Concerning the Stand-Off Distance of the Bow Shock

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Outline

- Bow shock and magnetopause definitions
- What use is a standoff distance?
- Past empirical studies
- The new velocity gradient method
- Initial results
- Conclusion

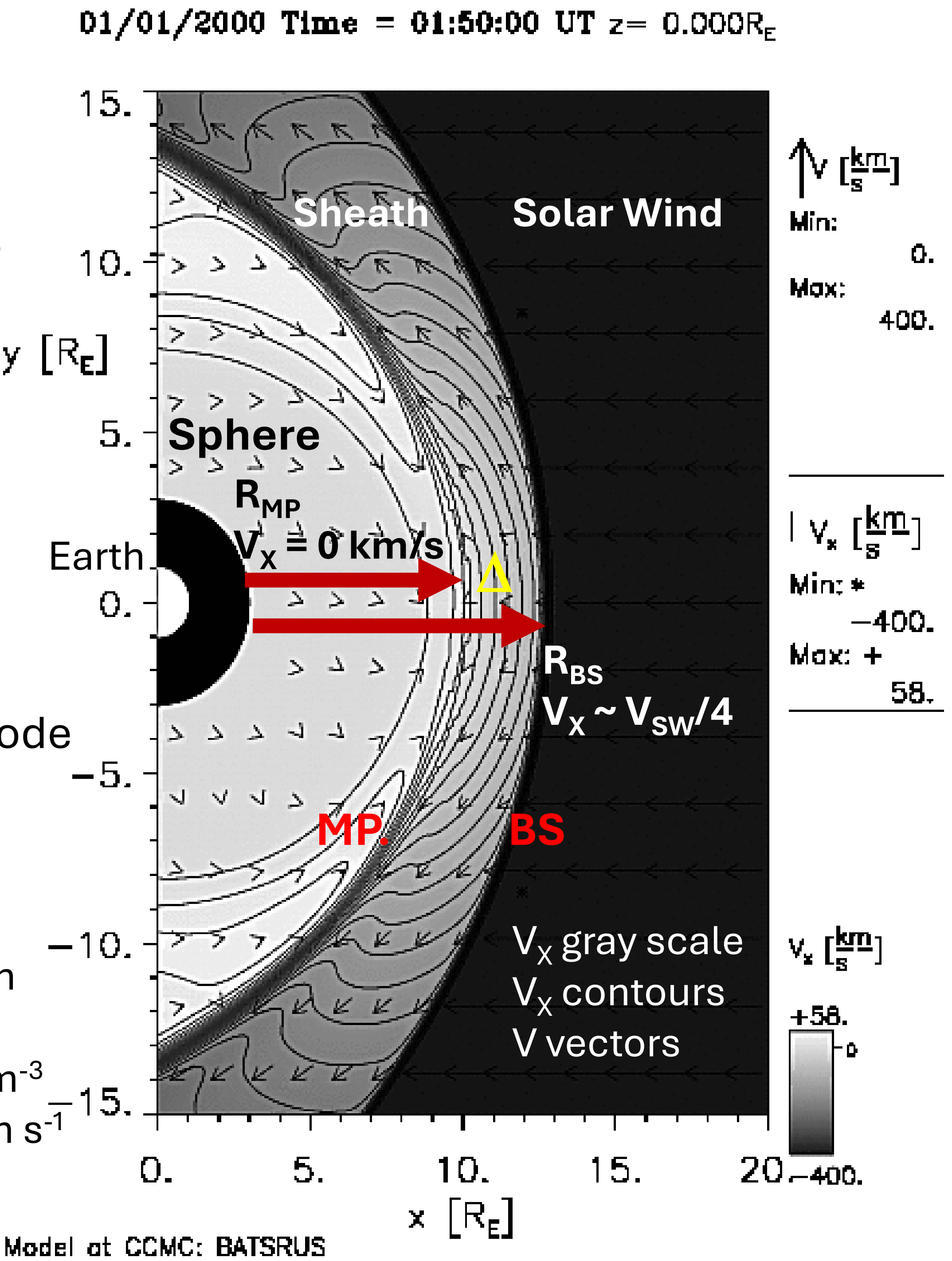
Bow Shock and Magnetopause Definitions

- At rest, the magnetopause lies along the locus of points where magnetosheath & magnetospheric pressures balance. At subsolar MP → $V_X = 0$

- At rest, the bow shock lies upstream from the magnetopause along the locus of points where fast mode wave speeds match incoming solar wind velocities. At subsolar BS → $V_X = V_{SW}/4$ (for large Mach numbers)

- The stand-off distance $\Delta = R_{BS} - R_{MP}$

U. Michigan
BATS-R-US
$N = 6.25\ cm^{-3}$
$V = -400\ km\ s^{-1}$
$T = 2x10^5\ K$
$B_Z = 5\ nT$



The Standoff Distance to the Bow Shock

- In gasdynamics, the standoff distance to the subsolar bow shock from the subsolar magnetopause is given by:

$$\Delta = R_{BS} - R_{MP} = R_{MP} * (1.1*(\gamma-1)M_S^2 + 2)/[(\gamma+1)*M_S^2]$$

- And empirical gasdynamic studies indicate that

$$\Delta = 1.1\ R_{MP} * V_{SHEATH}/V_{SW} = 1.1\ R_{MP} * \rho_{SW}/\rho_{SHEATH}$$

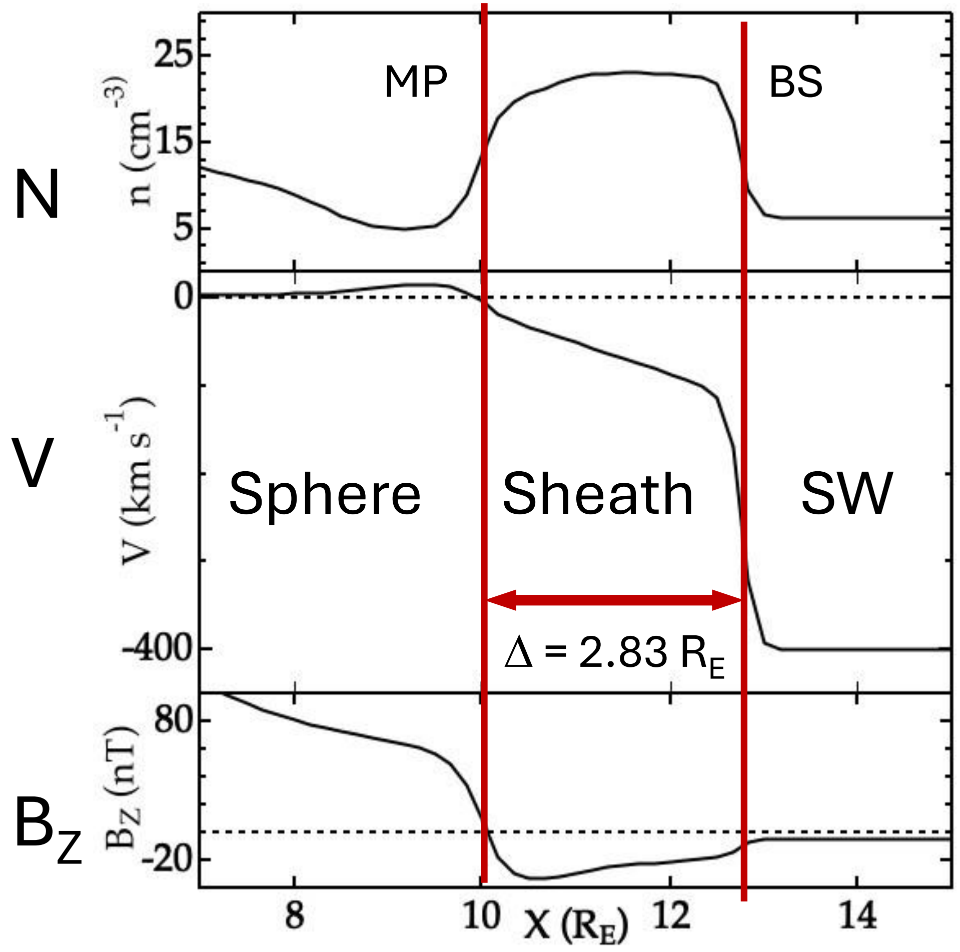
...depends on sonic Mach number M_S (known) and ratio of specific heats or adiabatic index γ (γ = 5/3 or 2 or something else). 1.1 is an empirical number. (Spreiter et al., 1966).

Factors Controlling the Standoff Distance

- It is a bit more complicated in MHD and kinetic codes
- Have to consider size and shape of the magnetosphere (depends on pressure and IMF B_Z), solar wind M_A and M_S, the spiral/radial IMF orientation, and maybe more (e. g. Cairns & Lyon, 1996)…
- **Let's identify R_{BS} and R_{MP} to determine whether 1.1 is a good empirical coefficient and the appropriate value for γ**

Simulated Magnetosheath Calculations are Easy to Understand

- Simulation



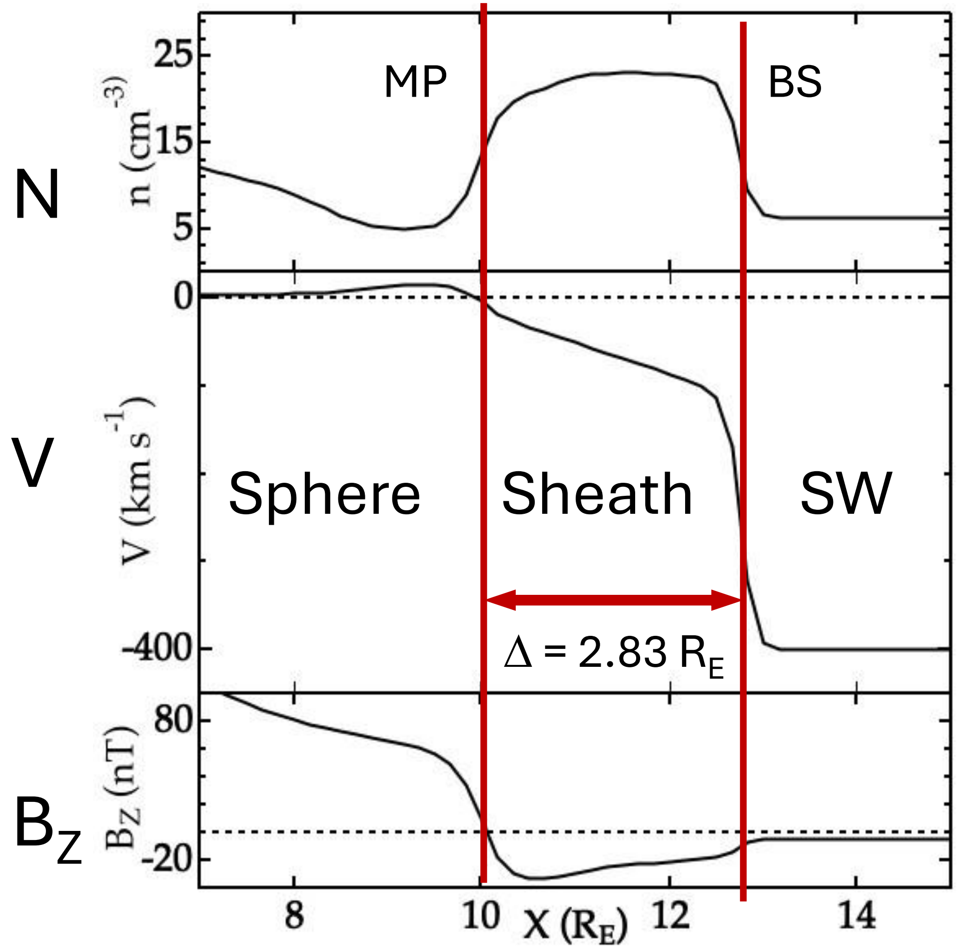
R_{MP}=10.00 R_E
R_{BS}=12.833 R_E
N_{SHEATH} = 22.5 cm^{-3}
N_{SW}= 6.25 cm^{-3}
V_{SW}= 400 km s^{-1}
V_{SHEATH} = 114 km s^{-1}

Δ = 2.83 R_E
1.1* R_{MP} * N_{SW} / N_{SHEATH} = 3.05 R_E
1.1 * R_{MP} *V_{SHEATH}/V_{SW} = 3.14 R_E

BATS-R-US at CCMC

Real Magnetosheath Calculations are Harder

- Simulation



BATS-R-US at CCMC

Real
Magnetosheath
Is
Messy

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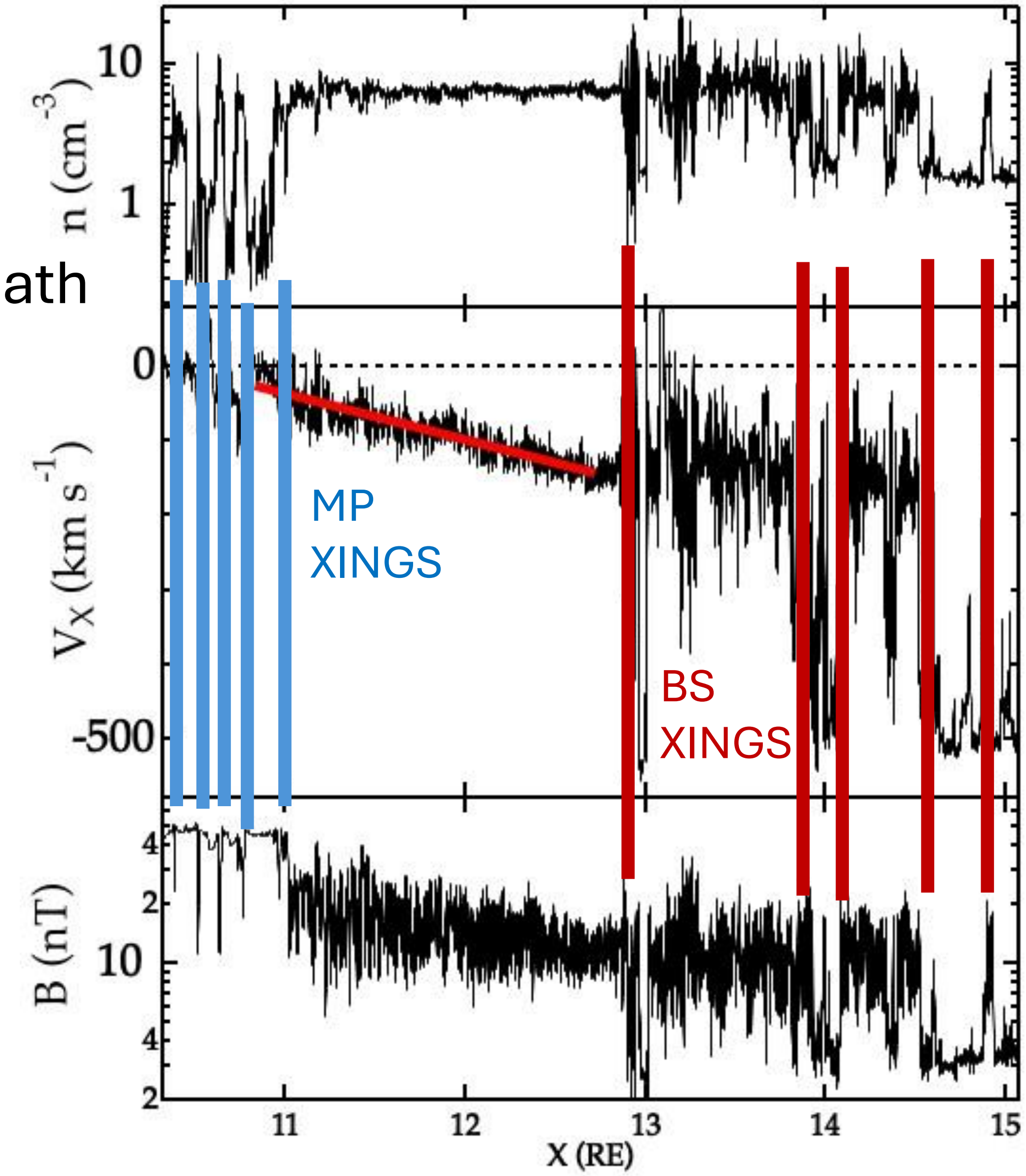
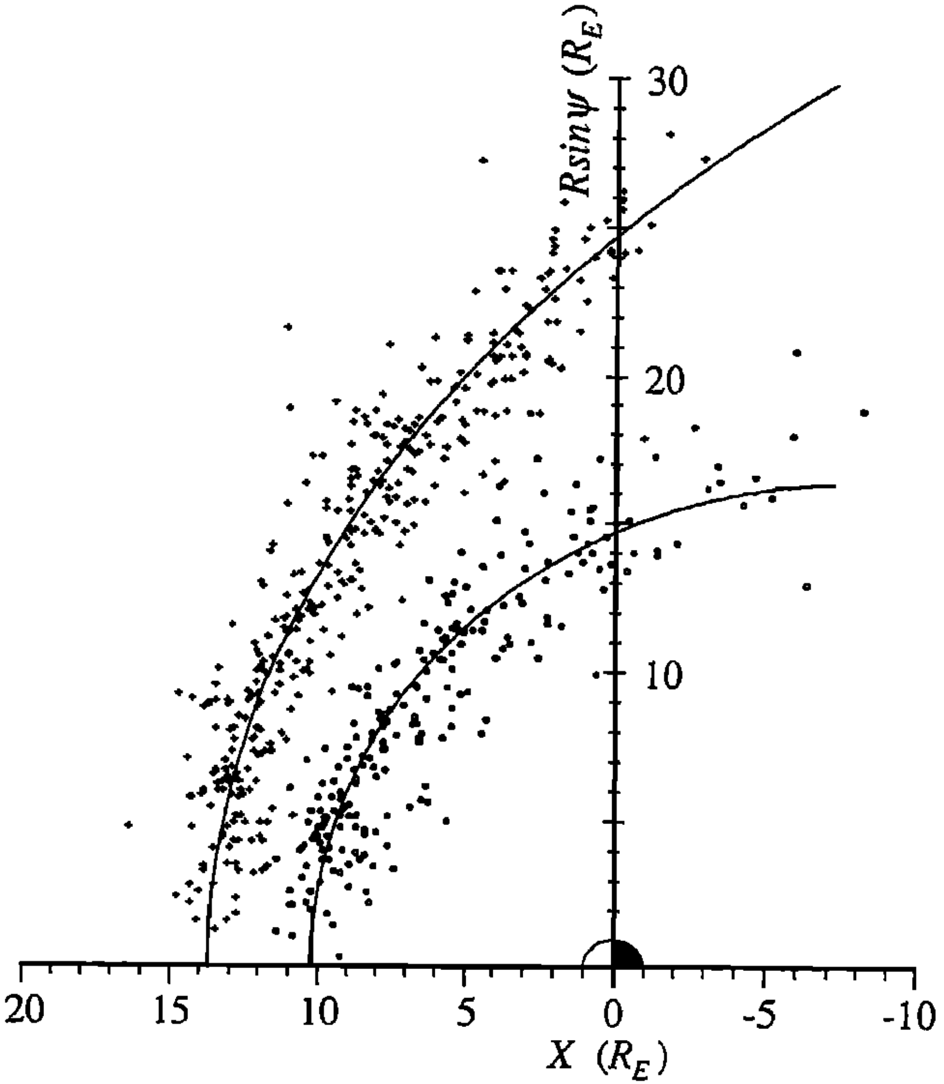


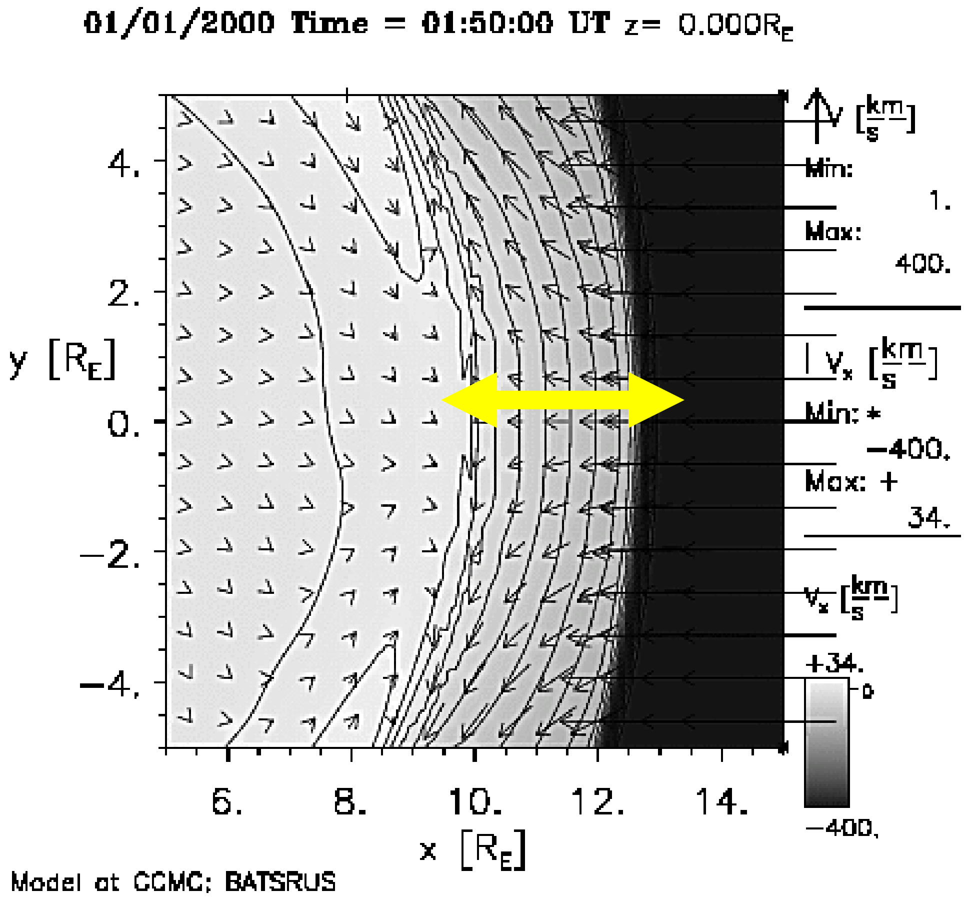
Empirical Studies of Bow Shock and Magnetopause Locations Define γ

- Where does all the scatter come from?
  - Uncertainties in solar wind measurements
    - Timing, spatial scale lengths, helium content
  - Crossings never occur in equilibrium (changing solar wind conditions cause boundaries to move past spacecraft, not vice-versa).



Farris and Russell (1991) have a study based on fit BS and MP positions
$R_{BS} = 13.7\ R_E$,
$R_{MP} = 10.3\ R_E$,
$\Delta = 3.4\ R_E$
$n_{SW}/n_{SHEATH} = V_{SHEATH}/V_{SW} = 0.33$
$\gamma = 1.76$

A New Method Employing the Linear Radial Gradient in Subsolar Velocity V_X



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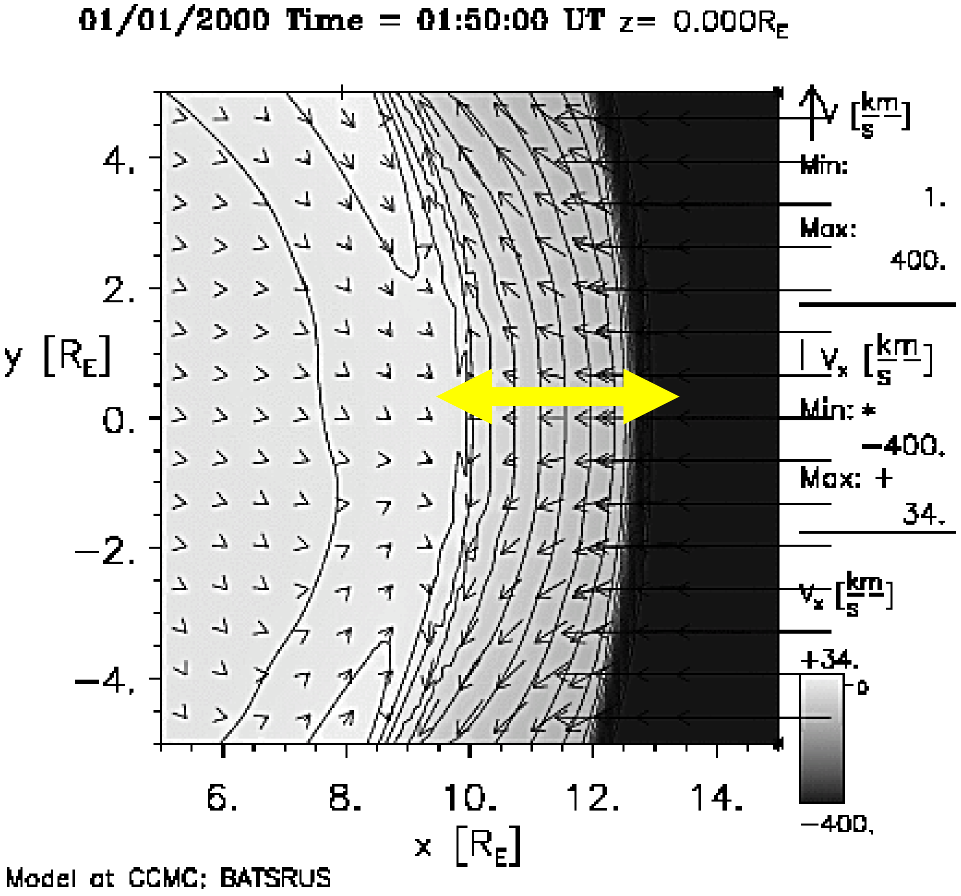
Observations Confirm Linear Gradient in V_X across Subsolar Sheath



BATS-R-US at CCMC

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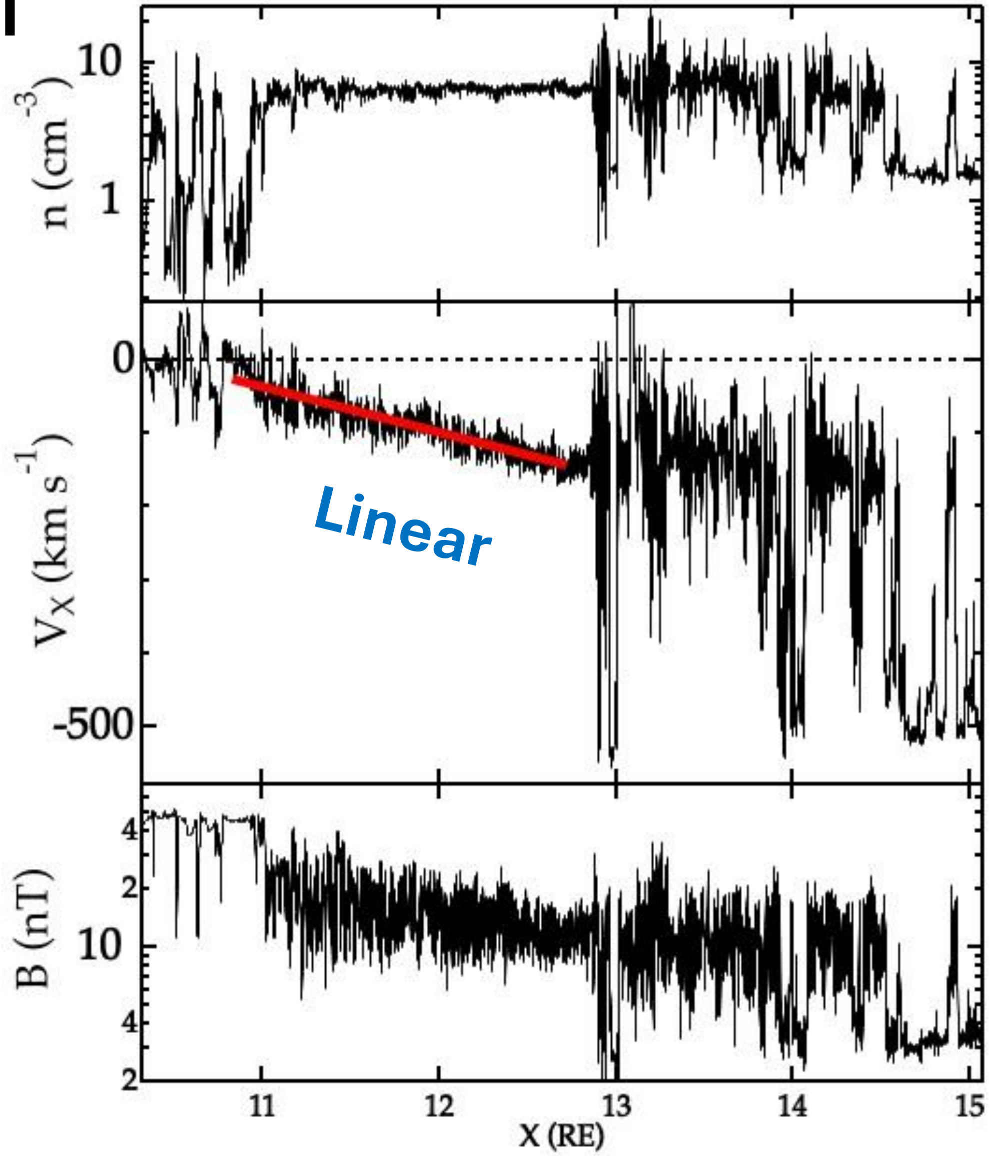

Our Plan

- 1. Fit line to gradient
- 2. Extend to find
  - R_{MP} Subsolar magnetopause, where $V_X = 0$
  - R_{BS} Subsolar bow shock, where $V_X = V_{SW}/4$
- 3. Then simultaneously
- 4. Check $\Delta = 1.1\, R_{MP} * V_{SHEATH}/V_{SW}$ and
- 5. Calculate $\gamma = \dfrac{(1.1 + \Delta/R_{MP})M_{MS}^2 - 2.2)}{(1.1 - \Delta/R_{MP})M_{MS}^2}$

→ Basically $\gamma \sim \Delta$

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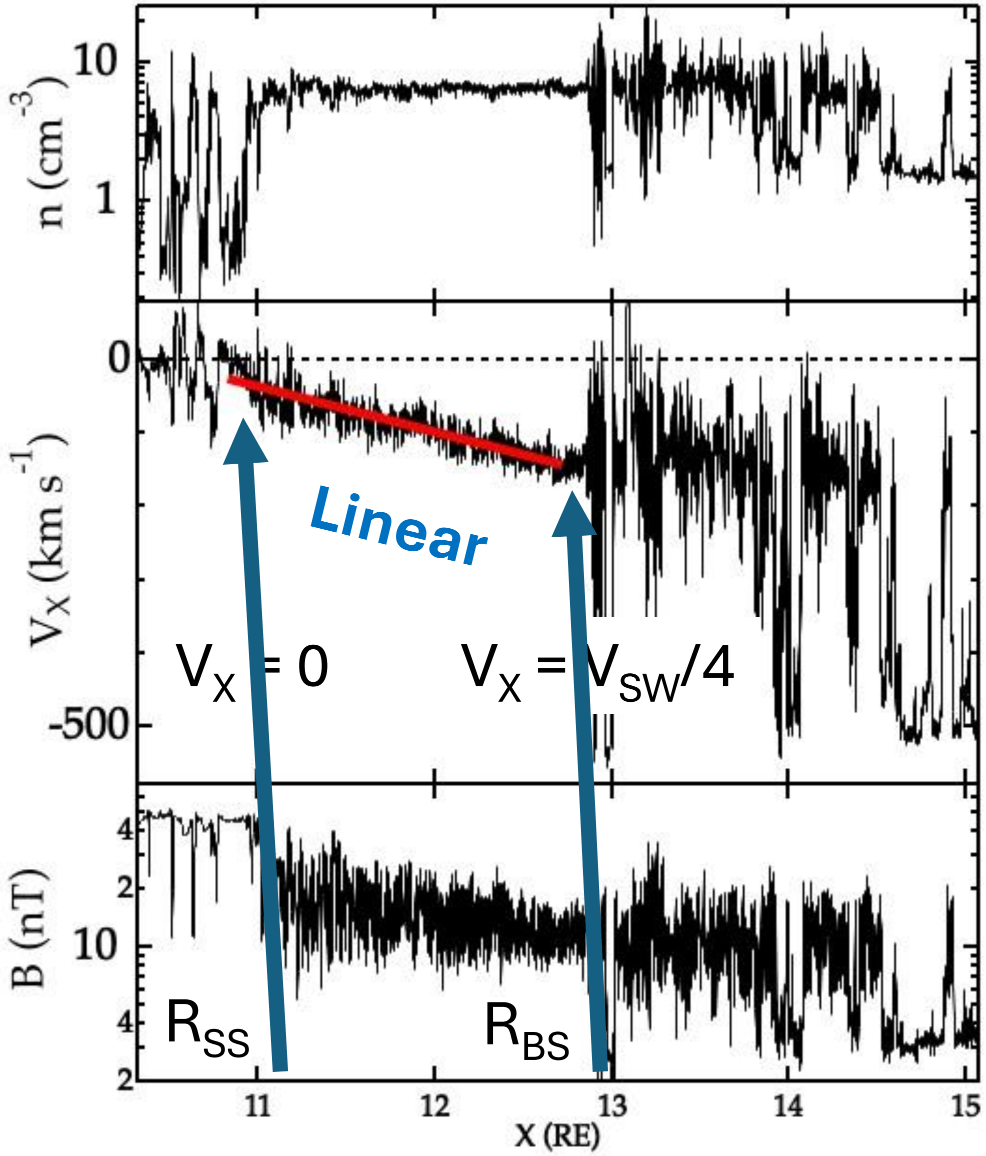
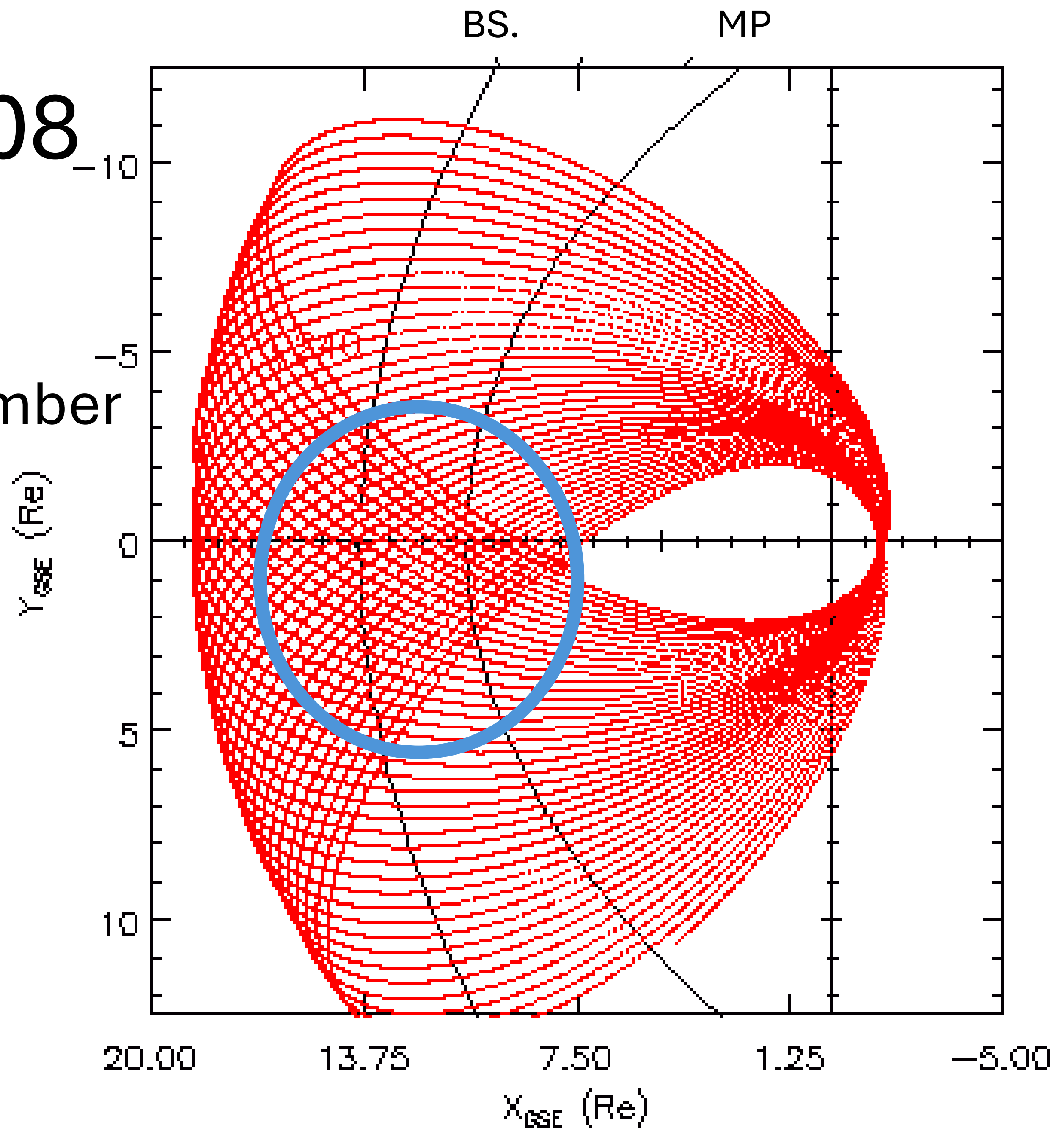


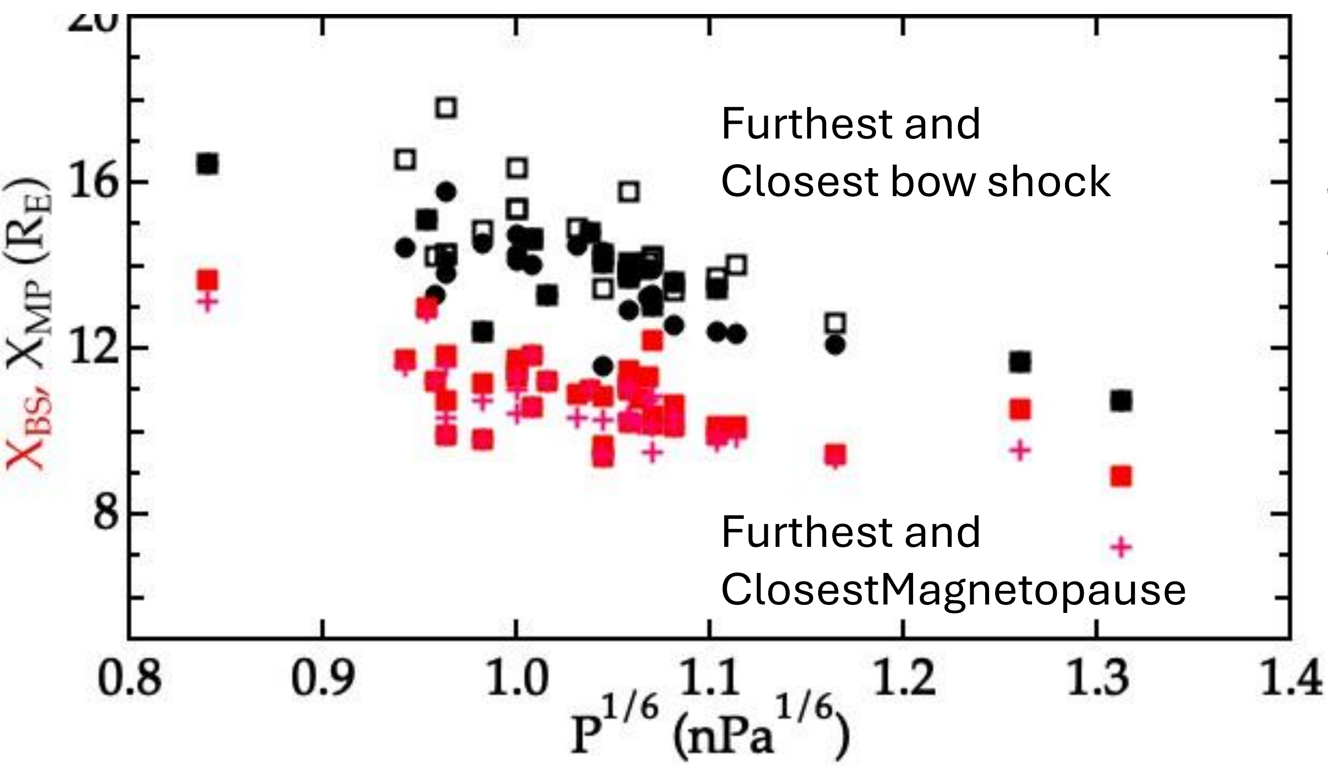
THEMIS-C Orbits in 2008

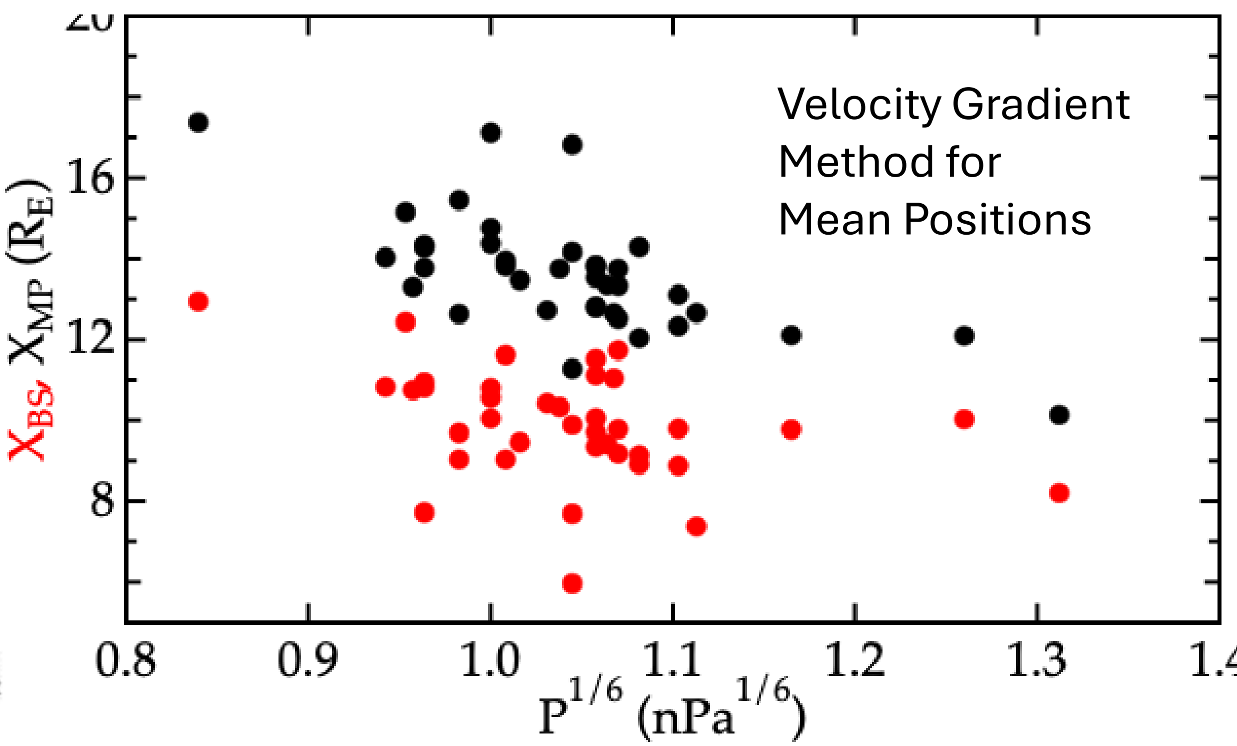
- Select passes through subsolar magnetosheath, July-September



Thanks to SPDF SSCWeb!

Boundaries Move Earthward as Solar Wind Dynamic Pressure Increases

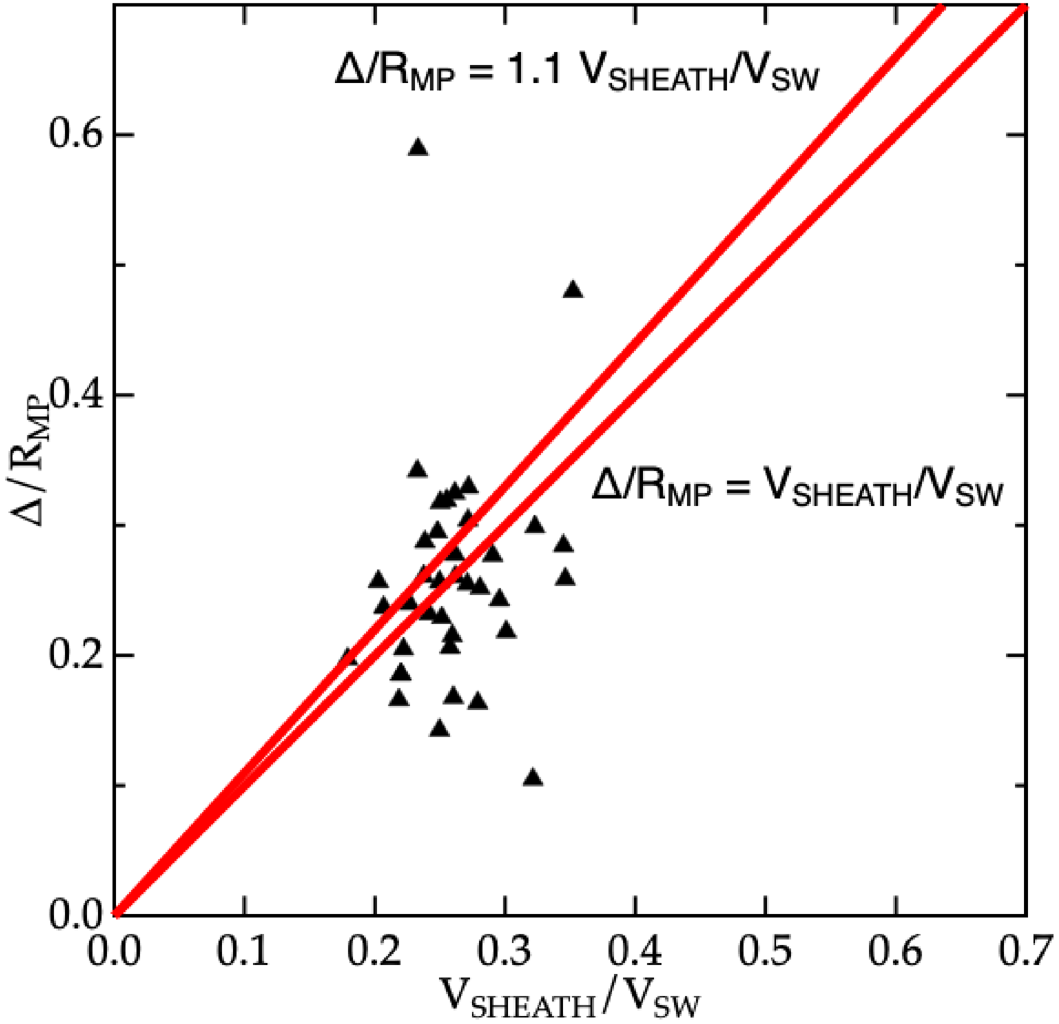




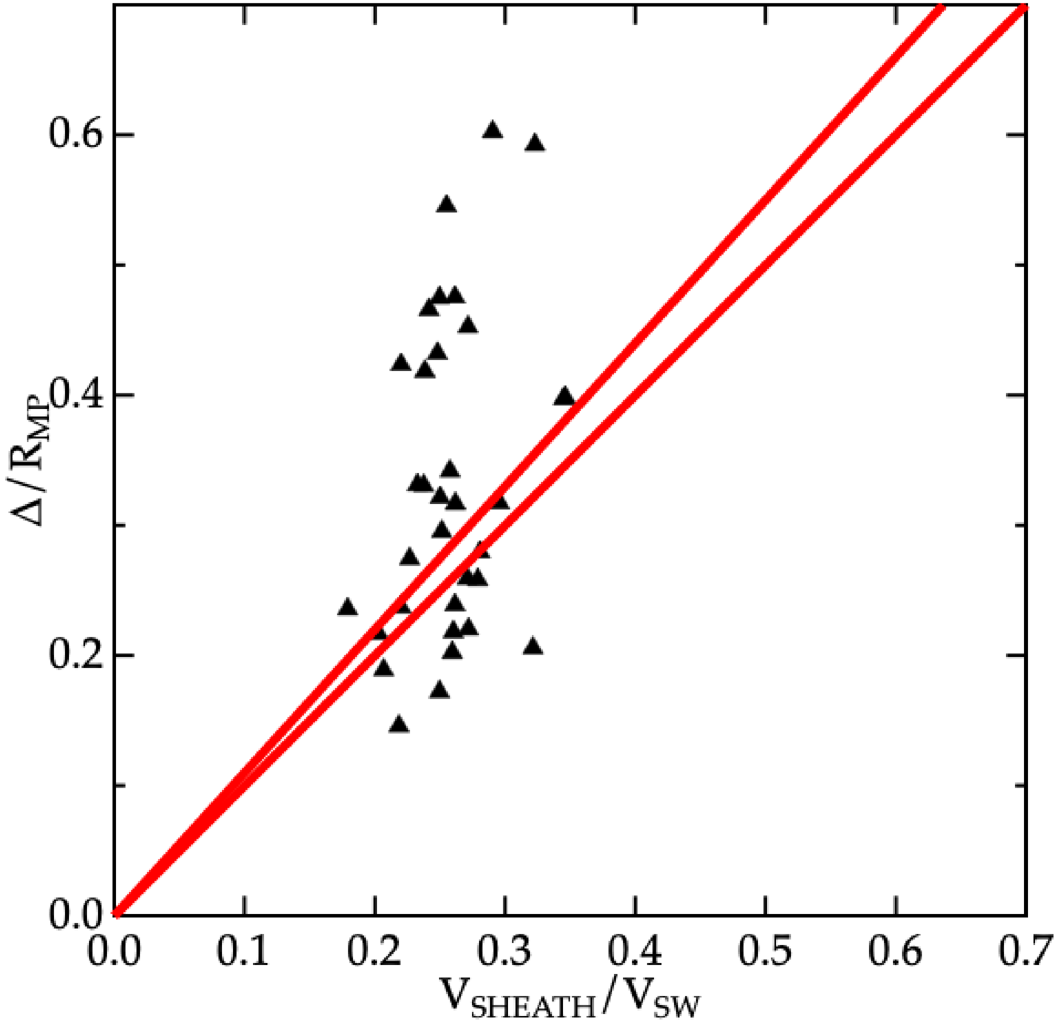
Solar Wind Dynamic Pressure

Does Stand-off Distance Depend on Velocity Jump at Bow Shock?

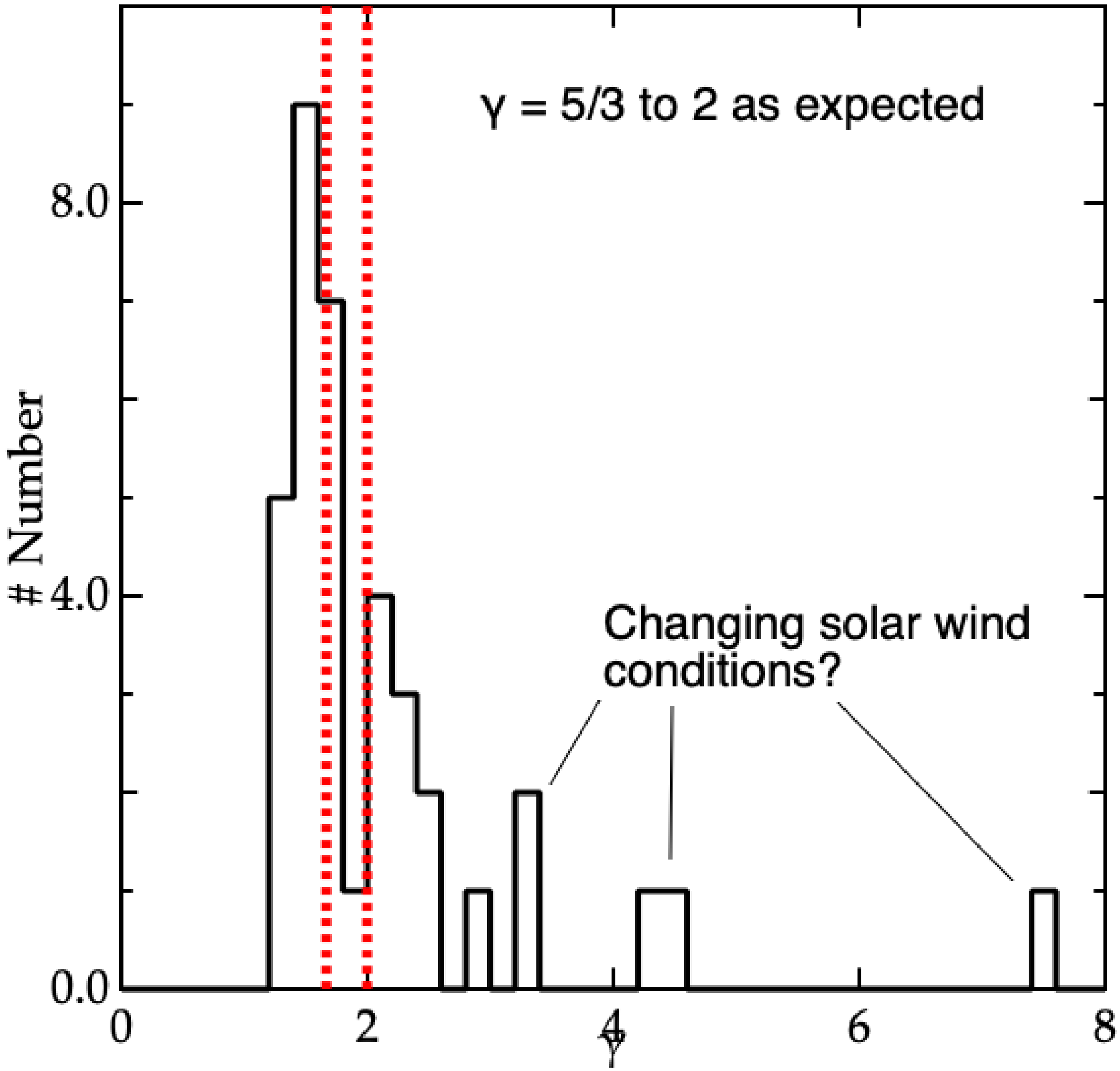
Closest Bow Shock, Furthest Magnetopause



Velocity Gradient Method



Histogram of γ



Summary

- A variety of factors control the locations of the bow shock and magnetopause.
- The same is true for the standoff distance between these boundaries
- Linear velocity gradients mean we can estimate simultaneous bow shock and magnetopause locations, and the stand-off distance between them for steady conditions.
- Preliminary results indicate that the ratio of specific heats in the solar wind is on the order of ~1.66 (=5/3) to ~2.00. More work needed. ☺