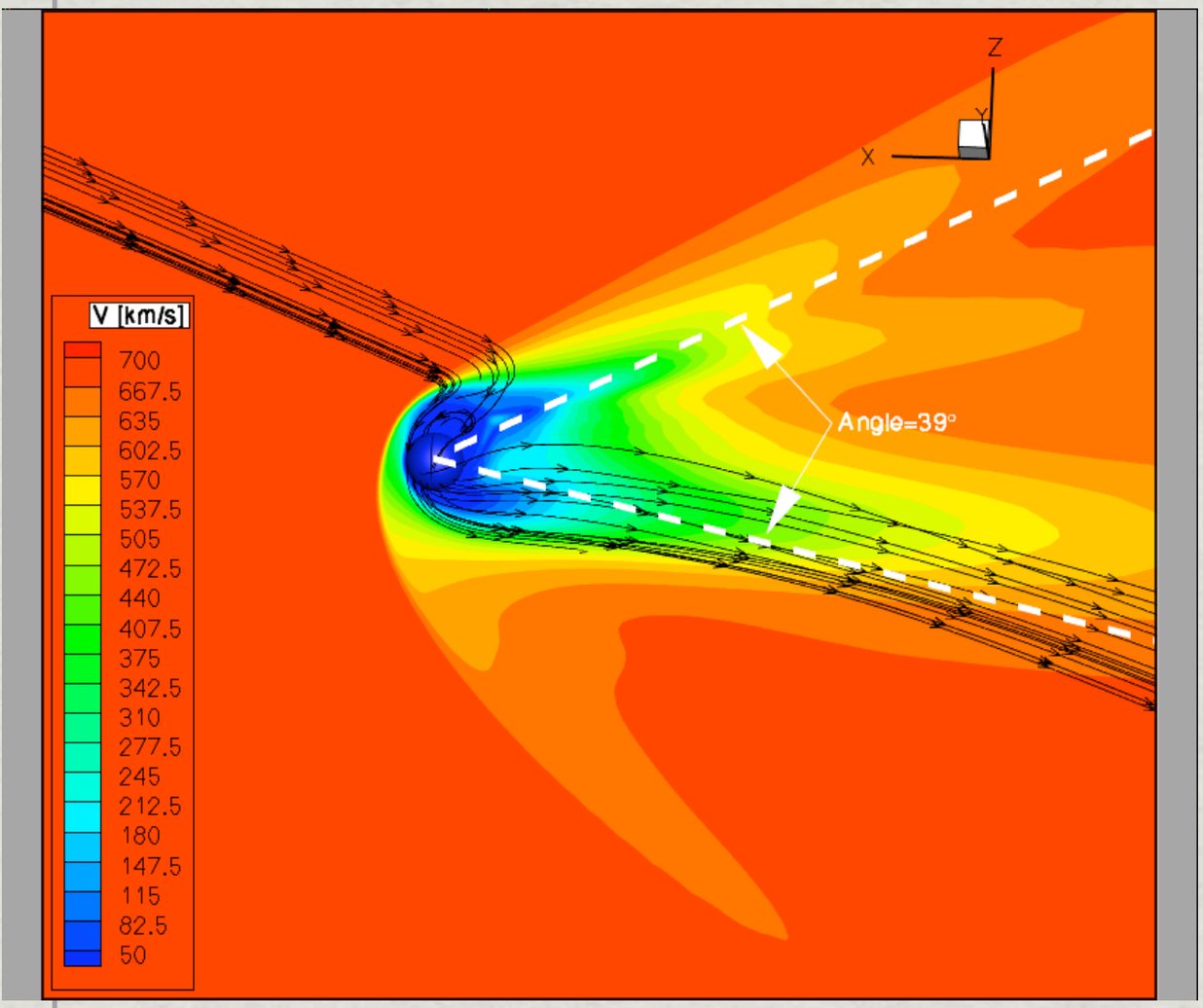
BC1



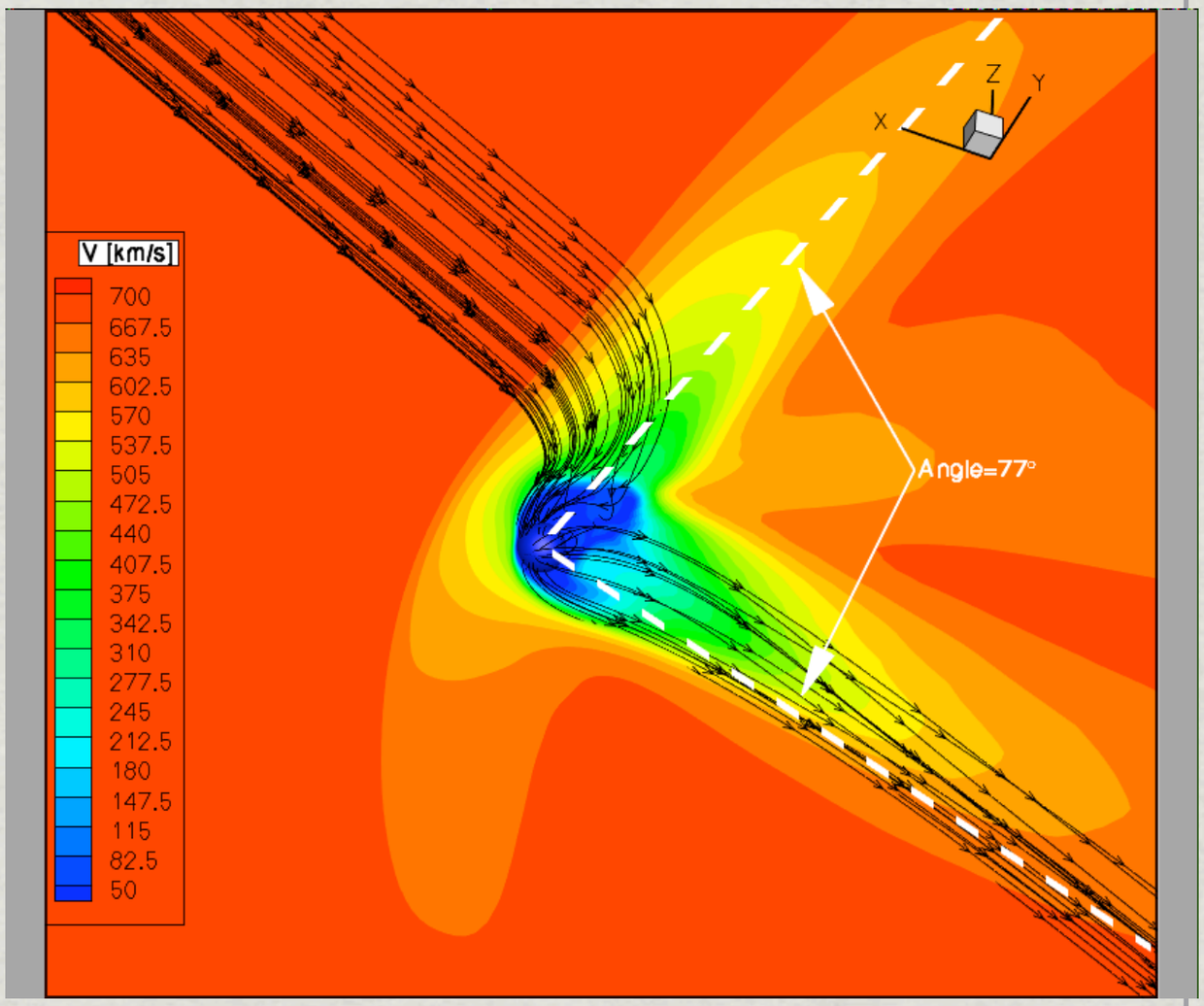


Solution at Minimum M_A: The Correct Plane

ORIGINAL CASE: M_A=1.78



ENHANCED CASE: M_A=1.14



- A significant B_y component can twist the lobes such that the y=0 plane is not meaningful.
- We show the solution in plane cutting through the lobes, and find an angle of 39° between the lobes. The angle between Alfvén characteristics is 33°.
- We also show the solution of a case with “enhanced” IMF conditions (right). The angle between lobes is 77°, and the angle between characteristics is 72°.

Conclusions

- Boundary conditions can really control the solution
  - BC1: gives larger dayside magnetosphere, and short tail
  - BC2: gives long tail and small dayside magnetosphere.
  - BC3: gives an intermediate result and stronger flux at 0LT
  - Through an iterative process we found a dipole of 200nT and an offset of .18R_M northward
- ICMEs
  - During the orbital phase we expect to observe several ICME encounters with Mercury
  - These times include large ram pressure that can completely compress the magnetopause.
  - They also have strong magnetic fields that can bring the cusps together, and they can lead to very low M_A

Thank You