# MDs in INTERPLANETARY SPACE and MIRROR MODEs in PLANETARY MAGNETOSHEATHS and the HELIOSHEATH

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# Interplanetary Magnetic Decreases, Magnetic Holes and Magnetic Depressions

- MDs, MHs and MDs: Different names for same phenomenon.

- Properties of MDs: 1) usually defined as decreases of 0.5 $B_o$, 2) scale sizes from few $\rho_p$ to >1,000 $\rho_p$, 3) can occur as single events, 4) wide range of angular changes across the structures, 5) when occur in a series, are nonquasiperiodic structures, 6) are often bounded by sharp edges (slow shocks?).

# Magnetosheath Mirror Mode (MM) Structures

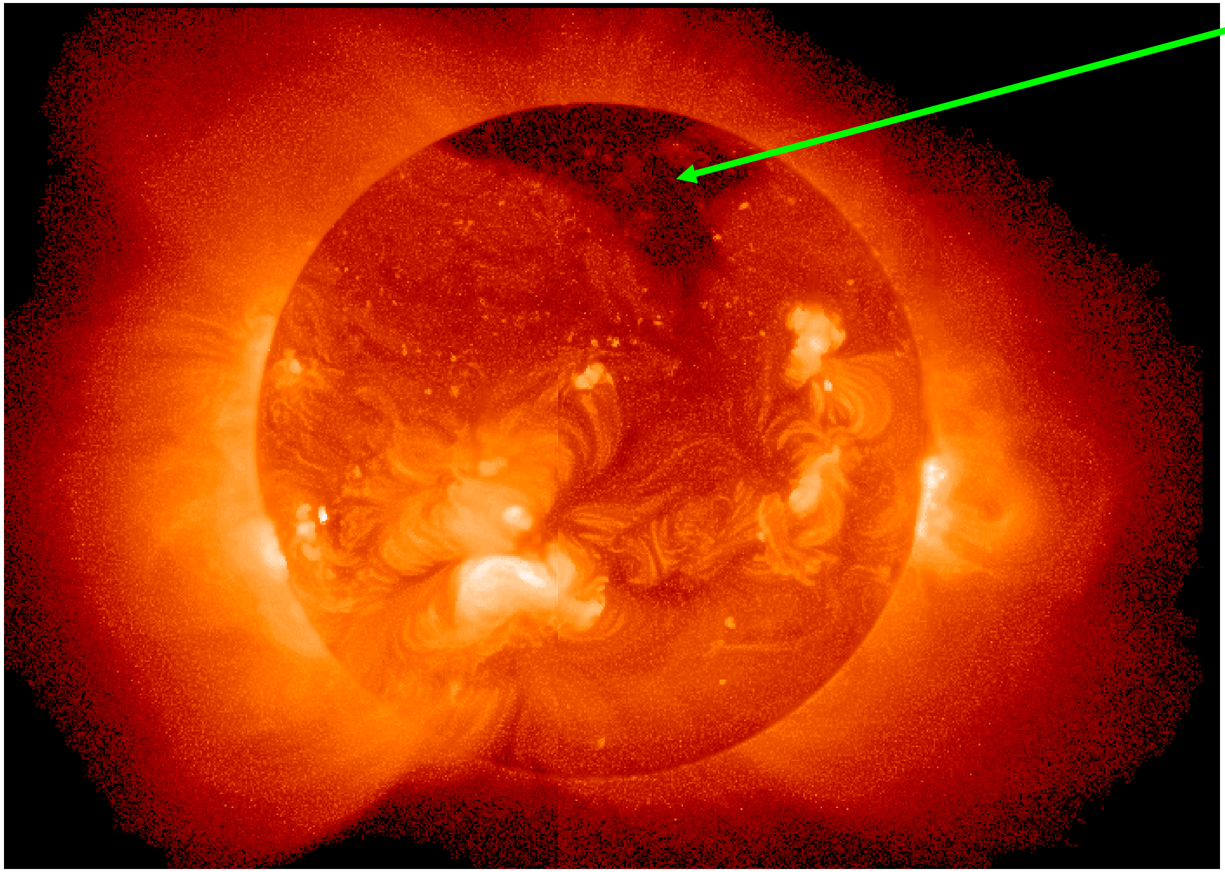
Mirror modes are nonoscillatory structures that are generated by an instability driven by plasma anisotropies:

$$\beta_\perp/\beta_{||} > 1 + 1/\beta_\perp$$

(Chandrasekhar et al., PRS, 1958; Vedenov and Sagdeev, 1958; Hasegawa, PF, 1969).

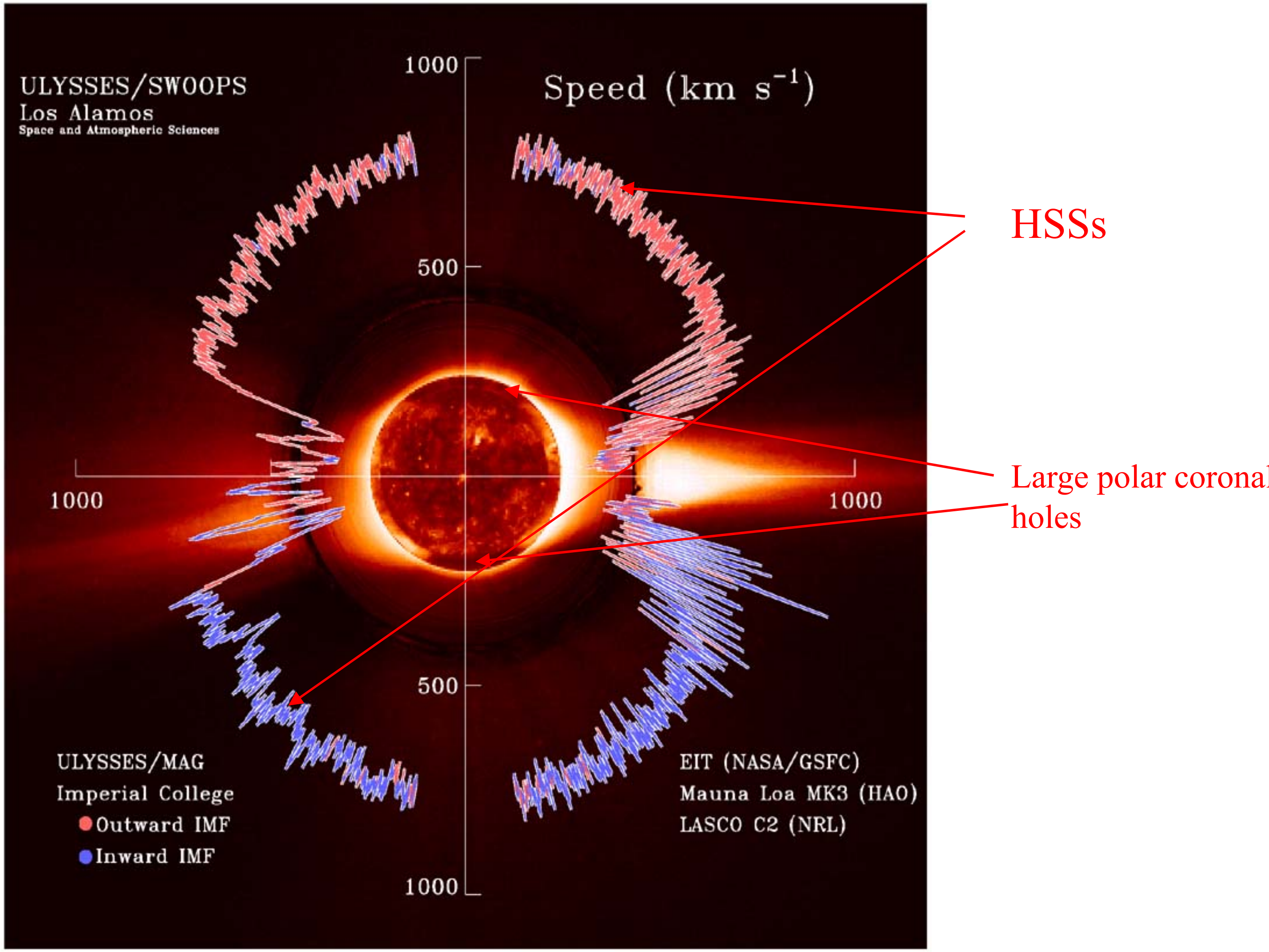
Characteristics of MMs: 1) there is little or no angular changes across the structures, 2) they occur in series, 3) they are quasiperiodic, 4) they are to first order pressure balance structures.

# DECLINING PHASE OF SOLAR CYCLE

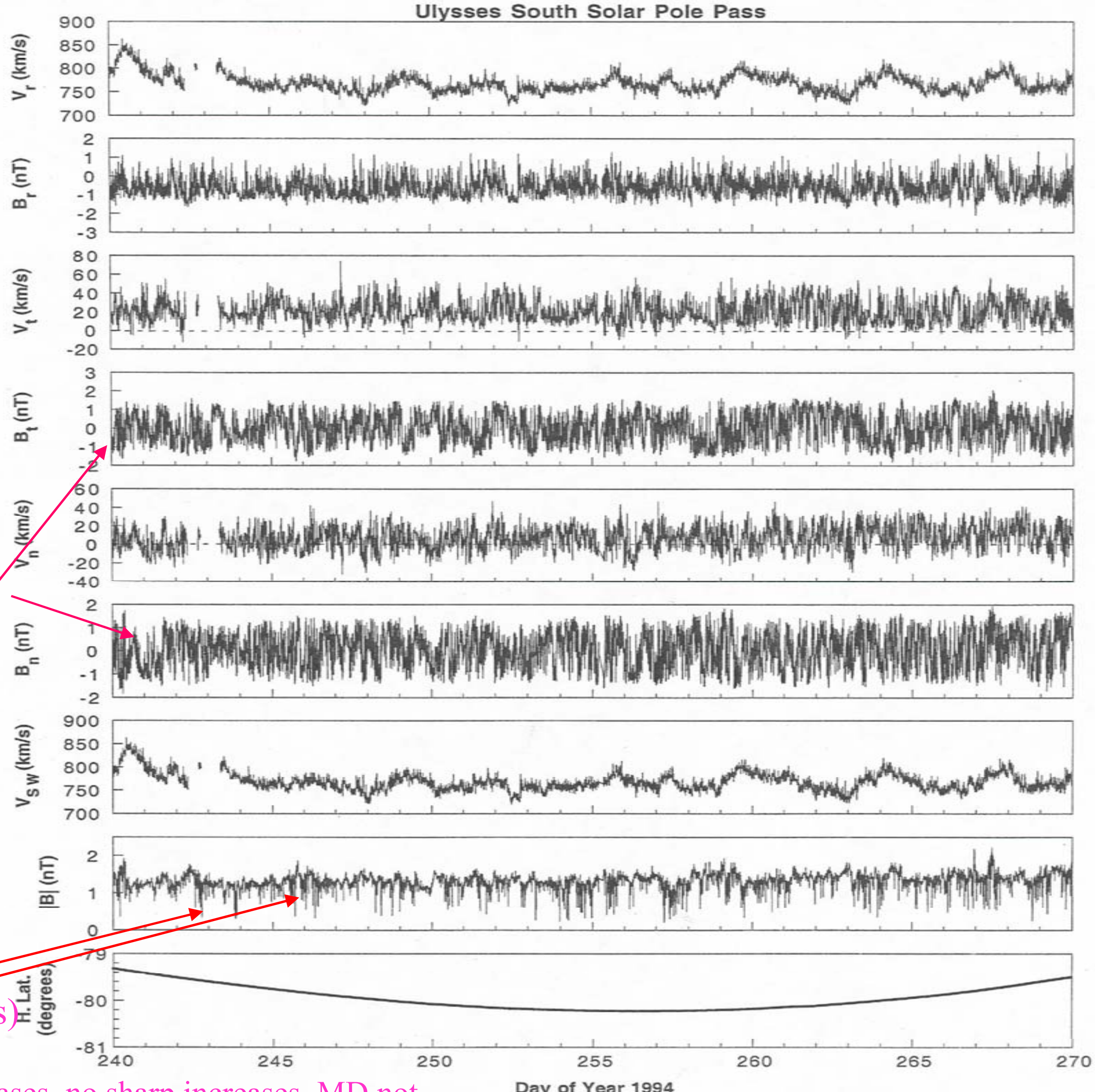



History: Maunder, Chree, Bartels

# ULYSSES DURING THE DECLINING PHASE OF THE SOLAR CYCLE




McComas et al. GRL 2003

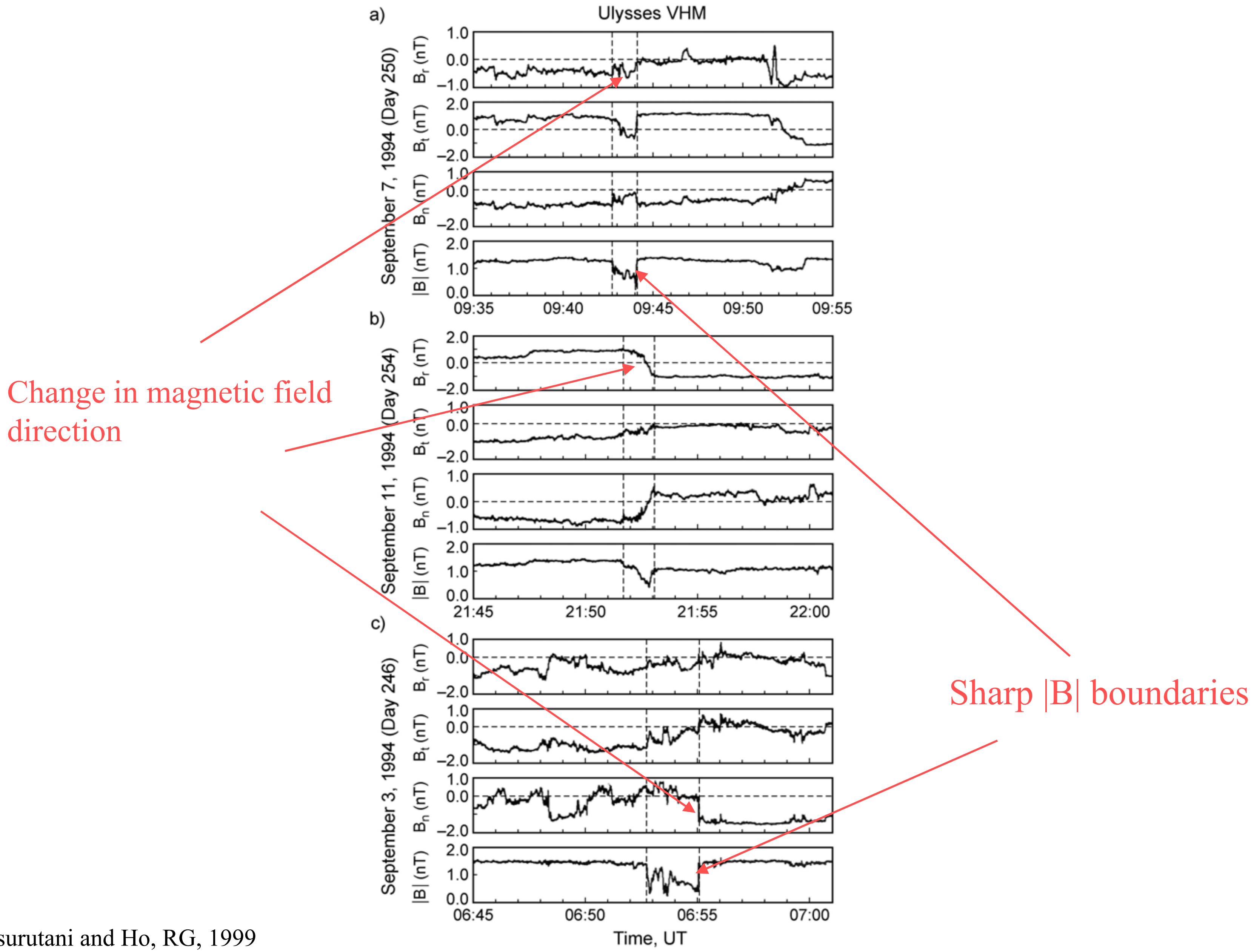



ΔB/|B| ~ 1-2
Alfven Waves

Magnetic
Decreases (MDs)

Note only decreases, no sharp increases. MD not quasiperiodic

# Examples of MDs



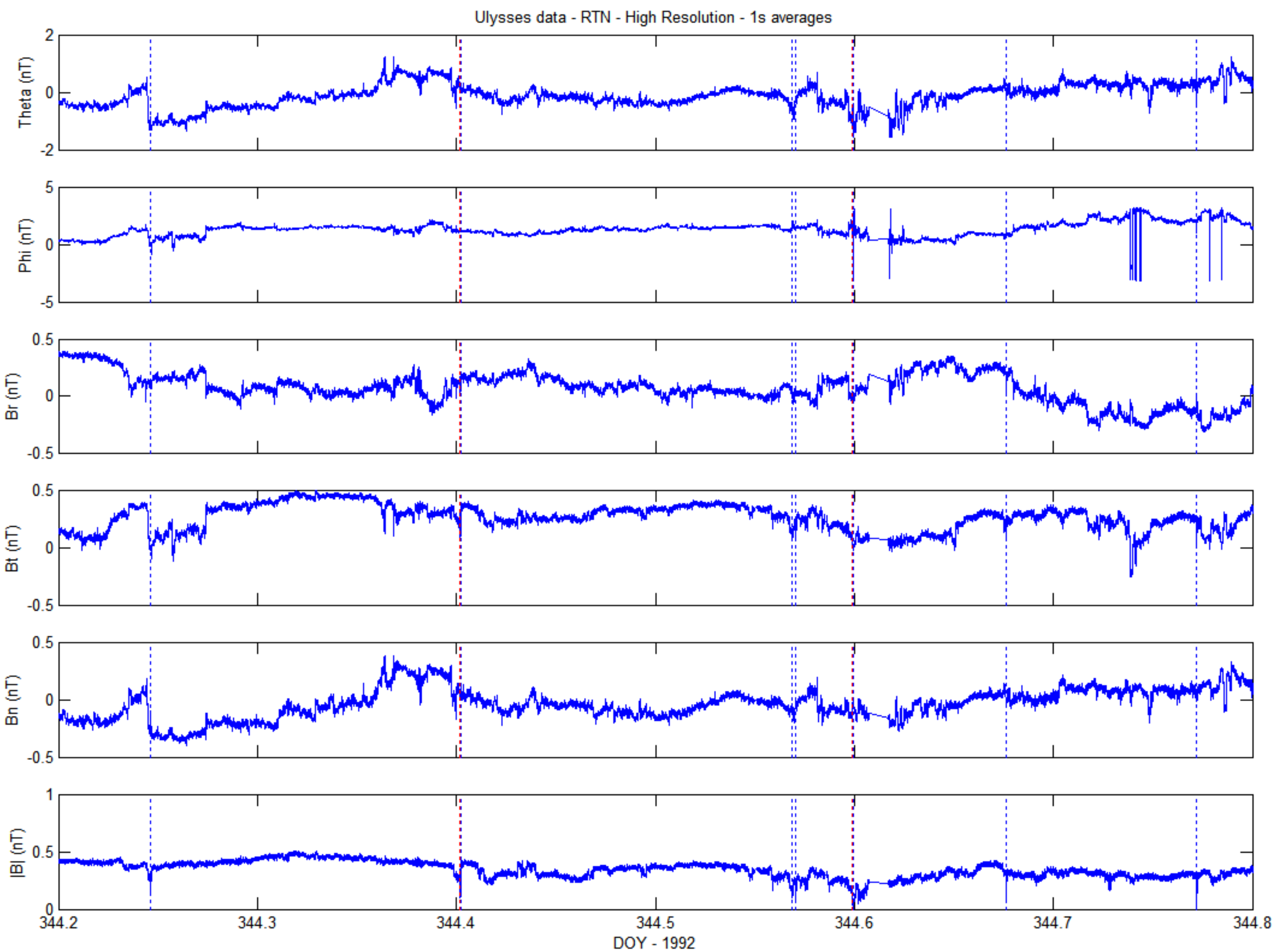

Tsurutani and Ho, RG, 1999

- MDs, MHs and MDs: Different names for same phenomenon.

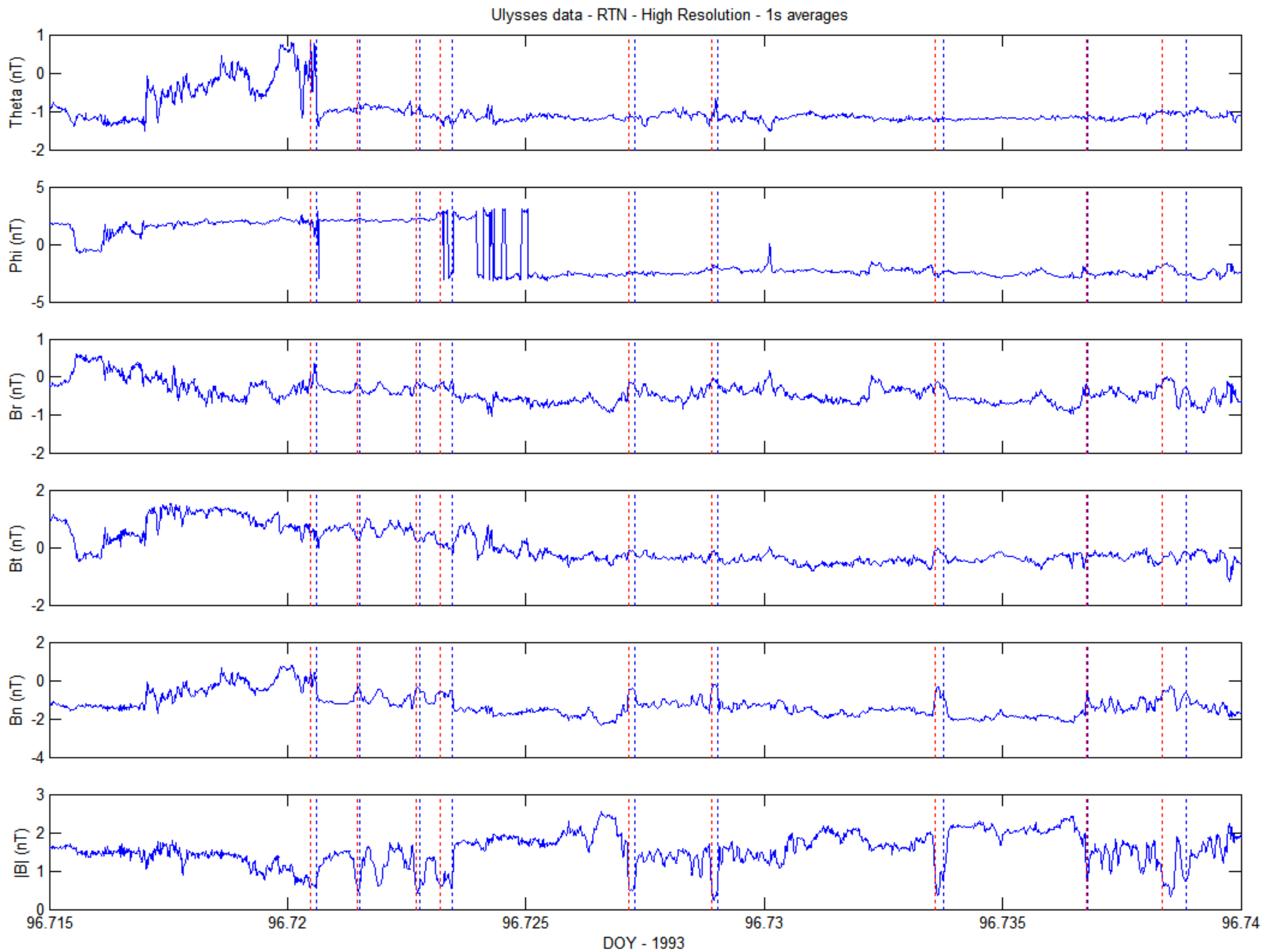
- Properties of MDs: 1) scale sizes from few $\rho_p$ to >1,000 $\rho_p$, 2) can occur as single events, 3) when occur in a series, are nonquasiperiodic structures, 4) are often bounded by sharp edges (slow shocks?).

- "Linear holes" (Burlaga and Lemaire, JGR 1978; Winterhalter et al., JGR 1994) is a subcategory of MDs with $\Delta\theta \leq 10^o$.

# USE OF IMDAD CODE TO IDENTIFY MDs:
## HIGH SPEED SOLAR WIND EXAMPLES

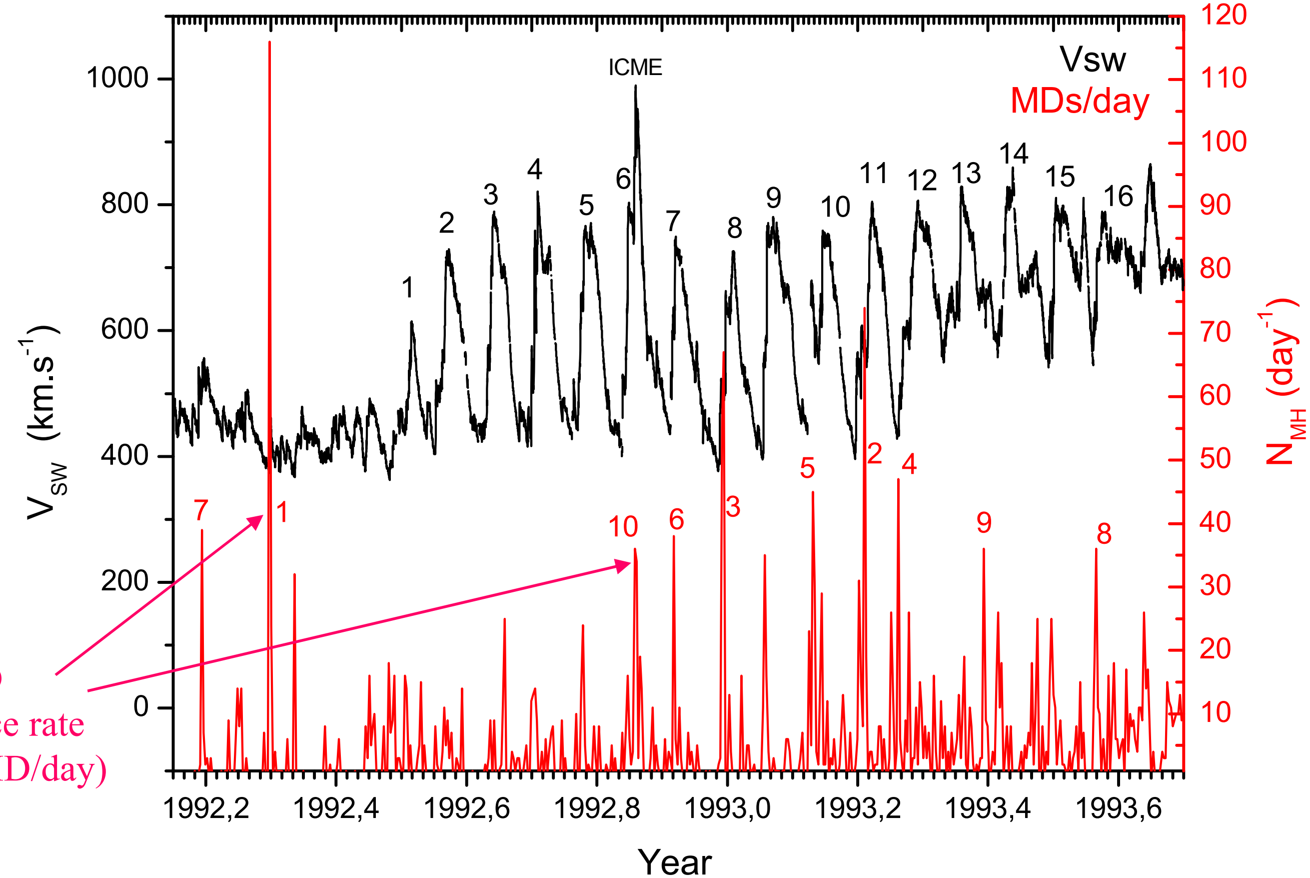



Guarnieri et al., EPS, 2009

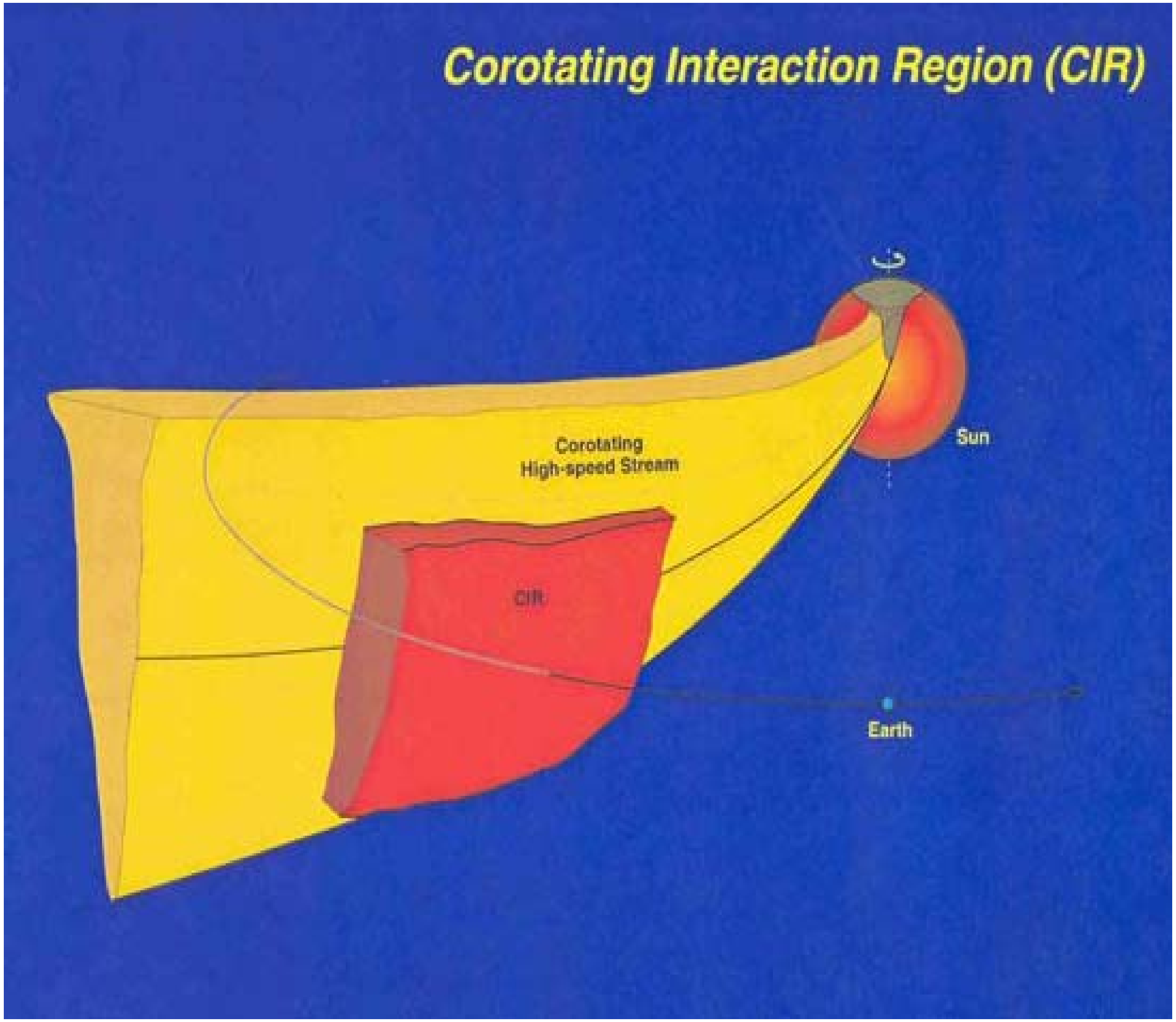


Ulysses data - RTN - High Resolution - 1s averages
Theta (nT)
Phi (nT)
Br (nT)
Bt (nT)
Bn (nT)
|B| (nT)
96.715
96.72
96.725
96.73
96.735
96.74
DOY - 1993

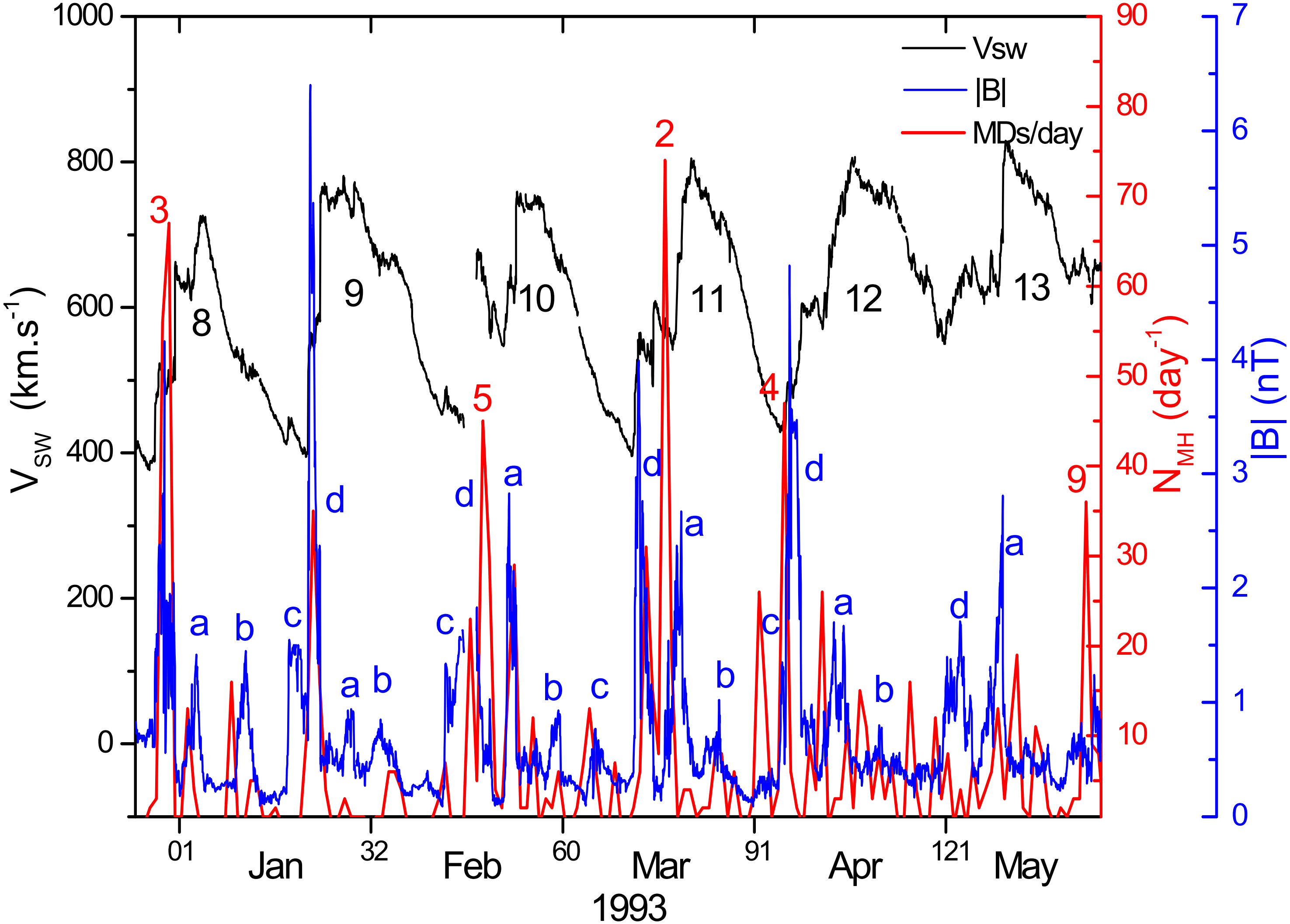
# ULYSSES FAST LATITUDE SCAN: COROTATING STREAMS




Large MD
Occurrence rate
Events (MD/day)

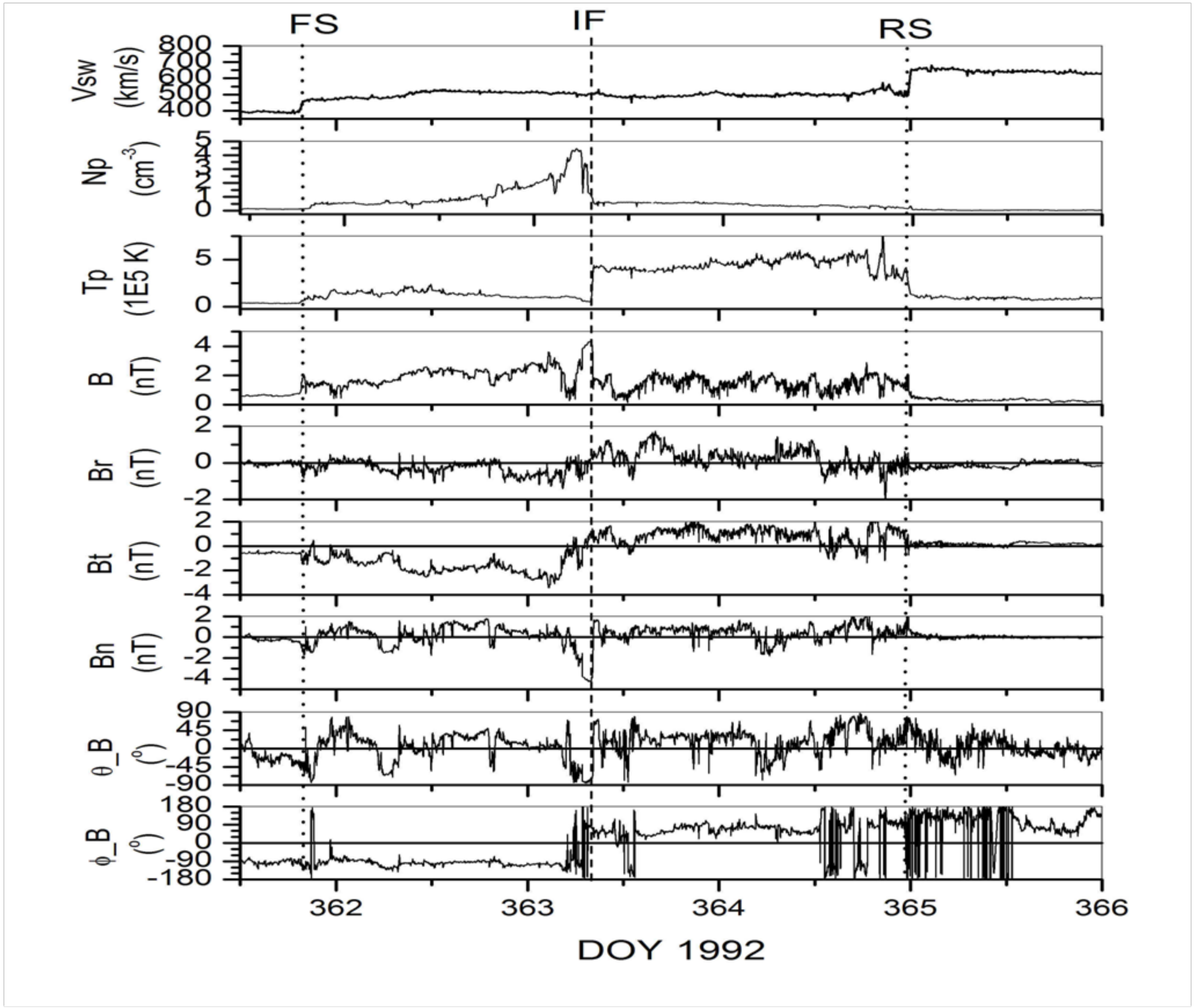


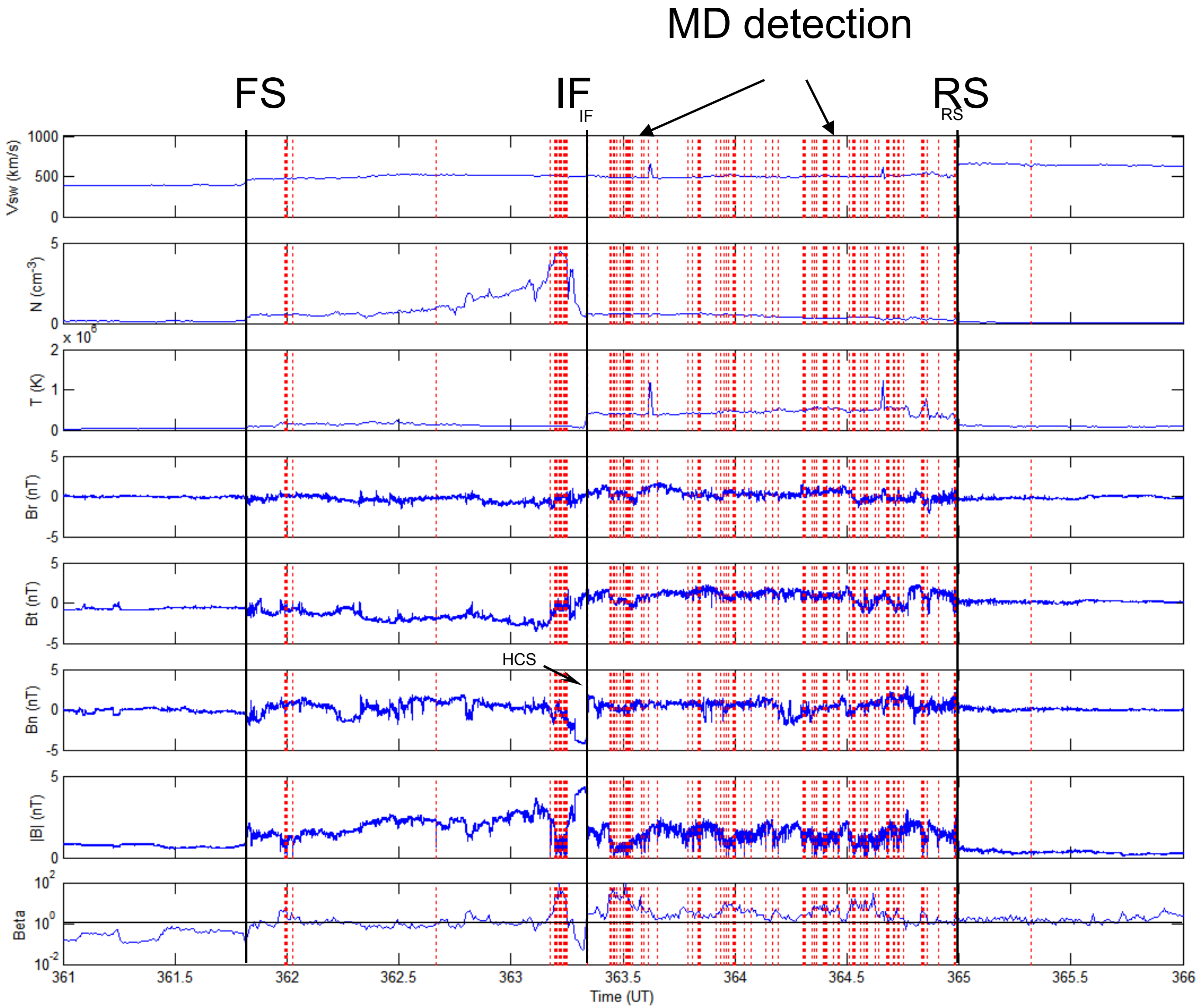

Tsurutani et al. JGR 2006



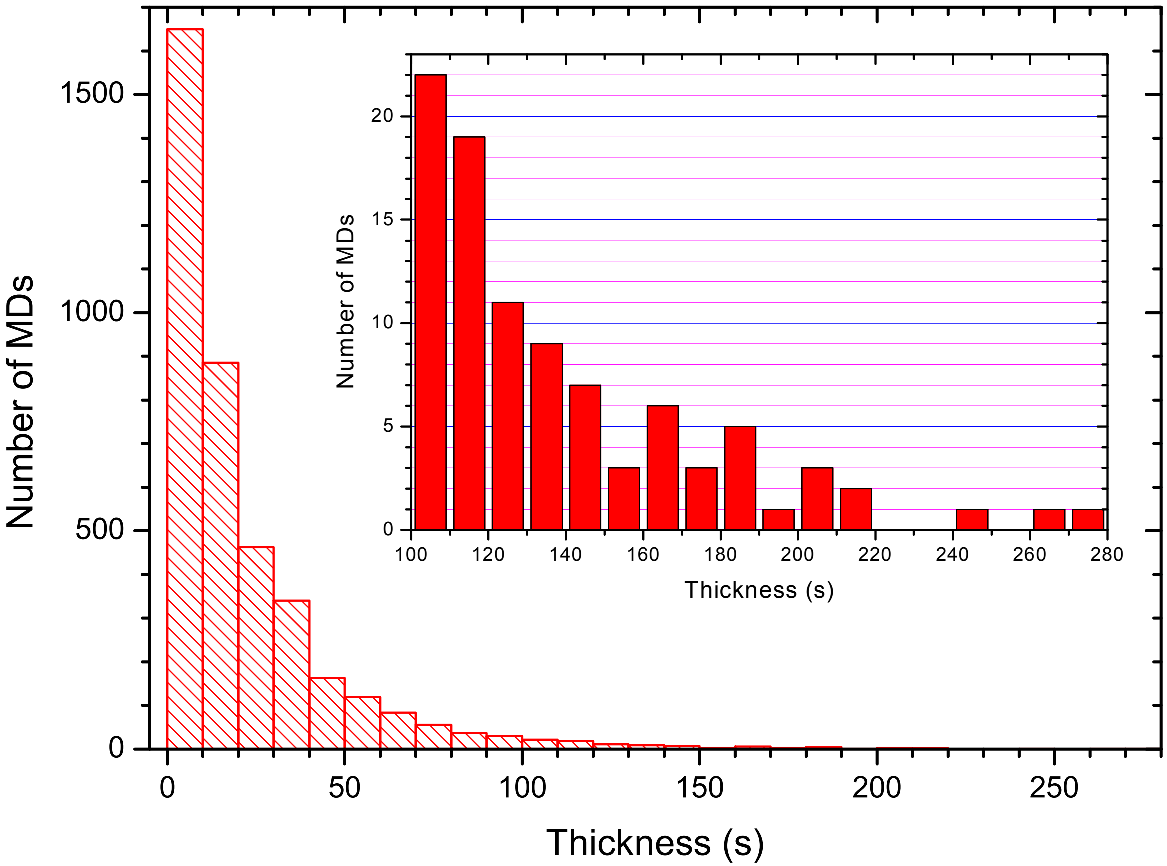

Tsurutani et al. JGR 2009

# CIR AT LEADING EDGE OF COROTATING STREAM #8



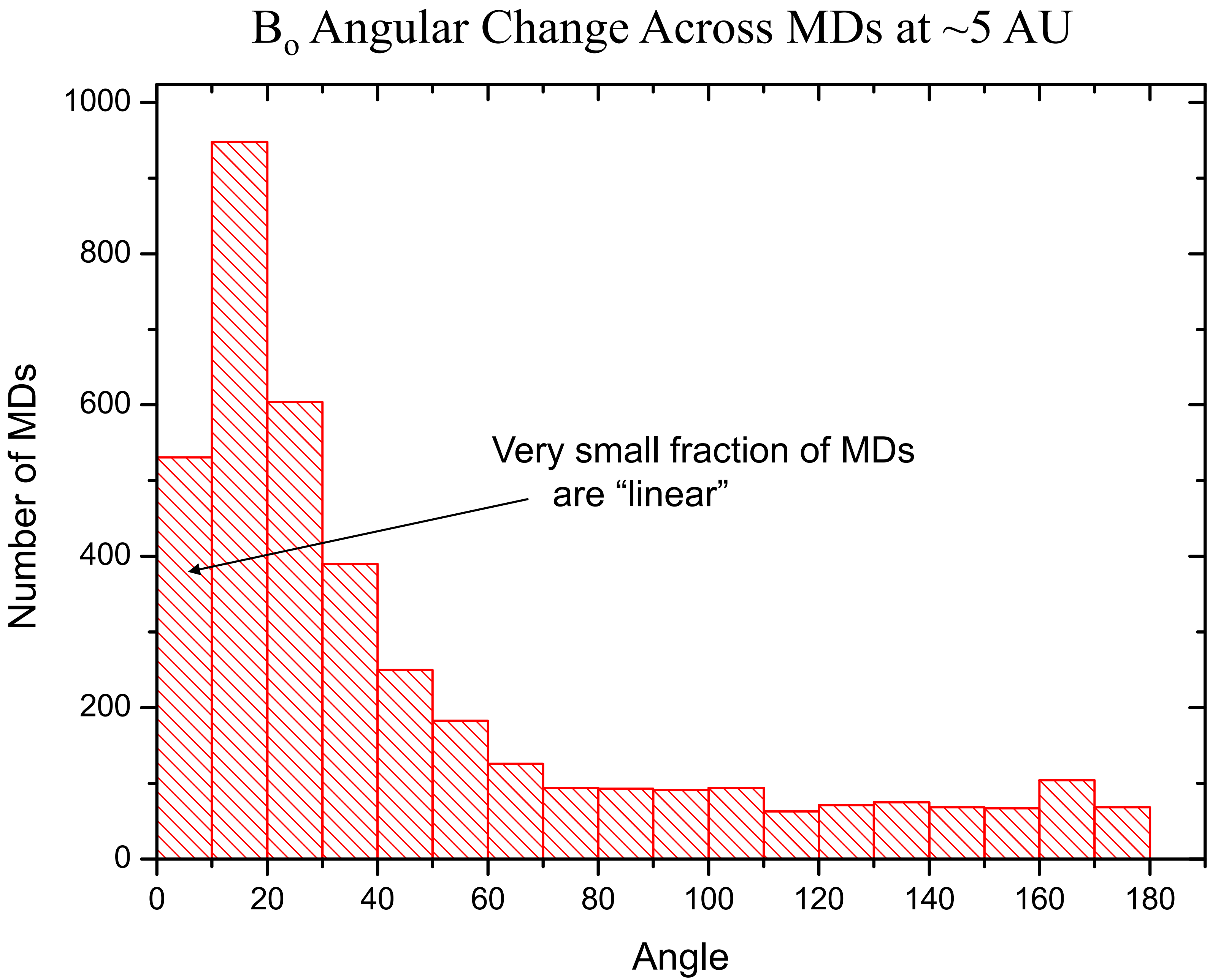


MD detection
FS
IF
RS
Vsw (km/s)
N (cm^-3)
T (K)
x 10^6
Br (nT)
Bt (nT)
Bn (nT)
HCS
|B| (nT)
Beta
Time (UT)

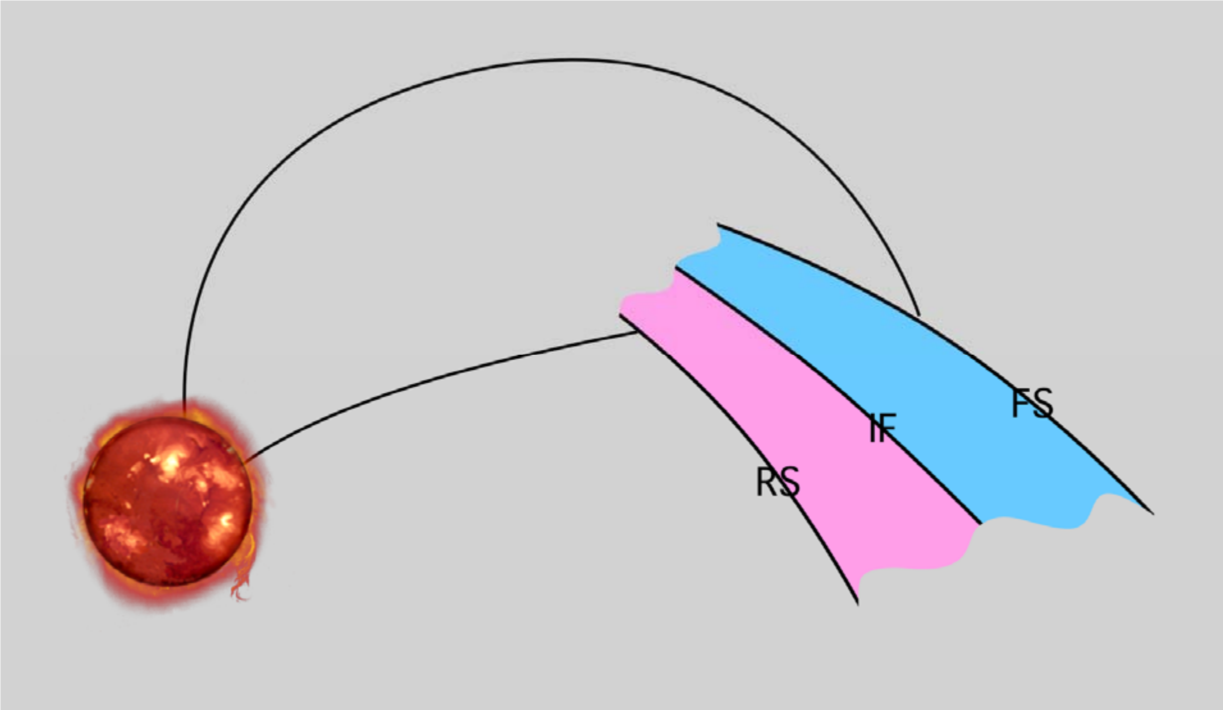


Number of MDs
Thickness (s)
0
500
1000
1500
0
50
100
150
200
250
Number of MDs
Thickness (s)
0
5
10
15
20
100
120
140
160
180
200
220
240
260
280


$r_p \sim 3$ sec



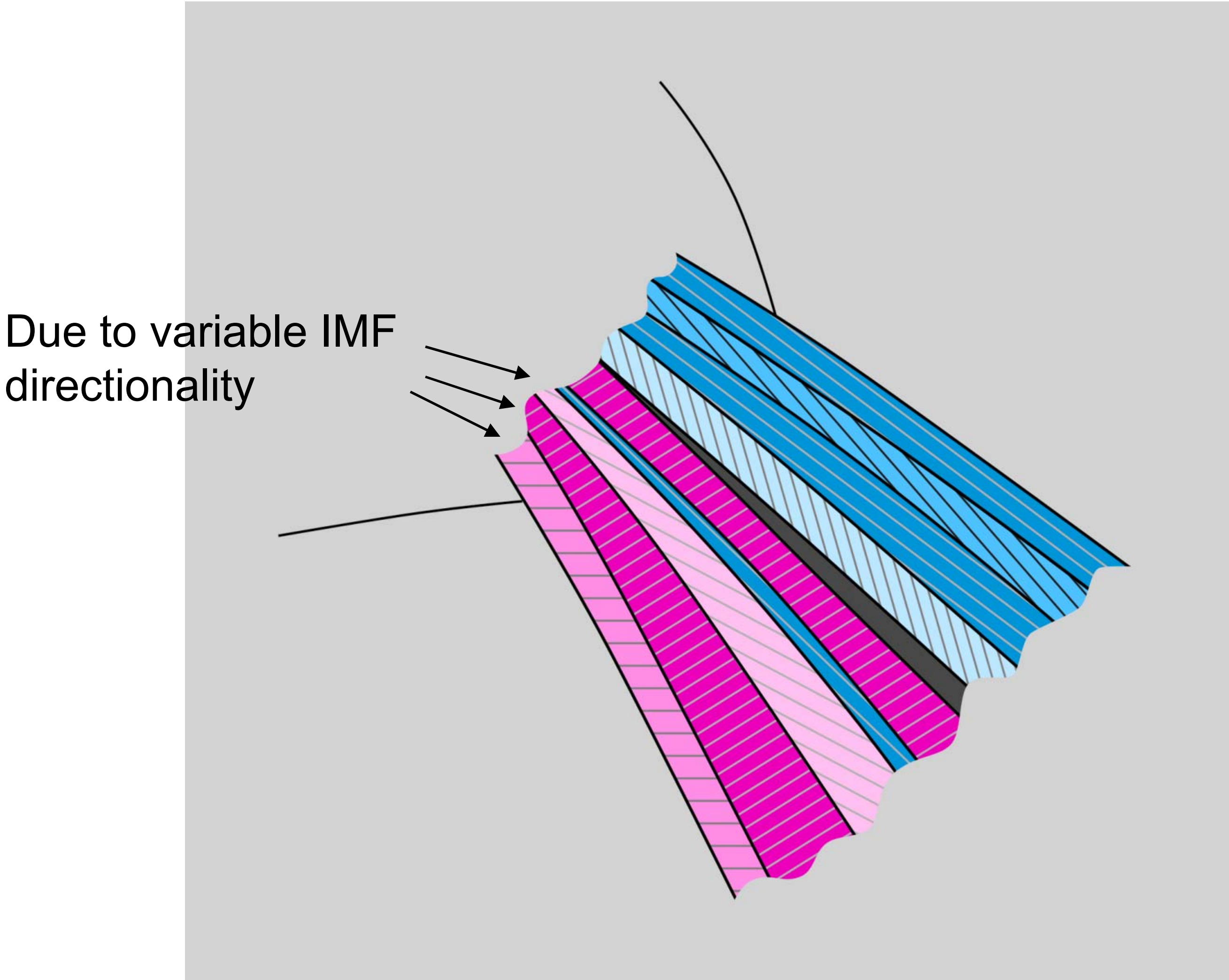
B$_o$ Angular Change Across MDs at ~5 AU
Very small fraction of MDs are "linear"
Number of MDs
Angle
0
200
400
600
800
1000
0
20
40
60
80
100
120
140
160
180


FS
IF
RS

# Reverse Shocks: Formation of High β Regions

- For a β =1 plasma, parallel shock:

Shock compression heats the plasma $T_{||}$, but no magnetic compression


Due to variable IMF
directionality

# 1. CONCLUSIONS: NEAR ECLIPTIC PLANE MDs

- MDs are formed from < 1 AU to > 5 AU in CIRs.

- The mechanism of mirror instability for MD formation in CIRs can be ruled out. Quasiparallel shock compression will lead to $\beta_{||}/\beta_{\perp} > 1$ anisotropies, conditions for mirror stability.

- No MMs detected downsteam of CIR FSs.  Why not?

# 1. CONCLUSIONS, CONTINUED

- For an upstream $\beta \sim 1.0$, an isotropic plasma and a shock Mach no. ~ 2,

$\beta = 2\beta_\perp + \beta_{||} = 3\beta_\perp$; Across the shock, the $T_\perp$, $\rho$, $B_o$ are compressed by ~2 (Kennel et al., 1985).

$\beta_\perp/\beta_{||} = 0.3/0.17 = 2$. But for MM instability ( $\beta_\perp/\beta_{||} > 1 + 1/\beta_\perp$), must be $> 1 + 1/\beta_\perp$ or ~4. The plasma is stable to MM growth.

# 1. CONCLUSIONS, CONTINUED

- One should not expect mirror instability to occur in interplanetary (CIR or ICME) sheaths, unless unusual conditions hold.

# Possible MD Formation Mechanisms in CIRs

- Shock-discontinuity interactions (Tsubouchi and Matsumoto JGR 2005).
- Wave-wave interactions (Vasquez et al. JGR 2007).
- Nonlinear wave evolution (Buti et al. GRL 2001)
- Dissipation of phase steepened Alfven waves (Tsurutani et al., GRL 2002a,b; NPG 2005)

# What Are Mirror Mode (MM) Structures?

Mirror modes are nonoscillatory structures that are generated by an instability driven by plasma anisotropies:

$$\beta_\perp/\beta_{||} > 1 + 1/\beta_\perp$$

(Chandrasekhar et al., PRS, 1958; Vedenov and Sagdeev, 1958; Hasegawa, PF, 1969).

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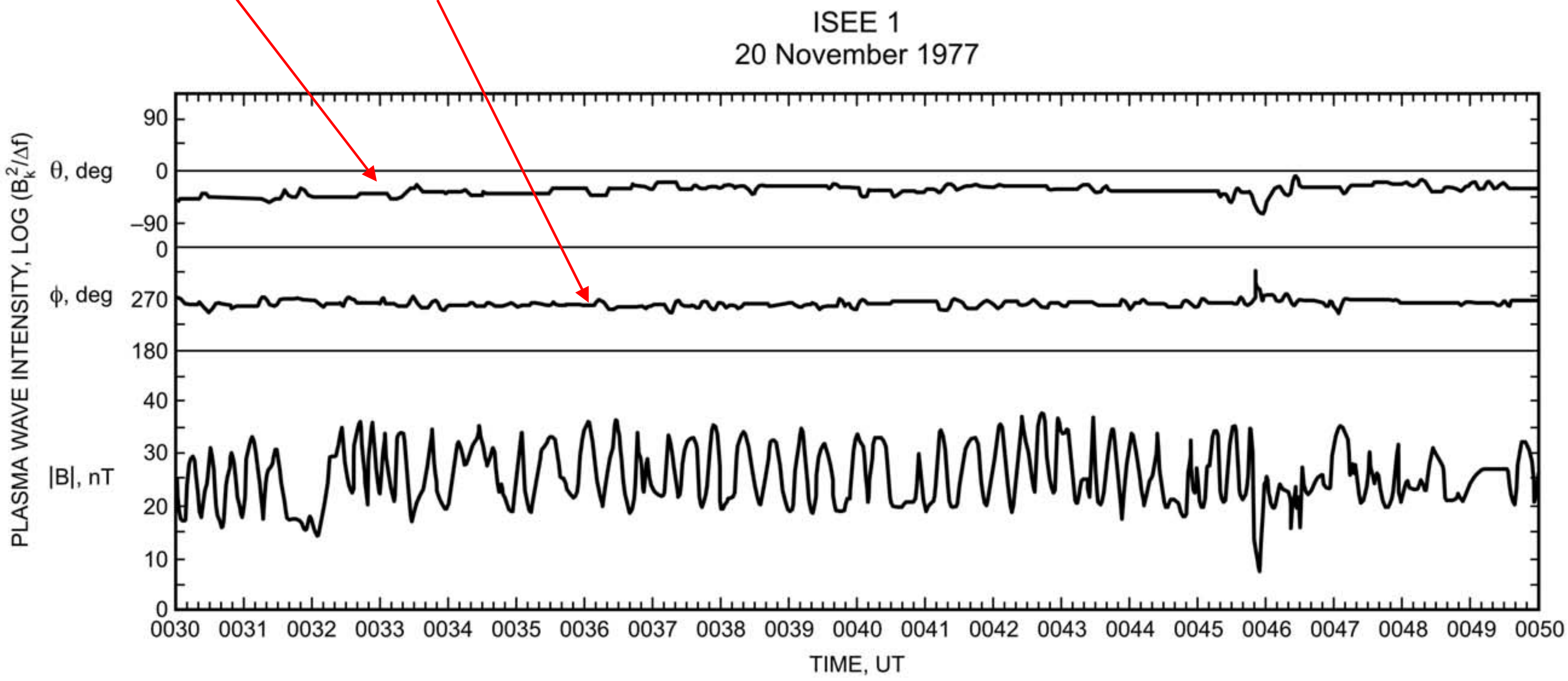
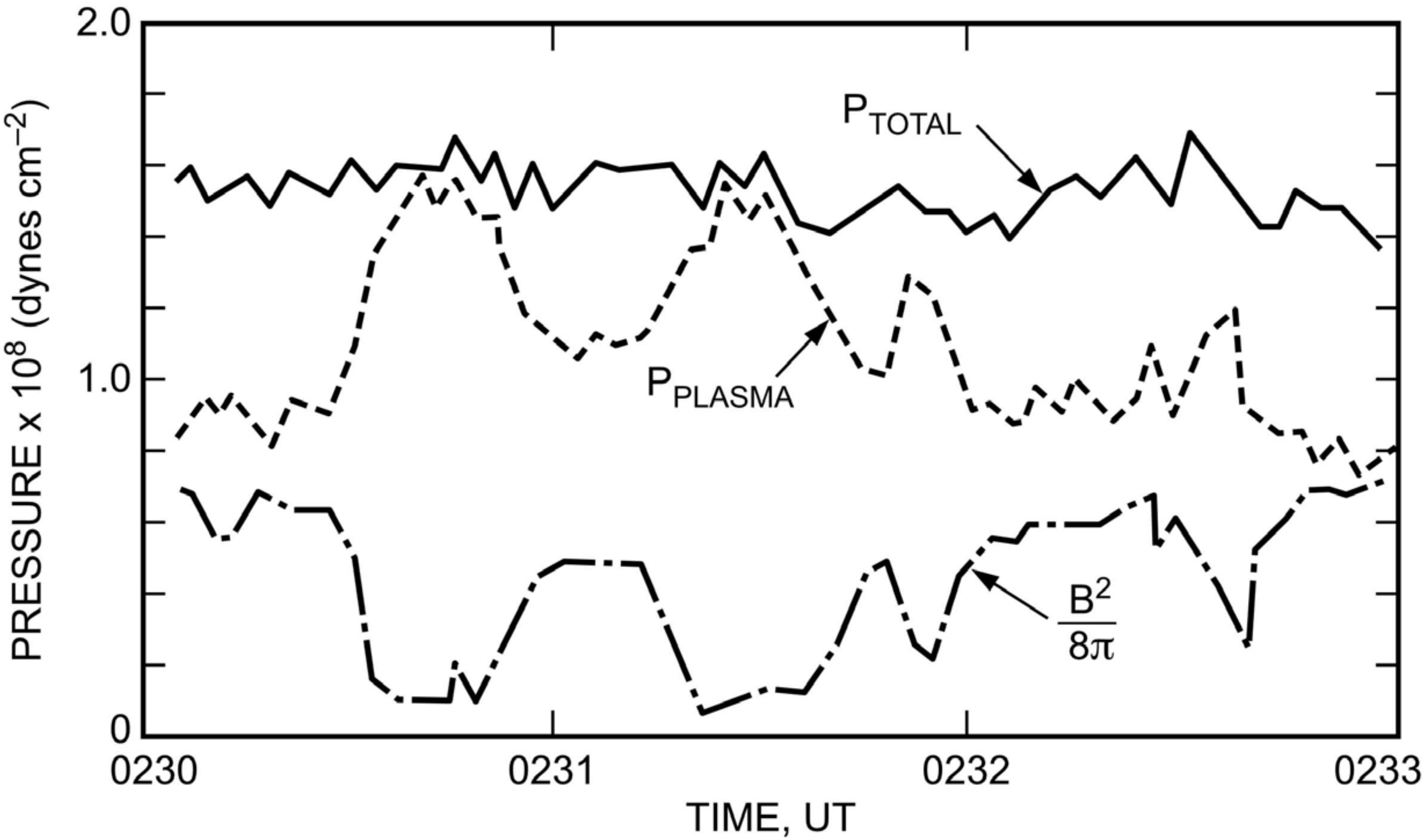
# Mirror Modes at Earth

Little or no angular changes

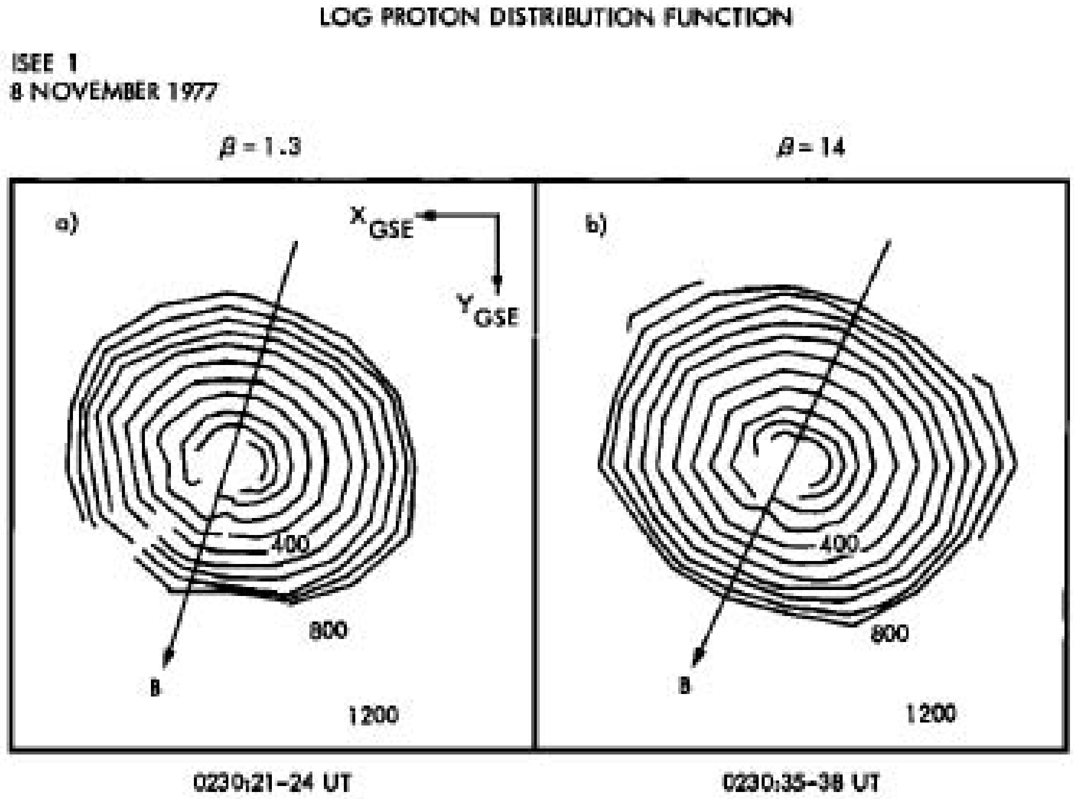


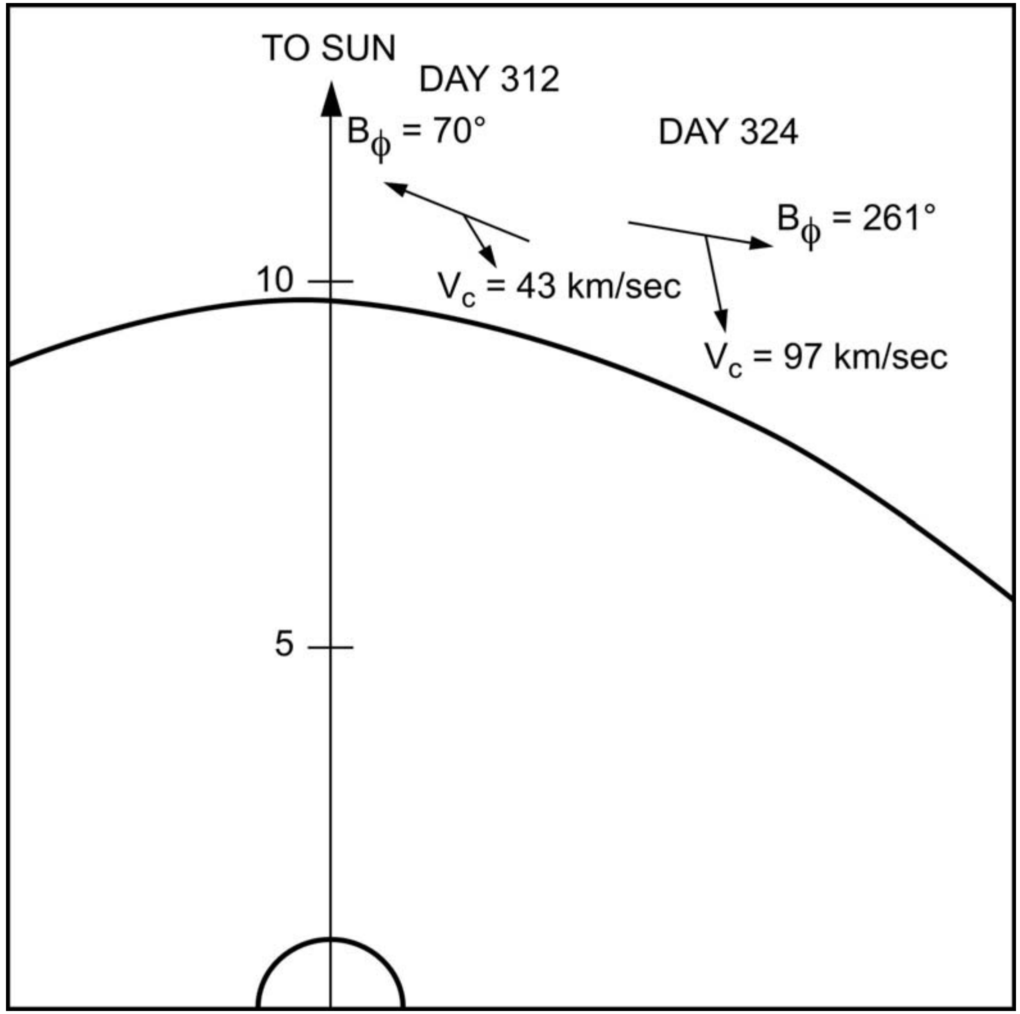

Tsurutani et al. JGR 1982

# Mirror Modes Are Pressure Balance Structures

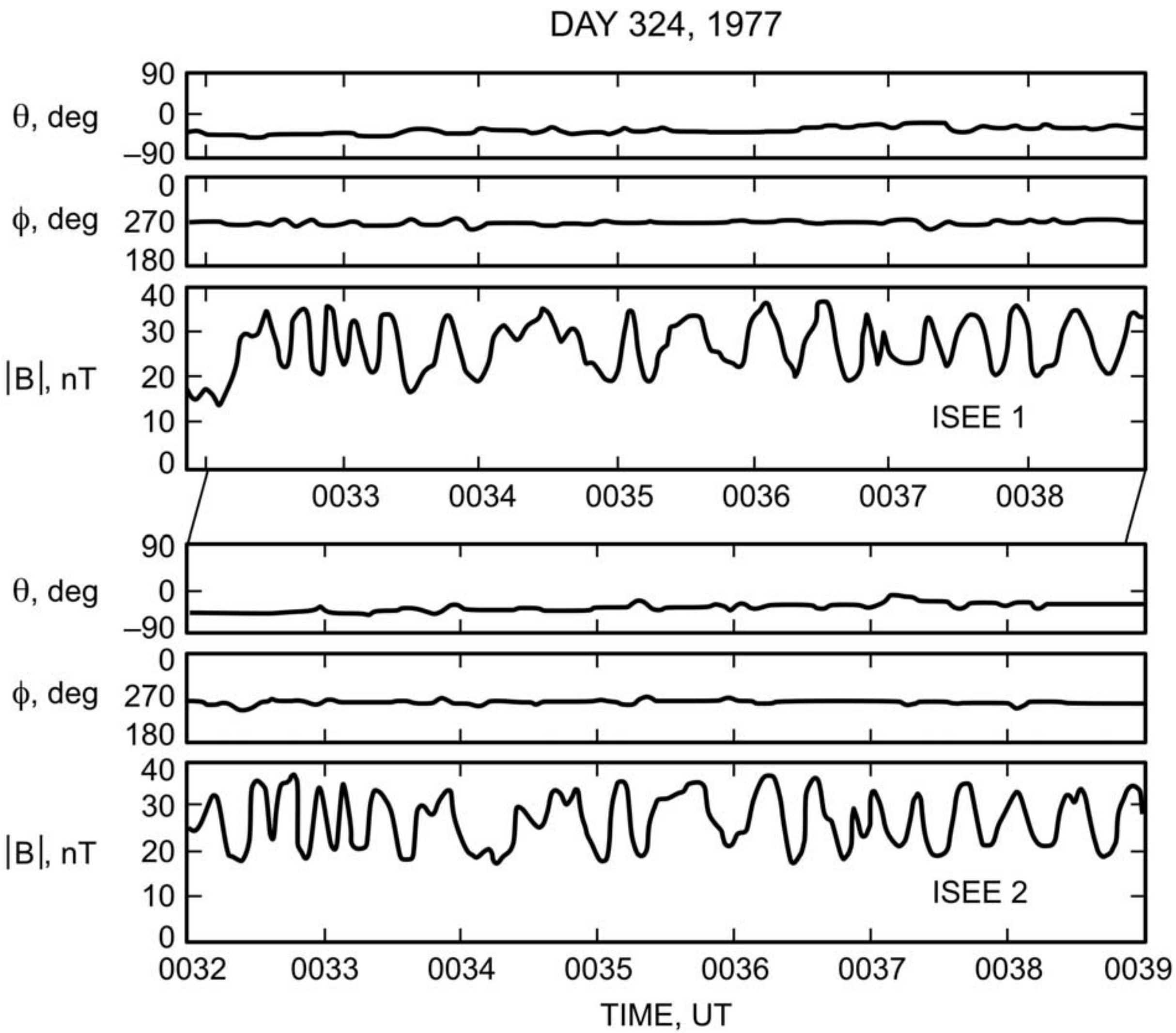



Tsurutani et al., JGR 1982


LOG PROTON DISTRIBUTION FUNCTION
ISEE 1
8 NOVEMBER 1977
β = 1.3
β = 14
a)
$X_{GSE}$
$Y_{GSE}$
400
800
B
1200
b)
400
800
B
1200
0230:21-24 UT
0230:35-38 UT

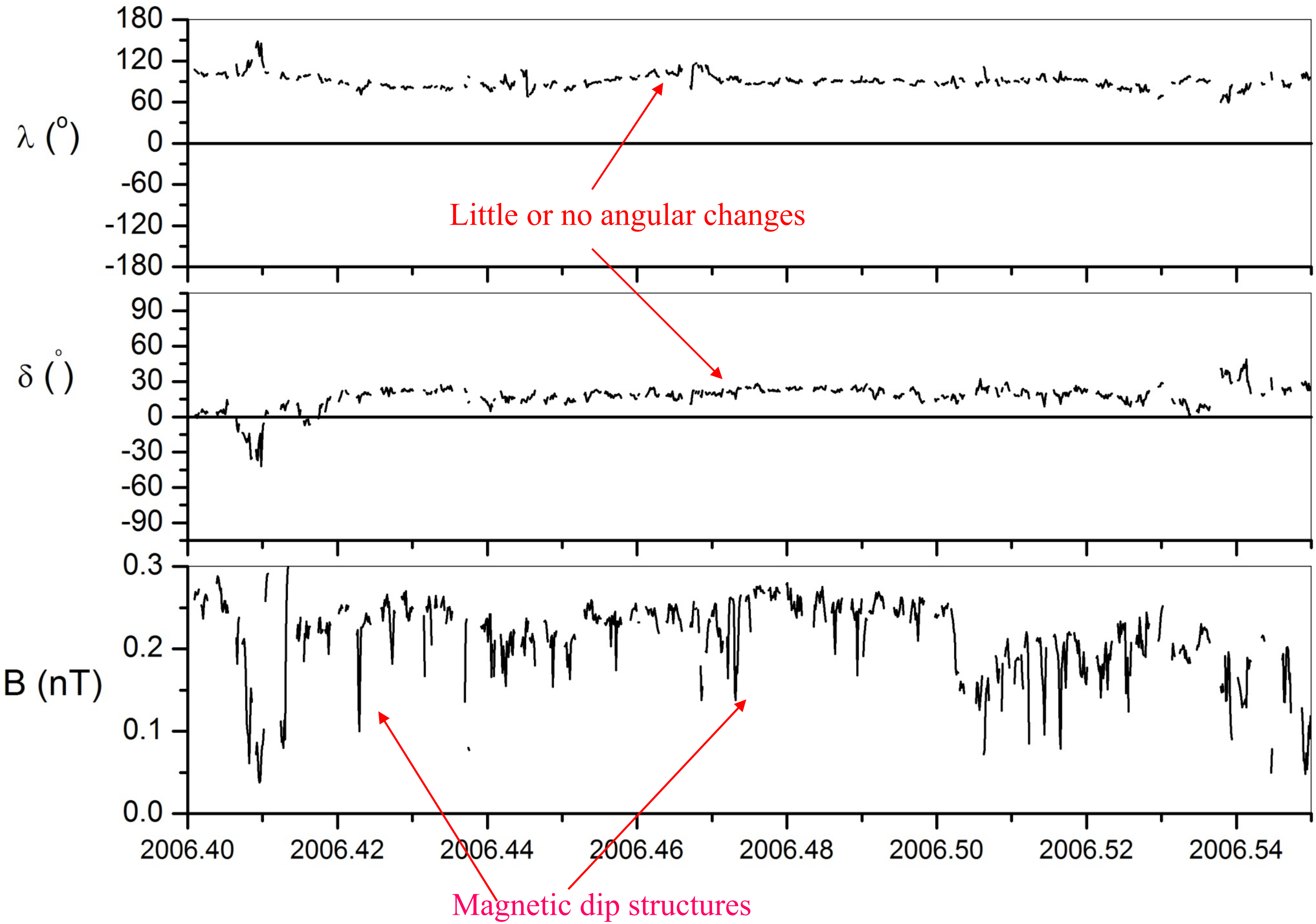

TO SUN
DAY 312
$B_\phi$ = 70°
DAY 324
$B_\phi$ = 261°
$V_c$ = 43 km/sec
10
$V_c$ = 97 km/sec
5

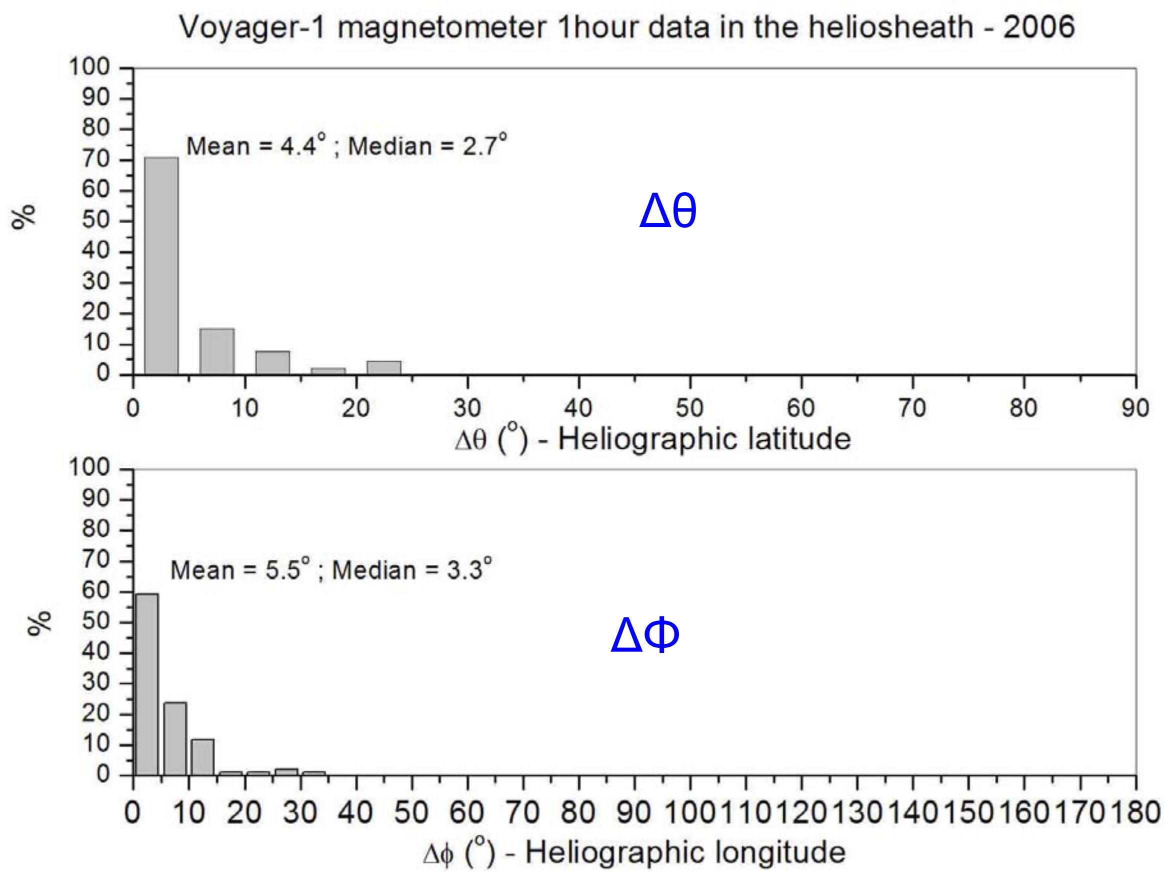
# MMs ARE CONVECTED STRUCTURES



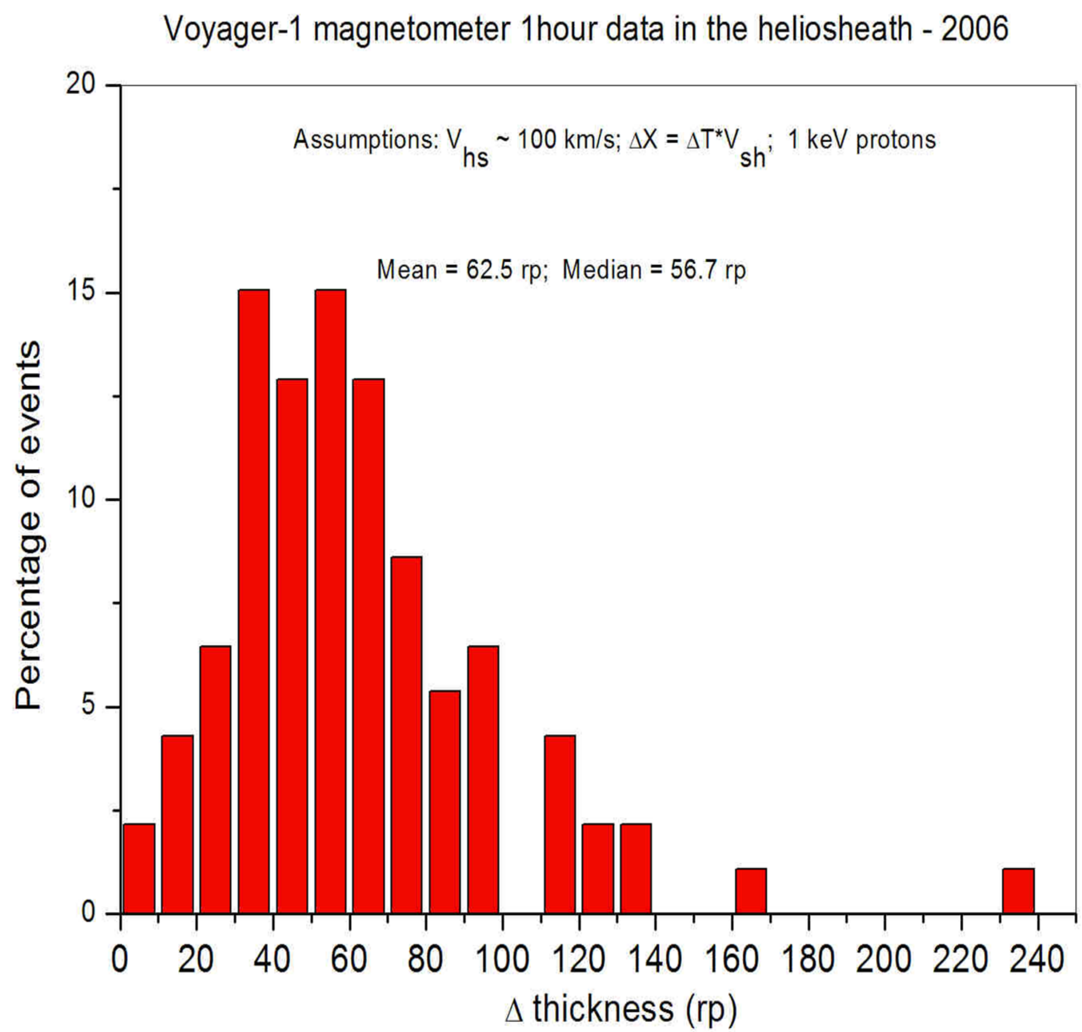

Tsurutani et al. JGR 1982

# Voyager 1 Heliosheath Magnetic Field Data





Voyager-1 magnetometer 1hour data in the heliosheath - 2006
Mean = 4.4° ; Median = 2.7°
Δθ
%
Δθ (°) - Heliographic latitude
Mean = 5.5° ; Median = 3.3°
ΔΦ
%
Δϕ (°) - Heliographic longitude


Voyager-1 magnetometer 1hour data in the heliosheath - 2006
Assumptions: V hs ~ 100 km/s; ΔX = ΔT*V sh; 1 keV protons
Mean = 62.5 rp; Median = 56.7 rp
Percentage of events
0
5
10
15
20
0 20 40 60 80 100 120 140 160 180 200 220 240
Δ thickness (rp)

# Scales of MM Structures

- ~20 $\rho_p$ in Earth's magnetosheath (Tsurutani et al. JGR, 1982)
- ~25 $\rho_p$ in the Jovian magnetosheath (Tsurutani et al. JGR, 1982)
- ~40 $\rho_p$ in the Saturnian magnetosheath ( Tsurutani et al. JGR, 1982)
- ~55 $\rho_p$ in the Heliosheath (this study)

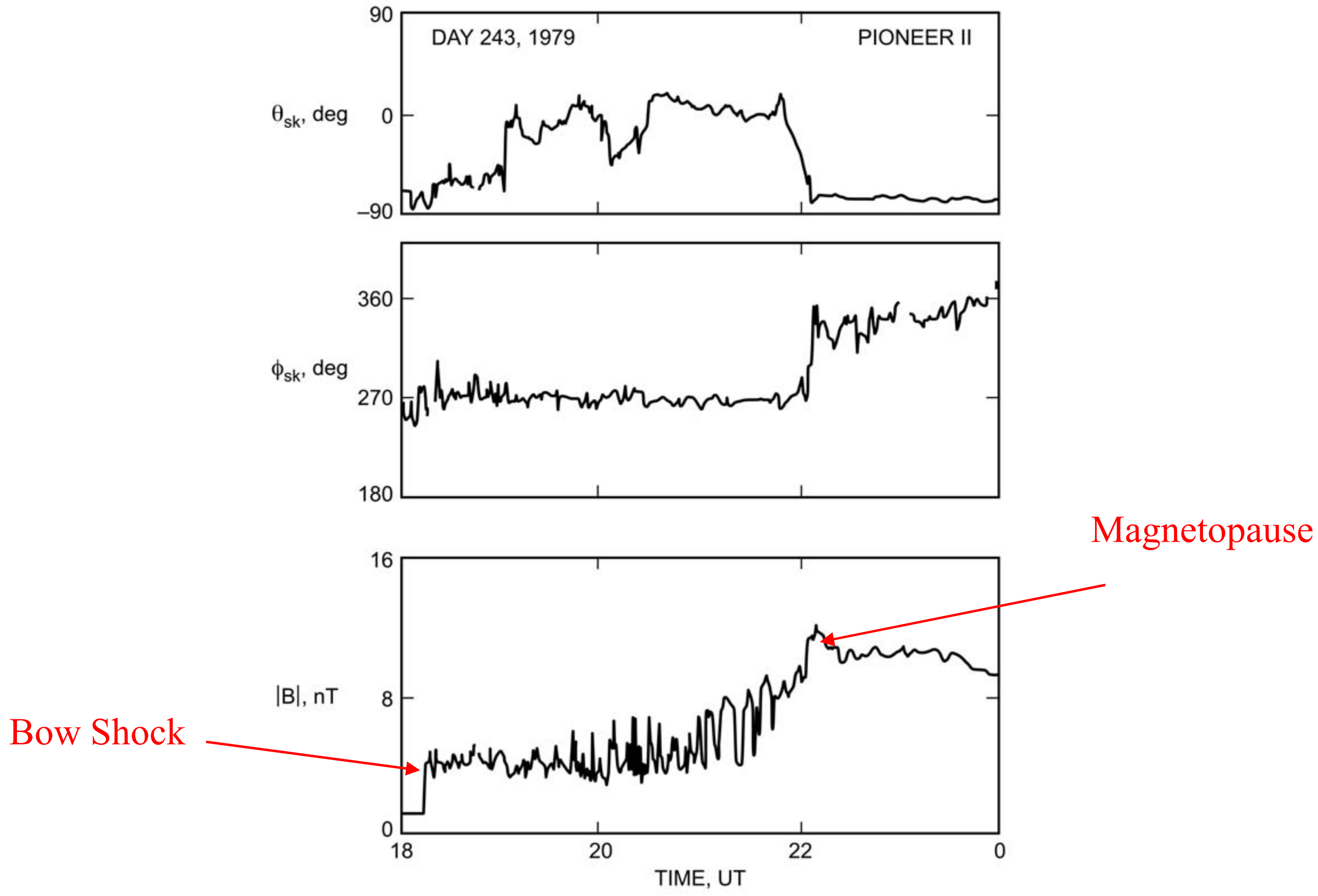
# The Mechanism for MM Formation in the Heliosheath

Upstream region of the termination shock: $\rho = 10^{-3}$ cm$^{-3}$, $T = 10^4$ K, $B_o = 5 \times 10^{-2}$ nT. Thus $\beta = 0.14$.

$V_{sw}$ to is observed to decrease by ~20% (mass loading effect). Thus $N_{pu} = 2.5 \times 10^{-4}$. If the IMF fluctuates by 10º (due to the presence of Alfvén waves) $\beta_\perp/\beta_{||} \geq 35$, whereas instability requires $\beta_\perp/\beta_{||} \geq 1$.

The region upstream of the TS should be MM unstable due to PU ion anisotropies. Perpendicular shock compression and the addition of pickup ions in the heliosheath will add free energy and drive the instability further.

# Revisiting the Saturnian Magnetosheath




Tsurutani et al. JGR 1982

# What is the mechanism for MM growth in the Saturnian magnetosheath?

- Planetary BS is large Mach No. ~15 shock. Compression across them is ~4.
- For an upstream (isotropic) plasma β of 1.0, downstream of the perpendicular portion of the shock, $\beta_\perp$ is unchanged (previous arguments). $B_{||}$ is 0.085. Thus $\beta_\perp/\beta_{||}$ =4. Only marginal instability.
- Field line draping adds ion anisotropy and drives the MM instability. Both perpendicular shock heating and draping are necessary.

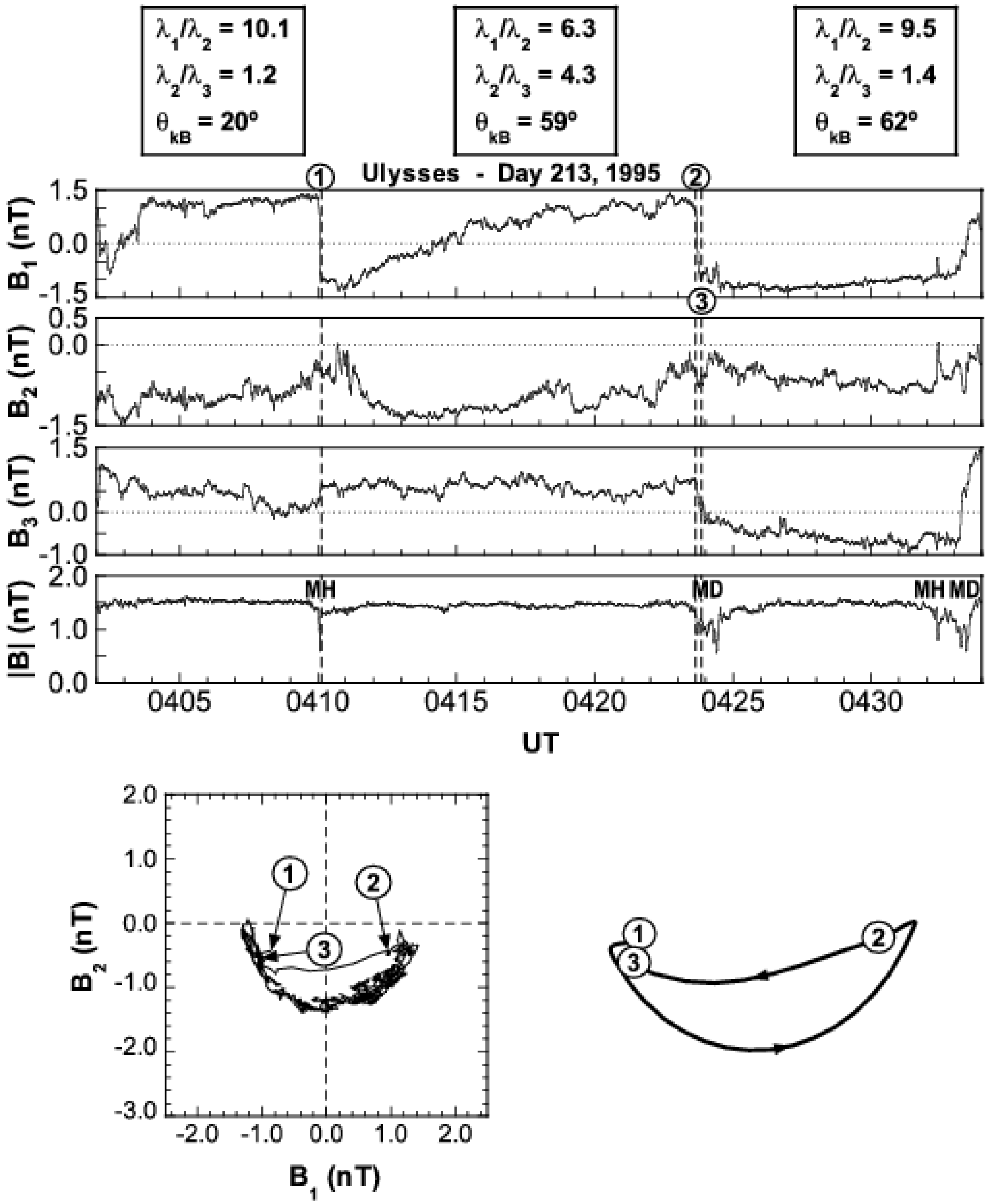
# 2. CONCLUSIONS

- The heliosheath mirror instability is driven by upstream pickup ions and then is enhanced by perpendicular shock compression of the anisotropic plasma plus further pickup of perpendicular ions in the heliosheath.

- For planetary magnetosheaths, the MM mechanism is likewise a multistep process: perpendicular shock compression plus magnetic field draping.

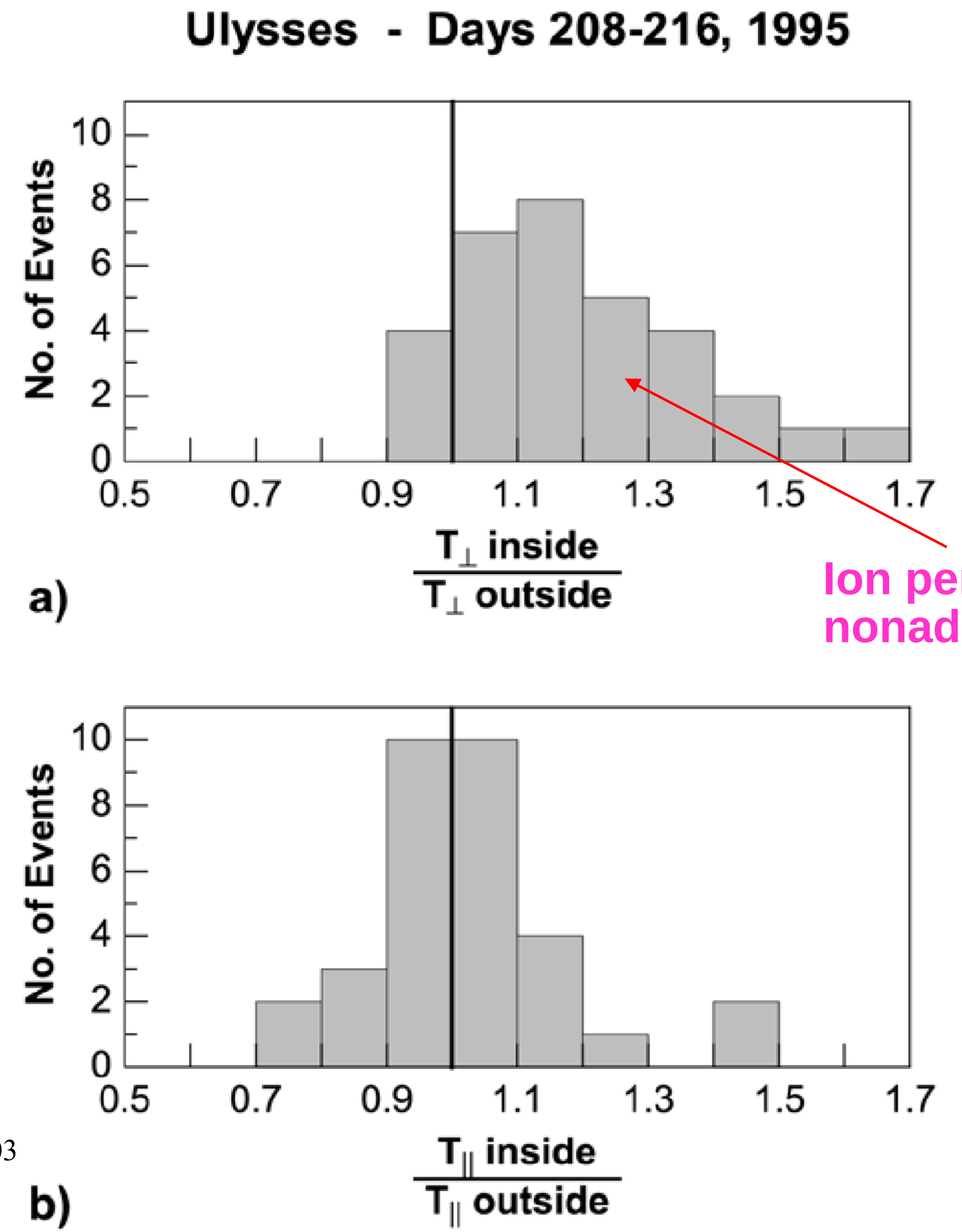
# THE END

- Thank you for you attention




Tsurutani et al. GRL, 2002

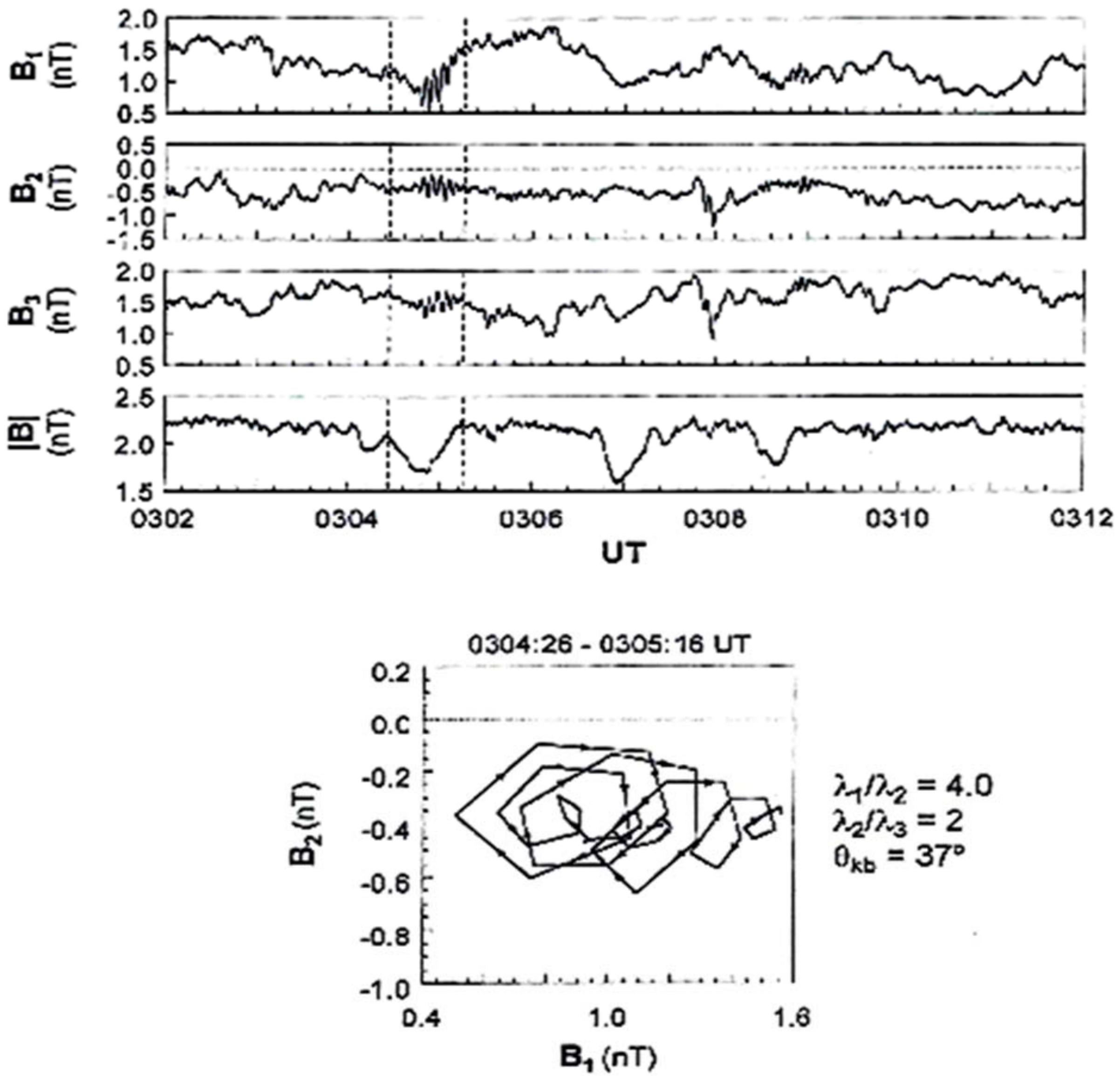
## Distribution of Protons $T_{inside\ MD}/T_{outside\ MD}$ Ratios
## Ulysses North Pole



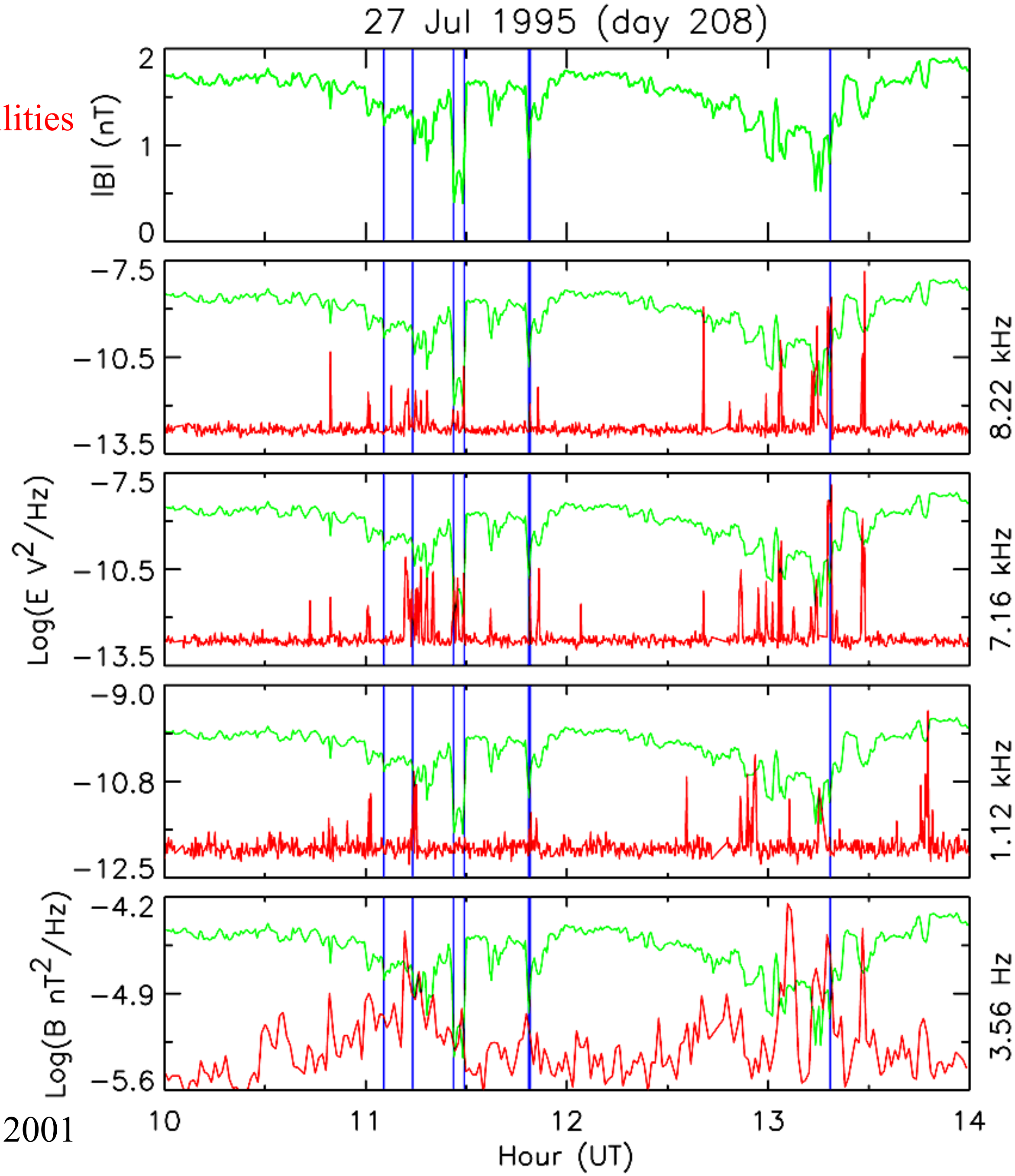

**Ion perpendicular heating: nonadiabatic**

Tsurutani et al. GRL, 2003

# Ion Cyclotron Instability inside a MD



Electron instabilities
Inside MDs




Lin et al. GRL, 2001

# PROPOSED IDEA FOR CAUSE OF MDs DETECTED IN HIGH SPEED STREAMS

- Alfven waves phase-steepen,

- The ponderomotive force associated with the steepened edge (RD) leads to heating of protons and electrons (thus the instabilities),

- The MDs are created by the diamagnetic effect of the heated ions and electrons.

Tsurutani et al. NPG, 2005