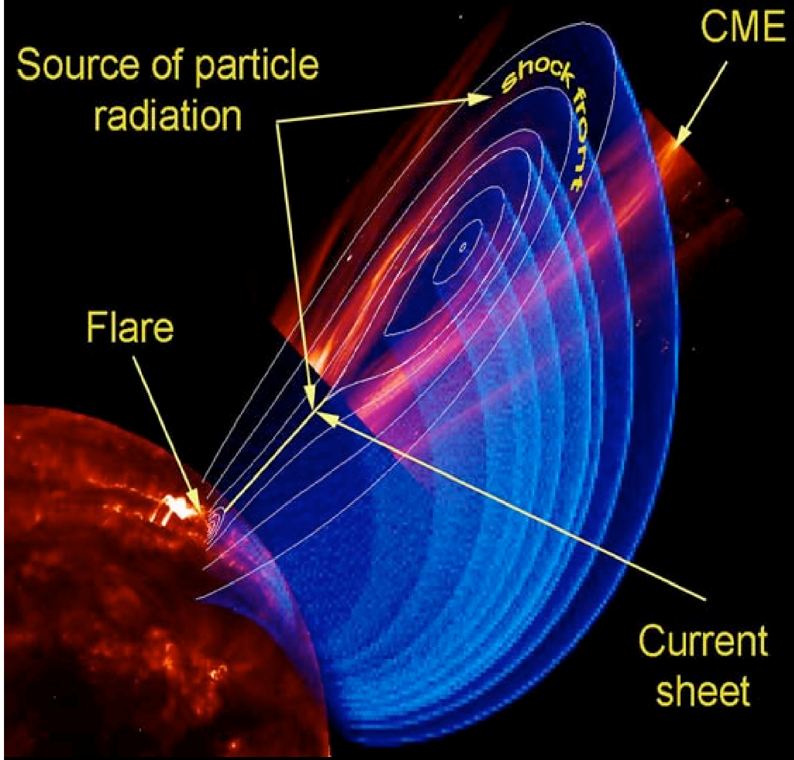
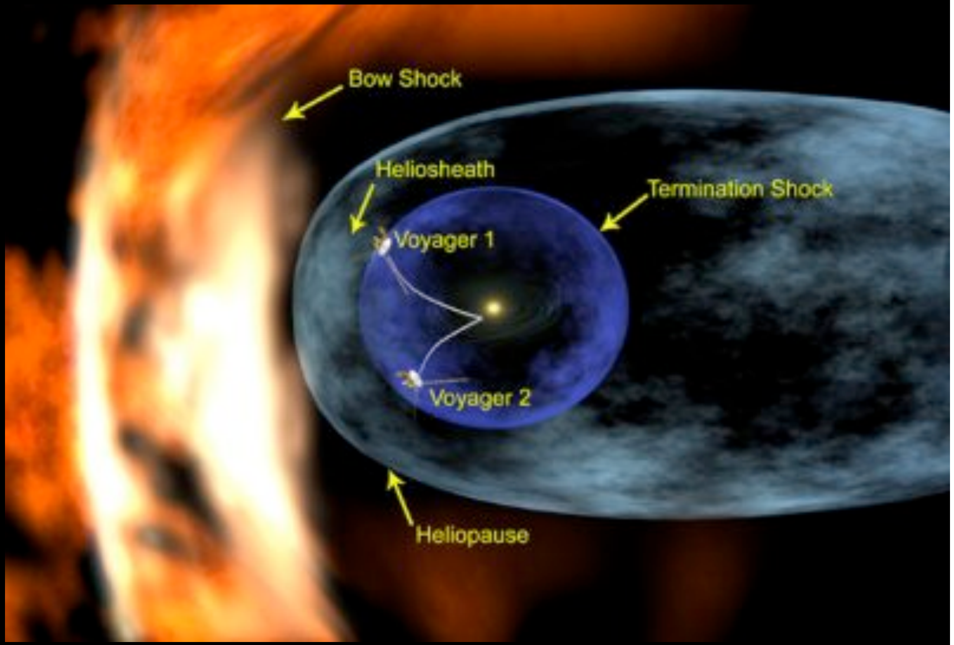
Comparative Shock Studies: From the Lower Corona to the Termination Shock



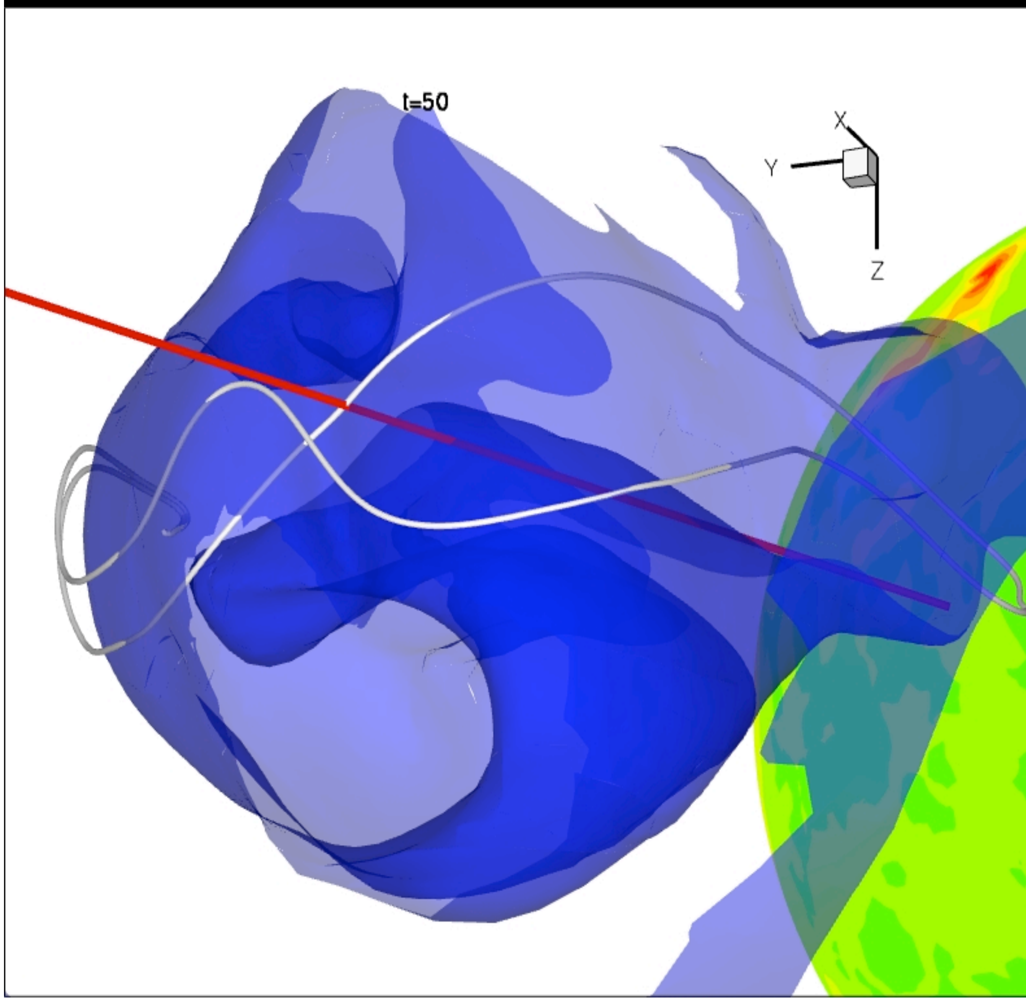


AGU Chapman Conference on Universal Heliophysical Processes (IHY)

Collaborators:

- Cristiane Loesch, Maria Virginia (INPE)
- Rebekah Evans (GMU);
- Indrajit Das (GMU)
- Yong Liu (UNH)
- Ward Manchester, Tamas Gombosi (Univ. of Michigan)

Evolution of Magnetized Shocks



How magnetic effects affect shock evolution?

Which type of flows we get in shocks?

Asymmetries in shocks?

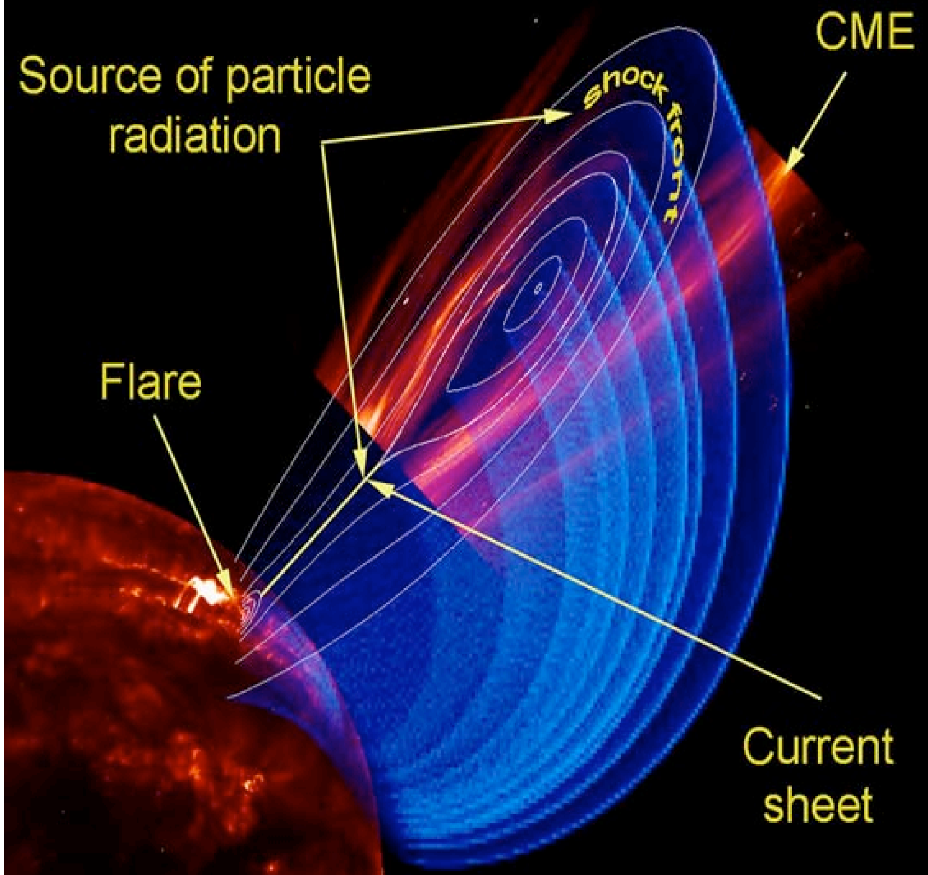
MHD instabilities?

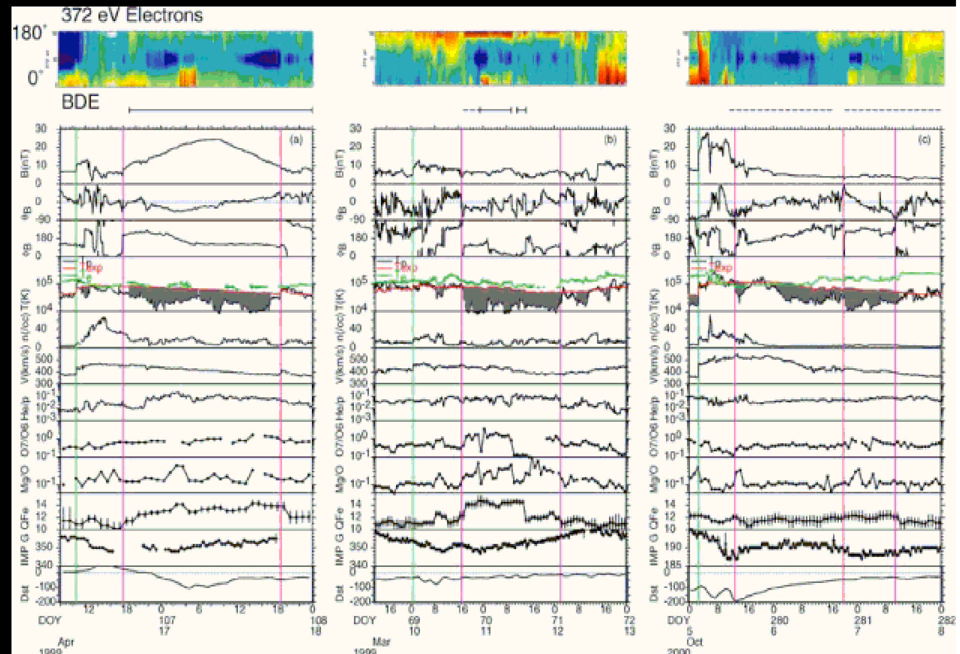
How reconnection affect shock structures?

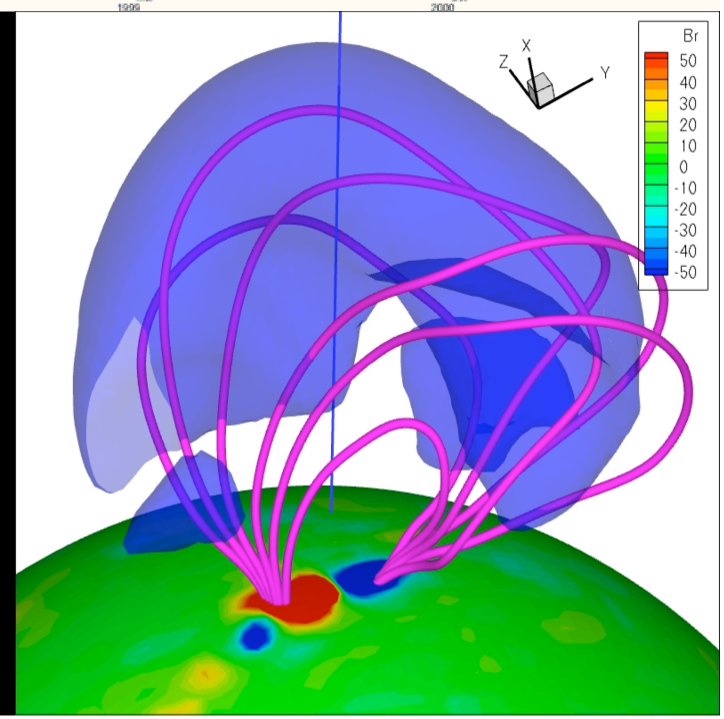
How a structured solar wind affect the evolution of the shock?

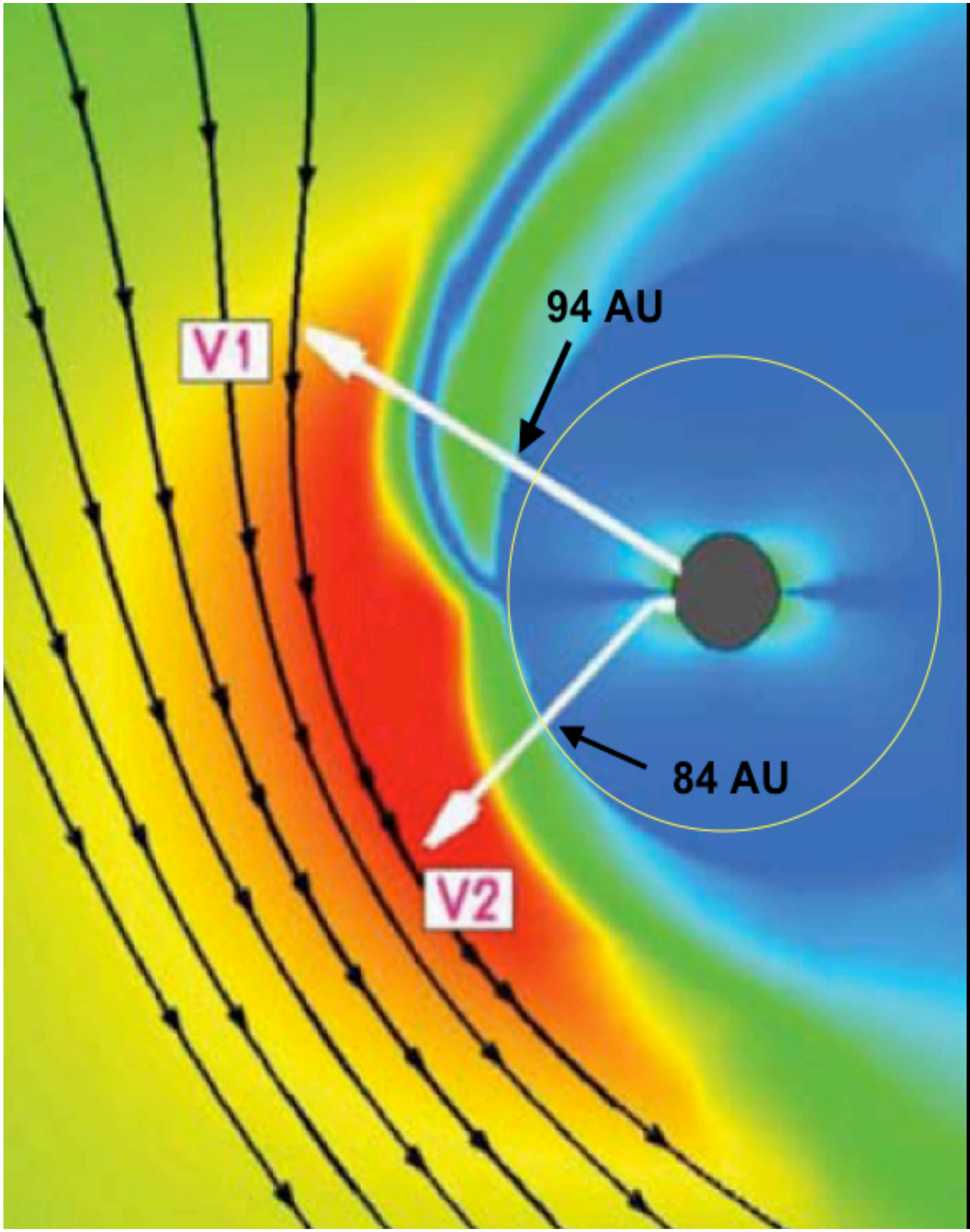
Y. Liu et al. 2008b

Shocks Driven by Coronal Mass Ejections







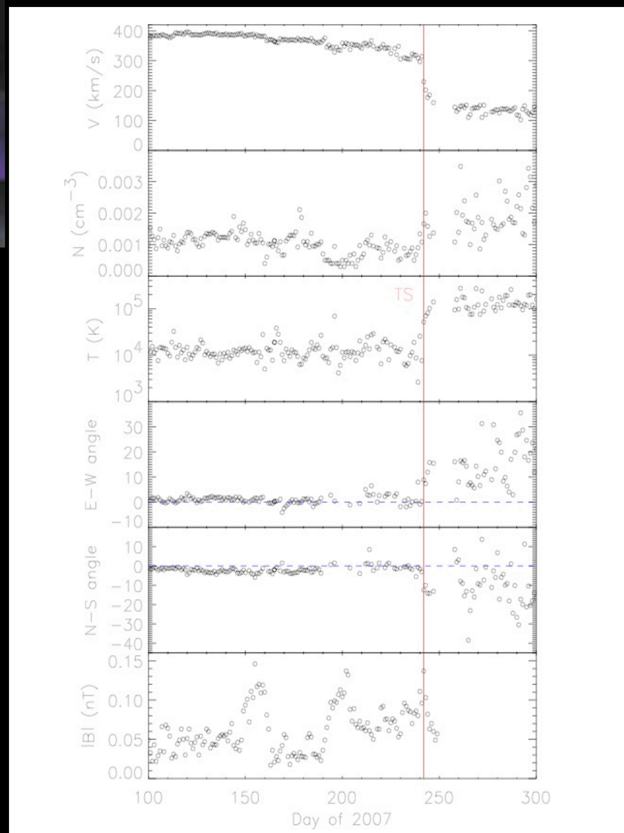


Most Distant Shock in The Solar System: The Termination Shock

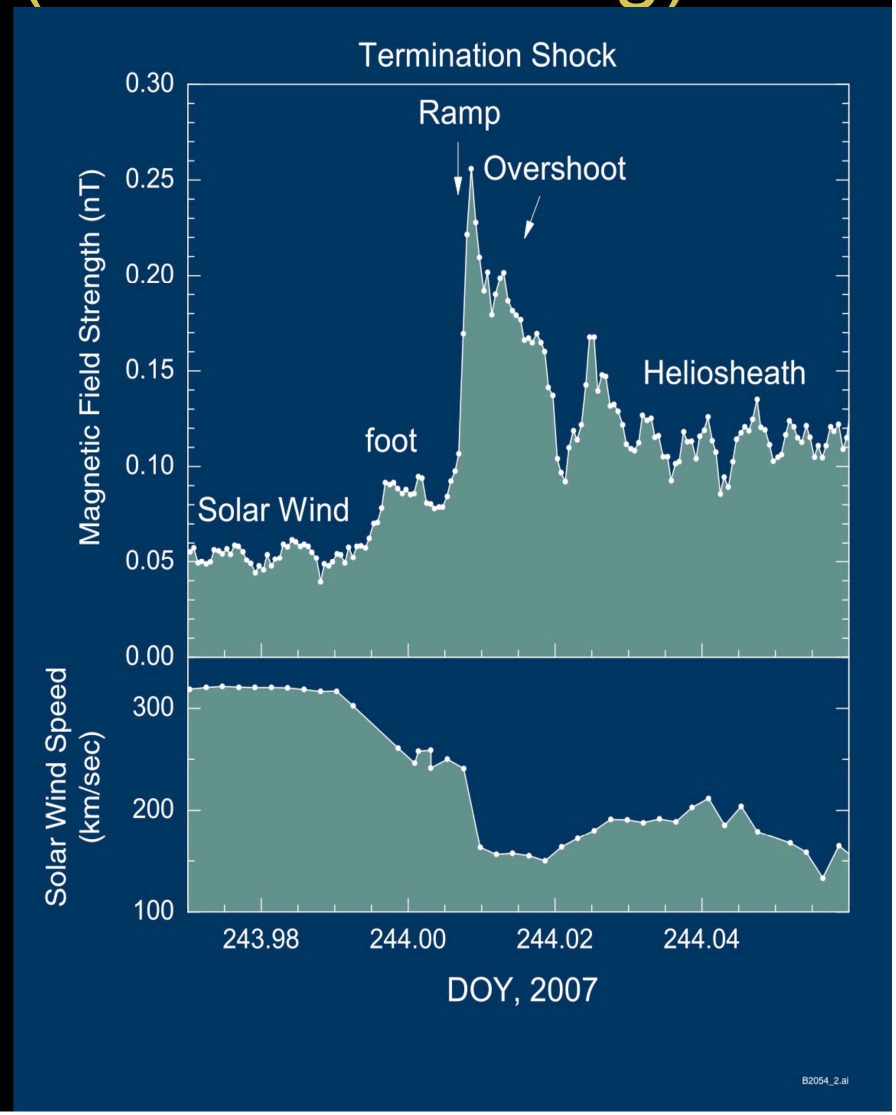
Voyager 1 crossed the Termination Shock in Dec 16, 2004

We have for the *first time* measurements *in-situ* of the boundaries of the heliosphere

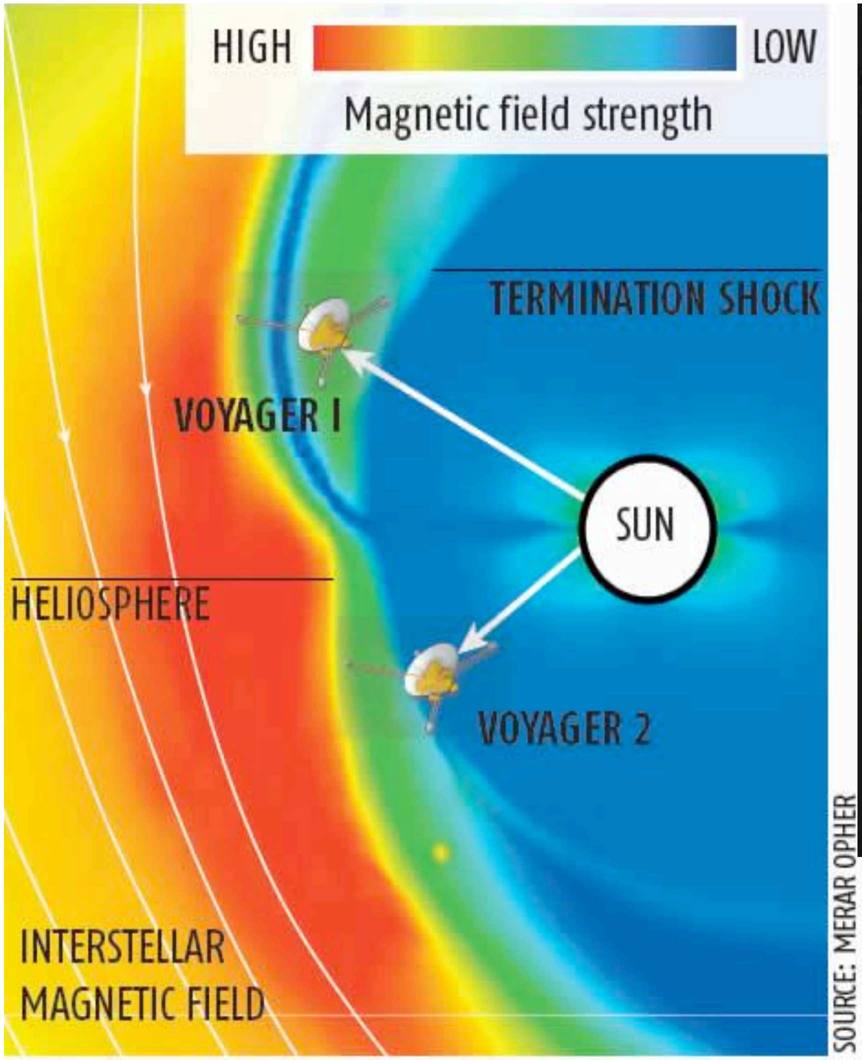
Voyager 2 crossed the TS In August 2007- (several crossing)

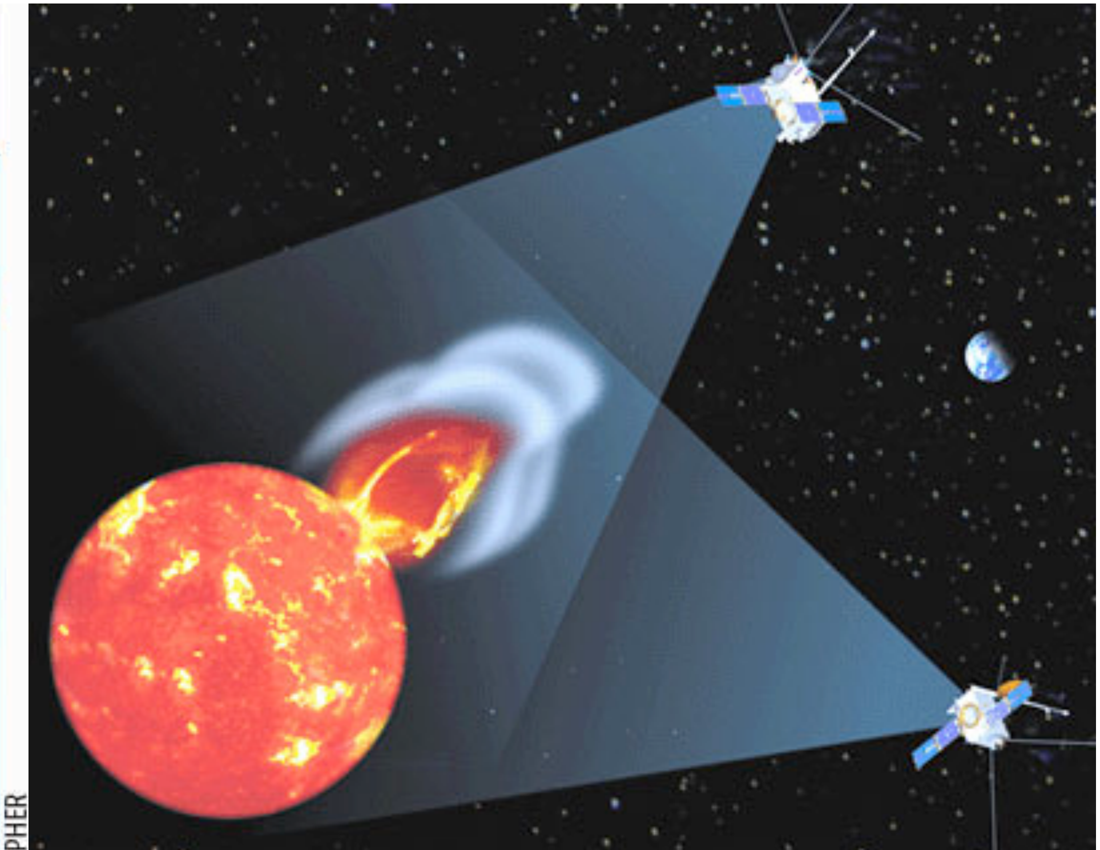


Richardson et al. 2008



Burlaga et al. 2008



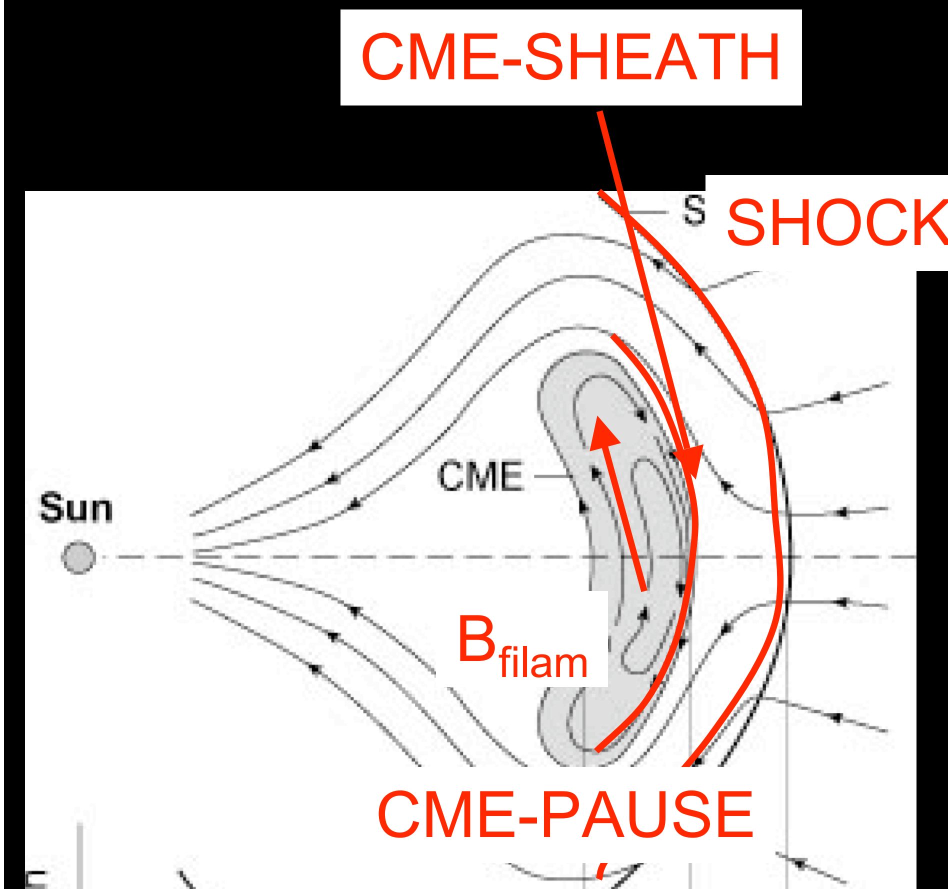


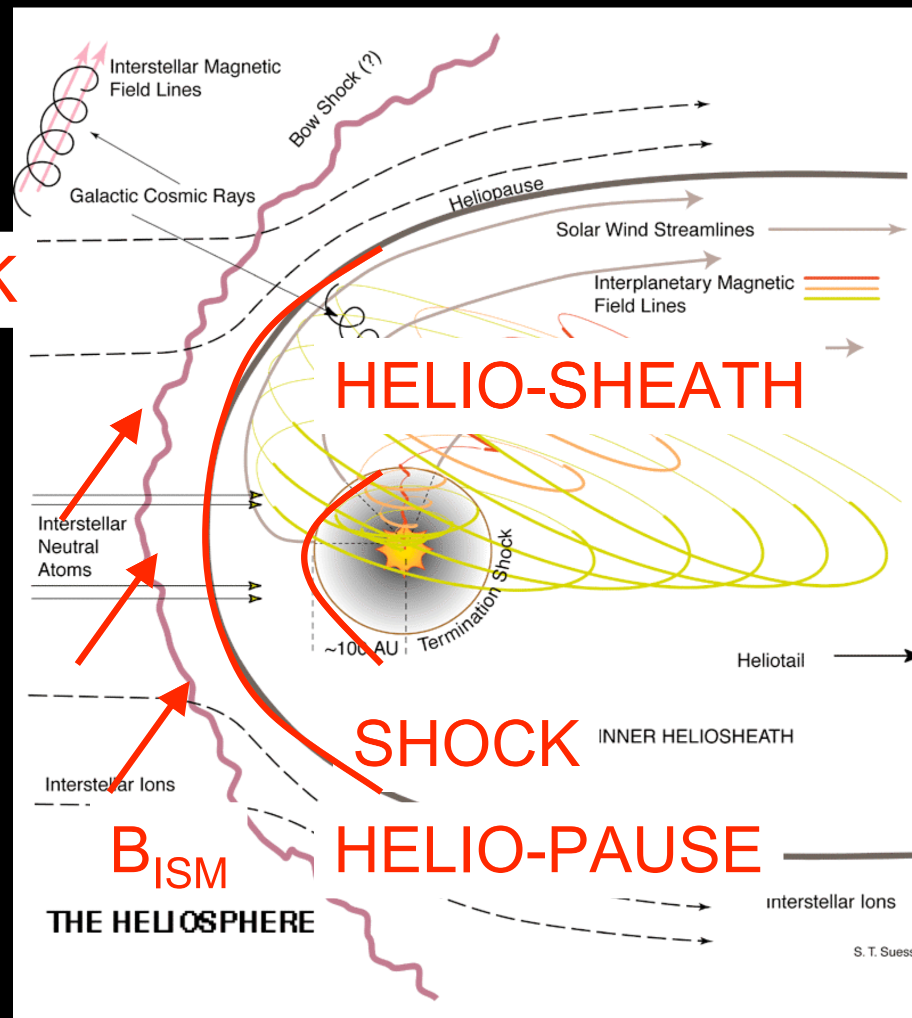
STEREO

Voyager

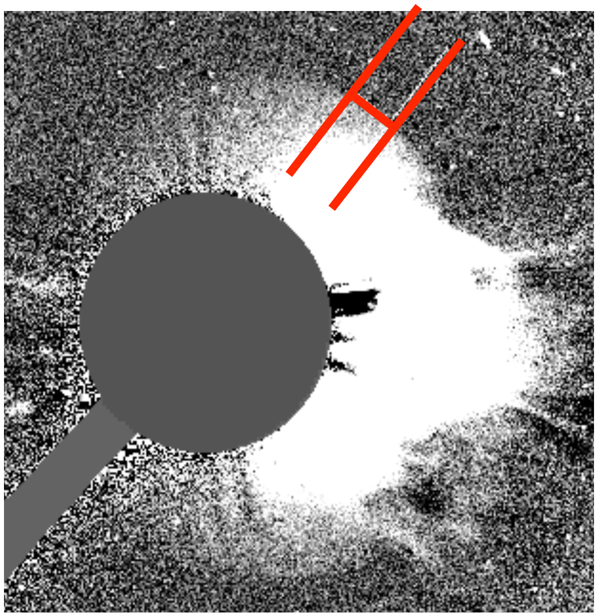
From Outer Heliosphere we can learn about Coronal Shocks

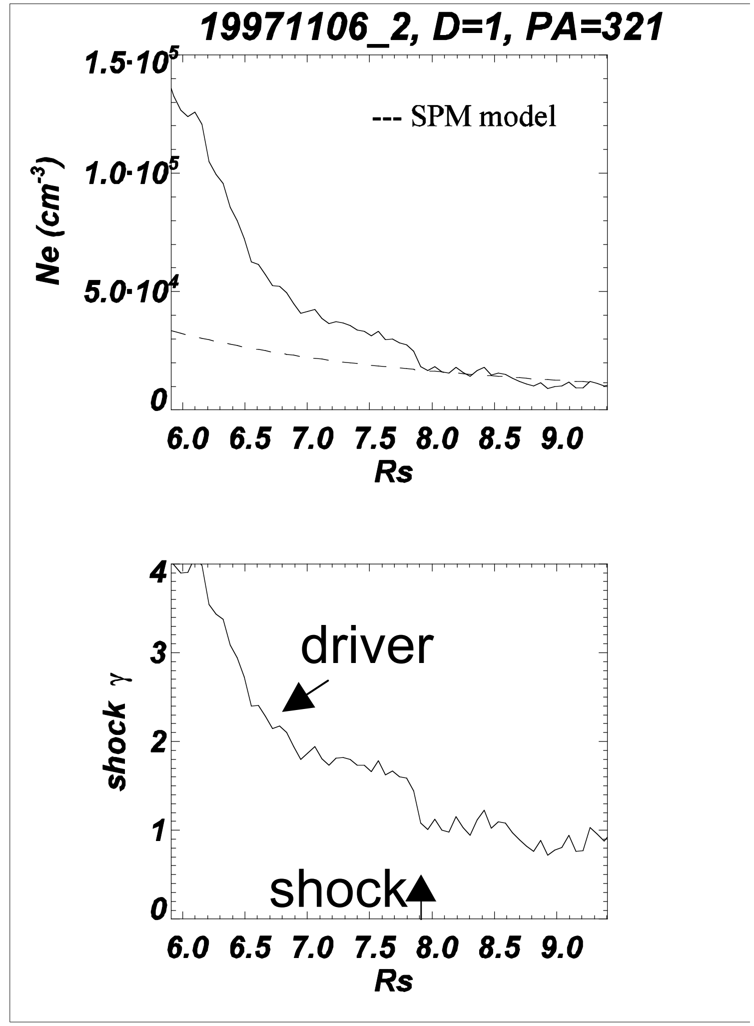
CME and Outer Heliosphere





Coronal Shocks:Measuring Shocks





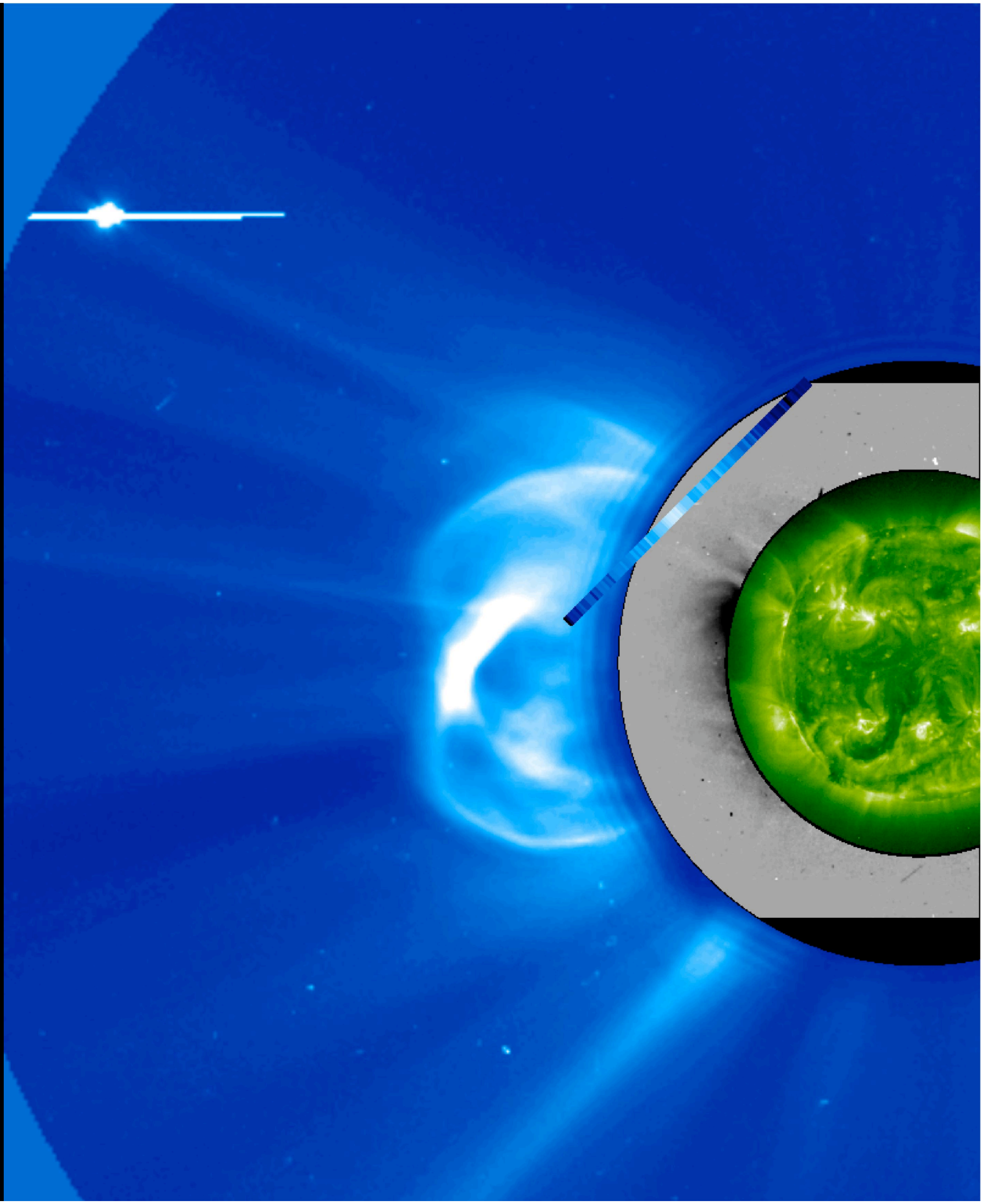
Shock brightness to density (ρ)
Shock strength, γ**=1+ρ/ρ0**
SPM model for the density of the back ground corona (ρ0).

Vourlidas & Ontiveros 2008

Development of Coronal Shocks Seen in the UV

John Raymond

Smooth, Faint arcs are often seen in White Light. convincing identification as shocks requires MHD Simulation matching profile (Manchester et al., Vourlidas et al.)



UVCS Shock Observations Analyzed so far

Date	Reference	H	V	n_0	Log T_O	X
06/11/98	Raymond et al.	1.75	1200	$1x10^6$	8.7	1.8
06/27/99	Raouafi et al.	2.55	1200		<8.2	
03/03/00	Mancuso et al.	1.70	1100	$1x10^7$	8.2	1.8
06/28/00	Ciaravella et al.	2.32	1400	$2x10^6$	8.1	
07/23/02	Mancuso&Avetta	1.63	1700	$5x10^6$	8.0	2.2

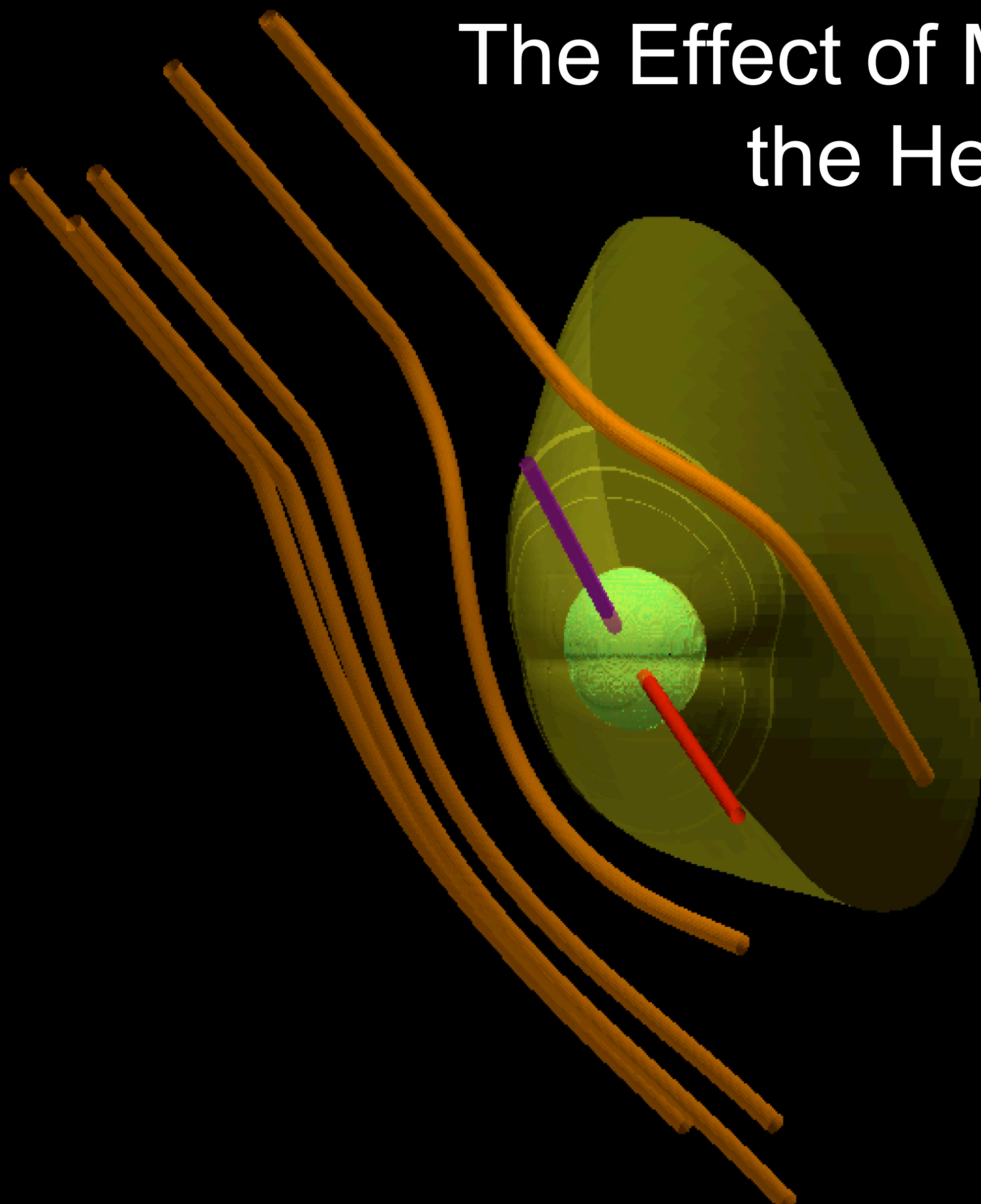
Modest heights, Modest compression, High T_O

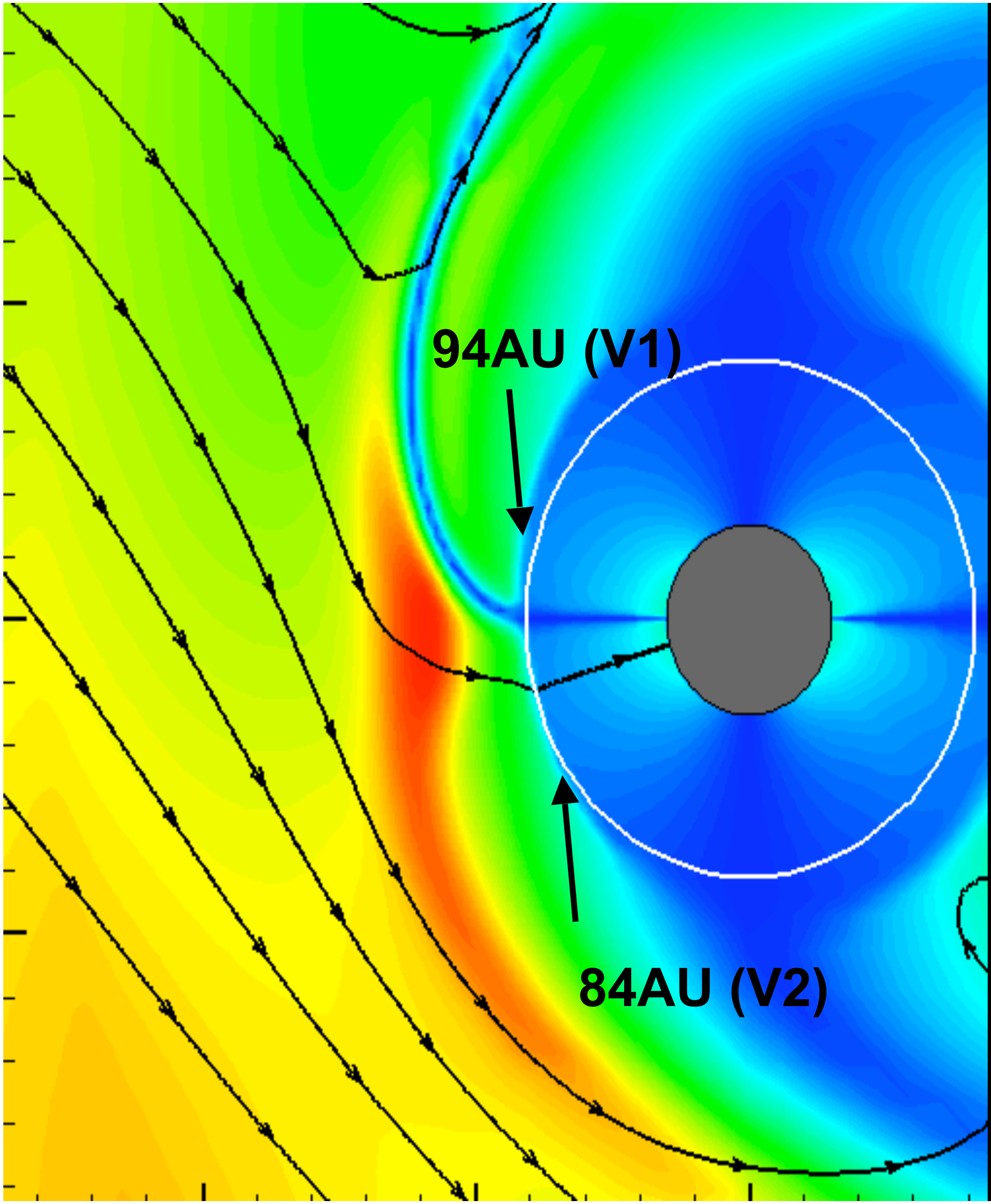
5 other shocks not yet fully analyzed (Ciaravella et. al. 2006)

Universal Processes in CMEs driven Shocks and Termination Shock

The Voyager 1 and 2
Data (and STEREO ?) seem to be revealing us Global features of the Heliosphere: Asymmetries

The Effect of Magnetic Field on the Heliosphere



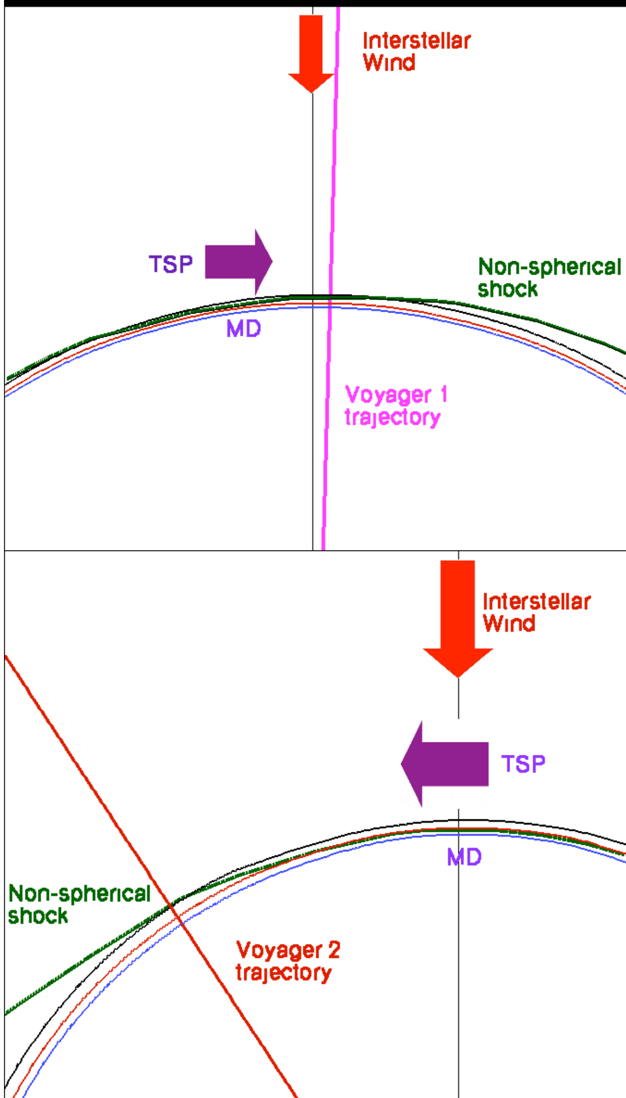


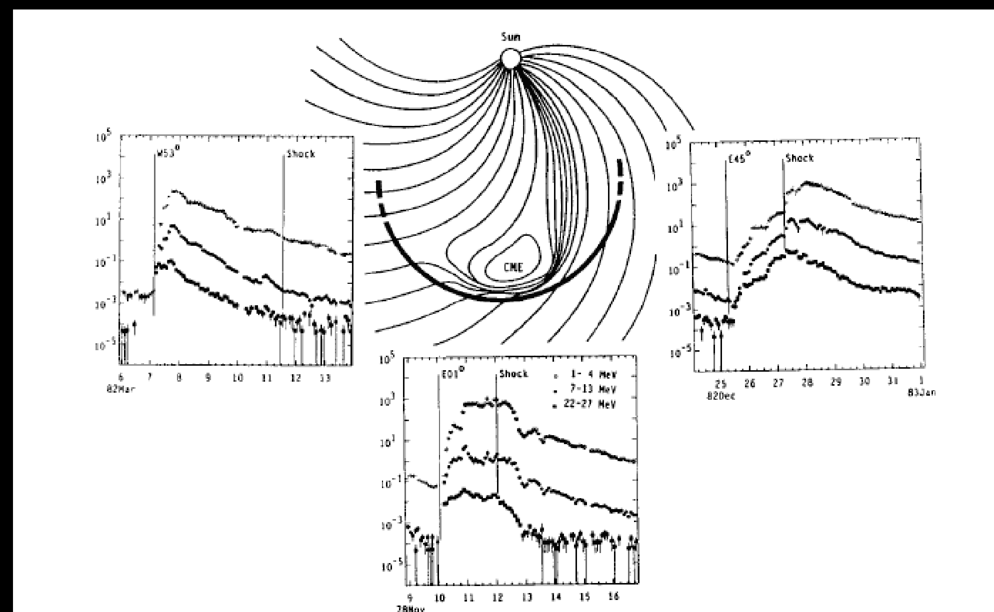
North/South Asymmetry: Position of the *Termination Shock* at V2 and V1

Crossing of TS by V2: closer to the Sun than V1

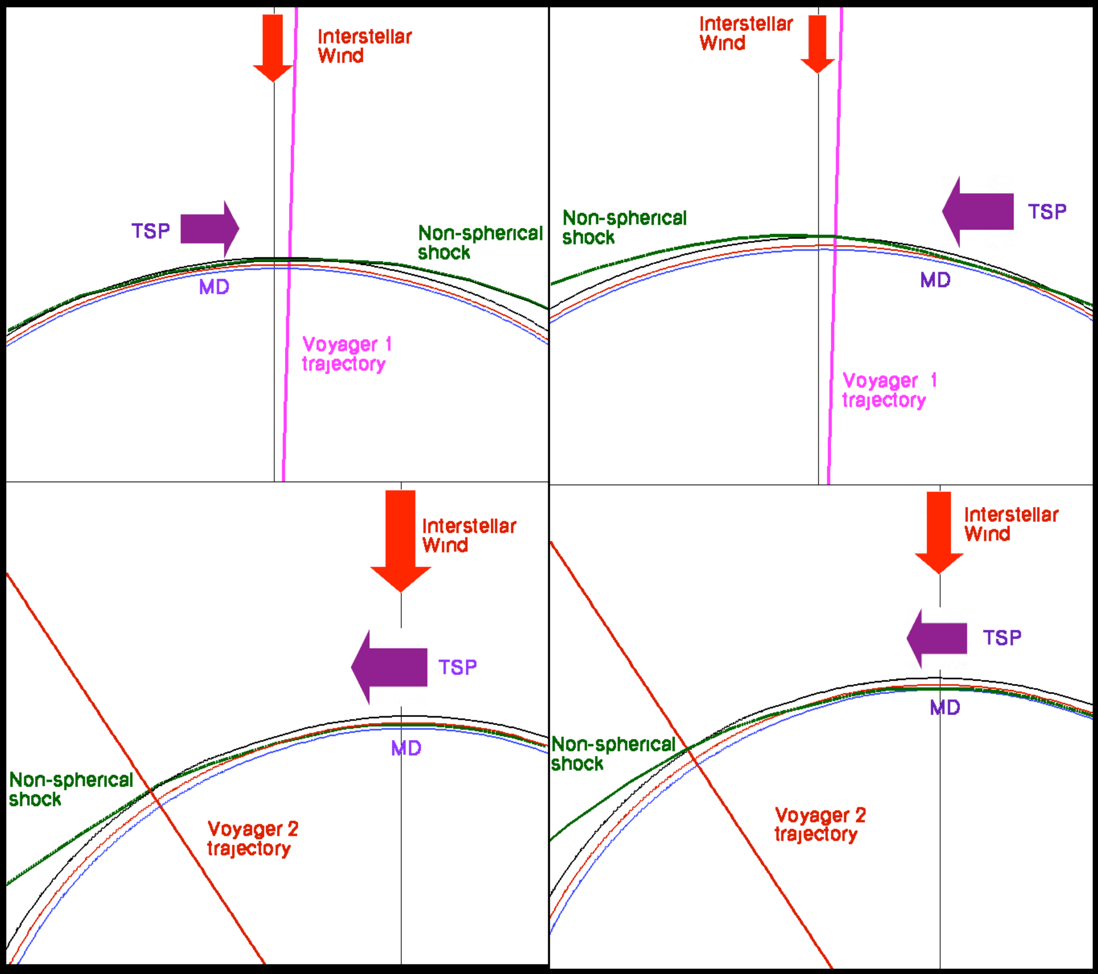
(not scaled model)

Shock Asymmetries/Magnetic Connectivity in Shocks



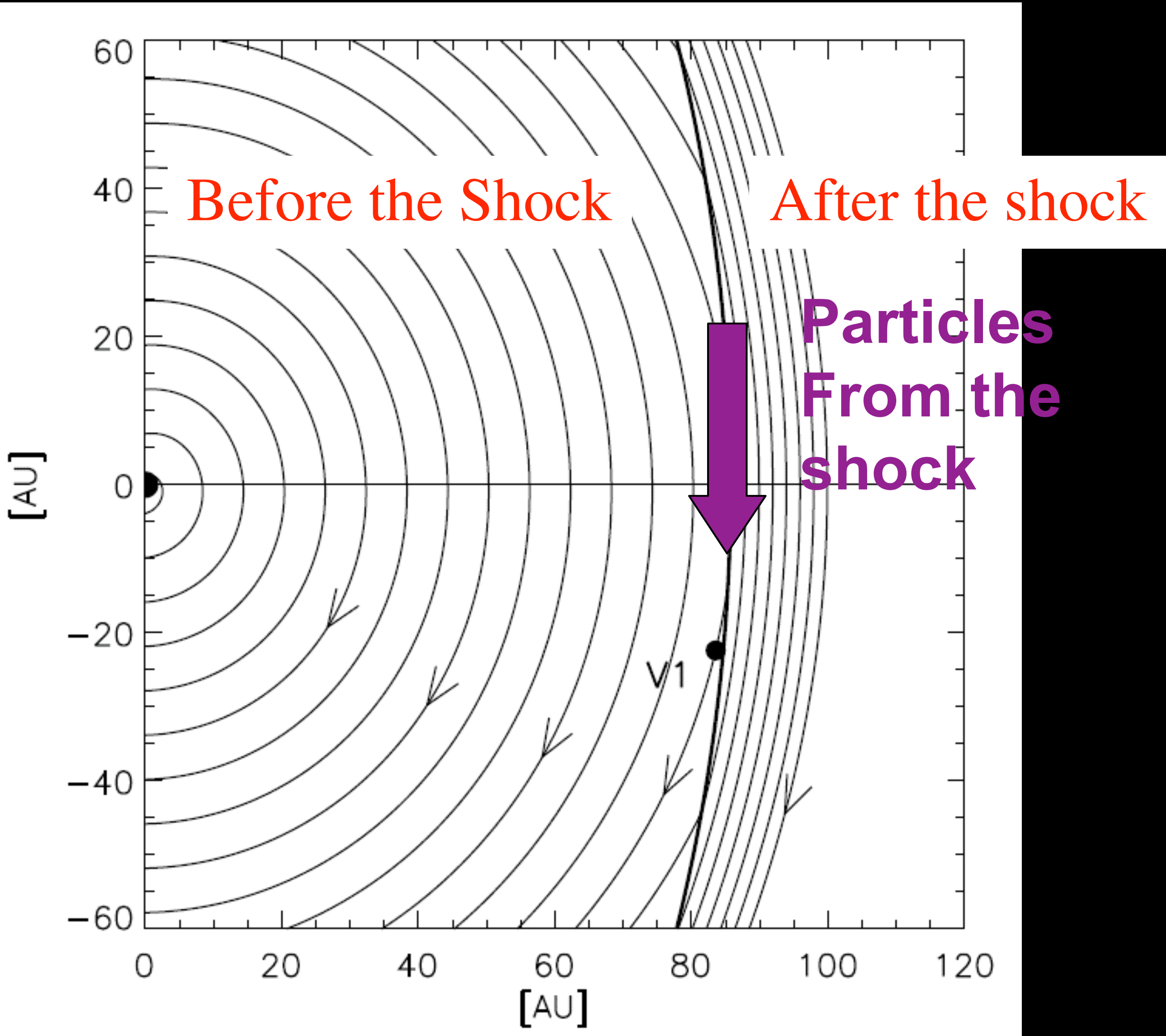


The Effect of Interstellar Magnetic Field in the Magnetic Connectivity



Opher, Stone, Gombosi *Science* 2007

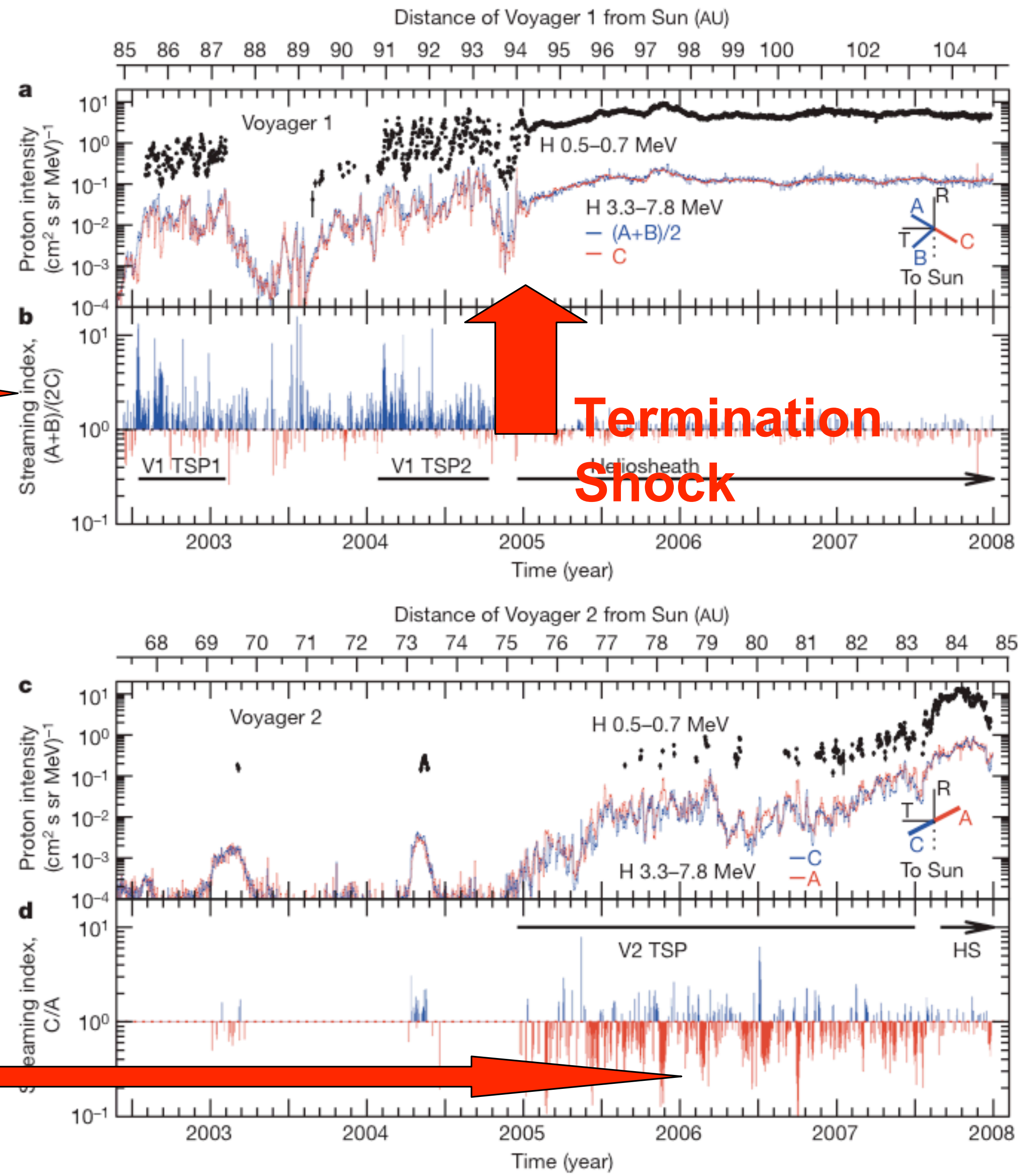
East-West Asymmetry of the Termination Shock and Magnetic Connectivity: Anisotropic streaming of Low Energy Particles



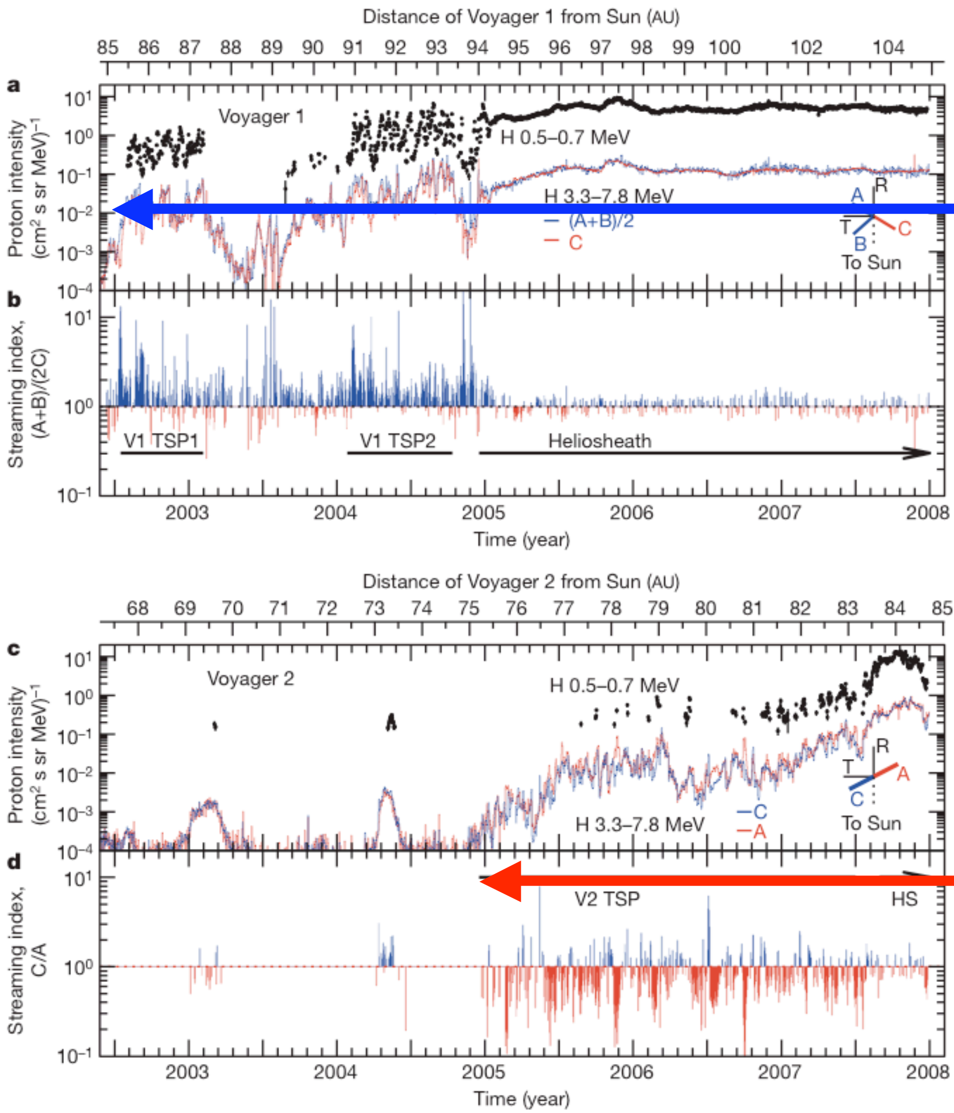
Voyager 1 connected to Termination Shock along magnetic field line that had crossed the shock and crossed back into the supersonic solar wind *(Jokipii et al. (2004); Stone (2005))*

Outward TSPs

Inward TSPs



The distance of the spacecrafts to the shock when starting to detect the low-energy particles from the shock



V1 at 85 AU

Voyager 1 started measuring the particles 3AU from a moving shock

Voyager 2 started measuring the particles 7AU from the shock

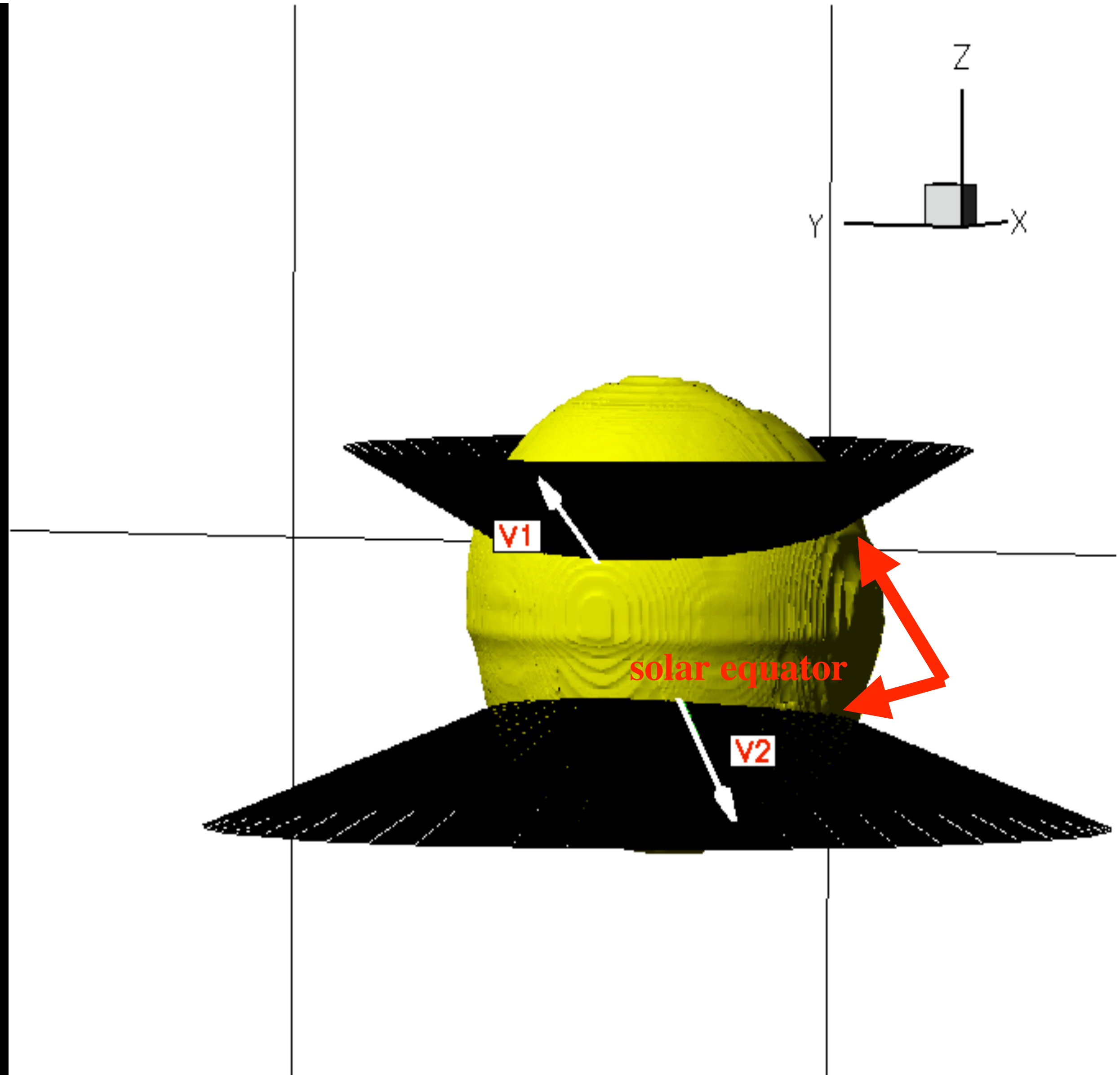
V2 at 75 AU

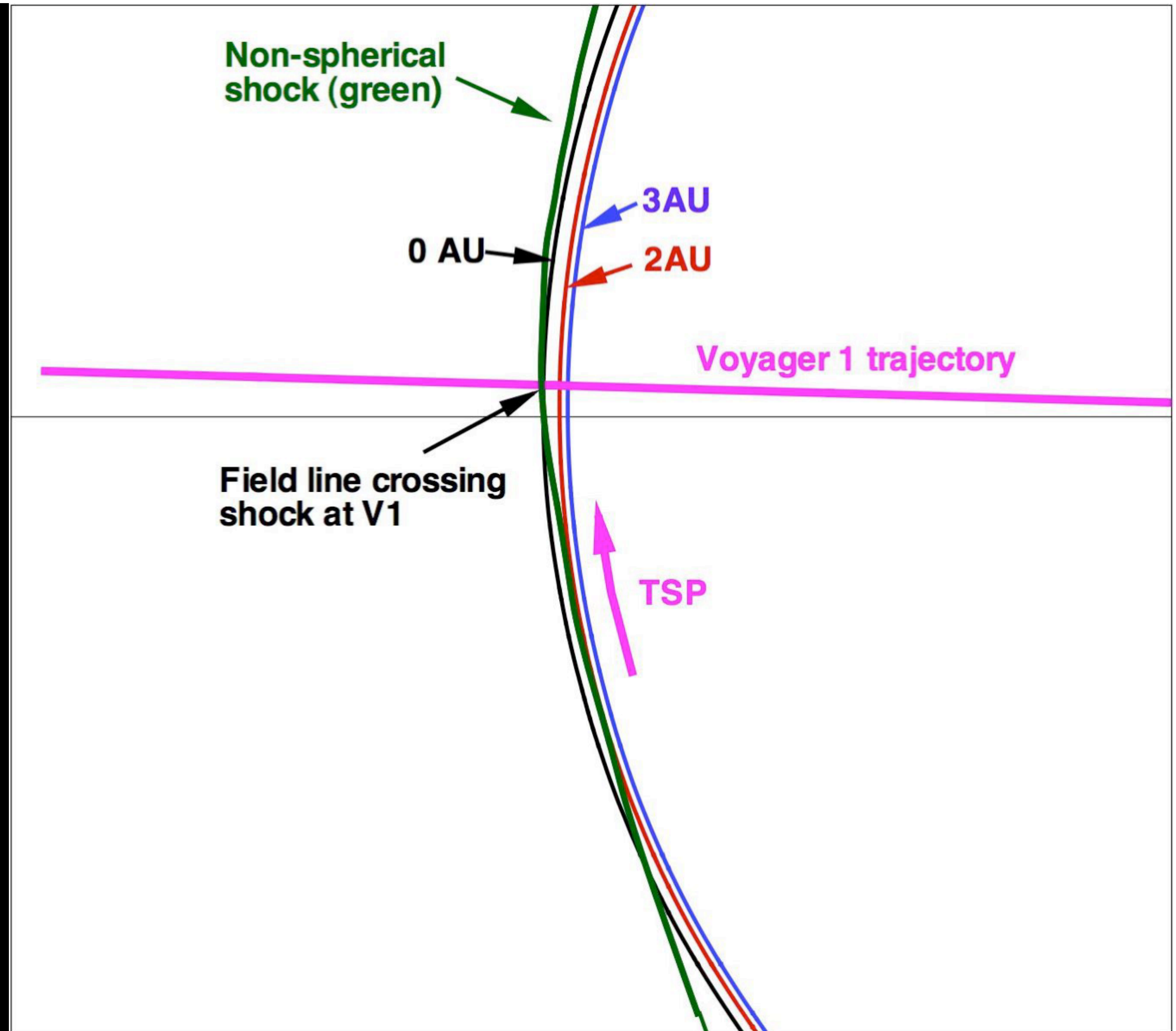
Acknowledgments: Stone et al.

Spiral Magnetic Field Crossing V1 and V2

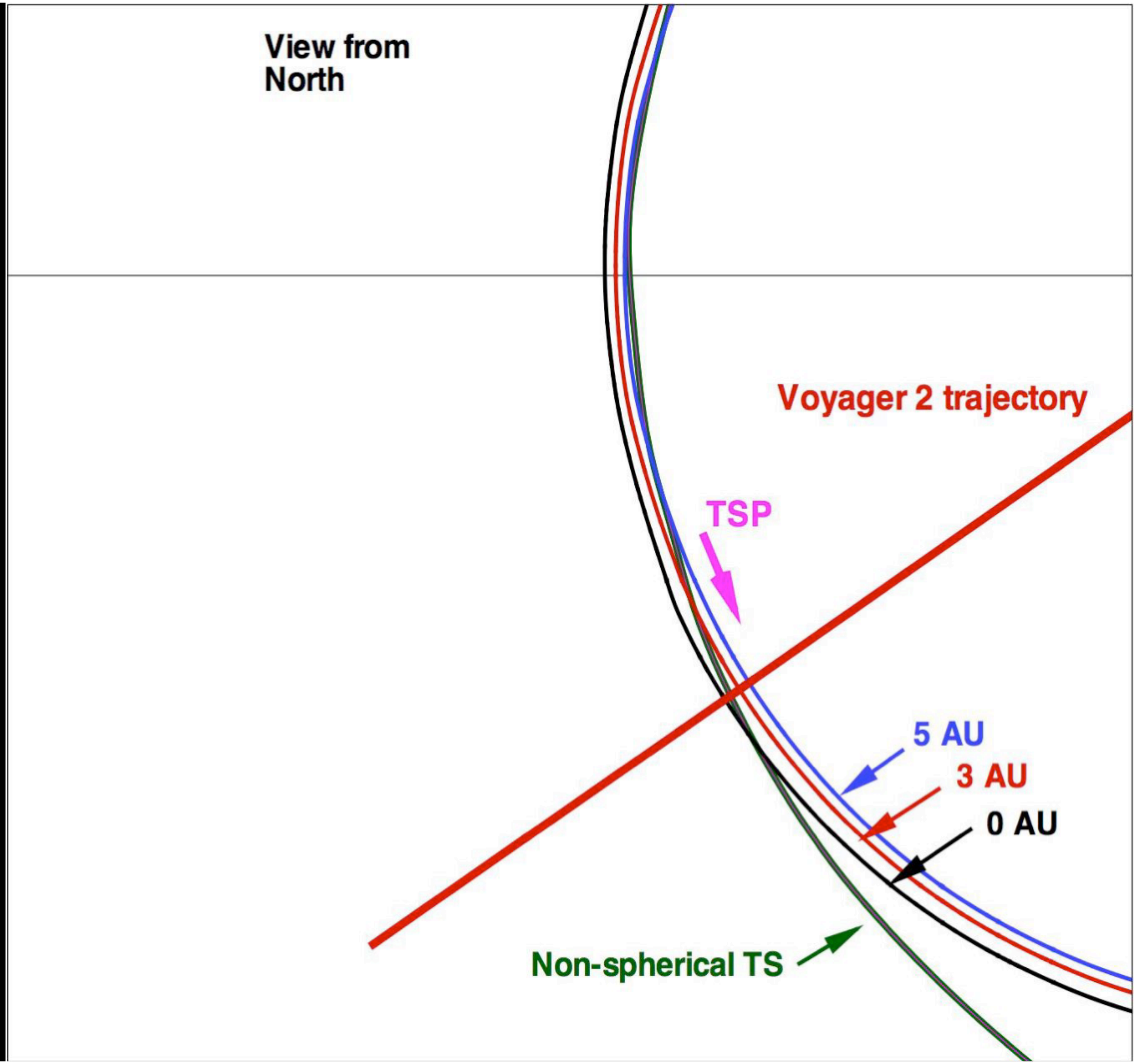
Shock closer to the Sun
near nose than in the flanks

In both Northern and Southern Hemisphere the cones intersect the Termination Shock closer to the equator near the nose





Opher et al.2006; 2007

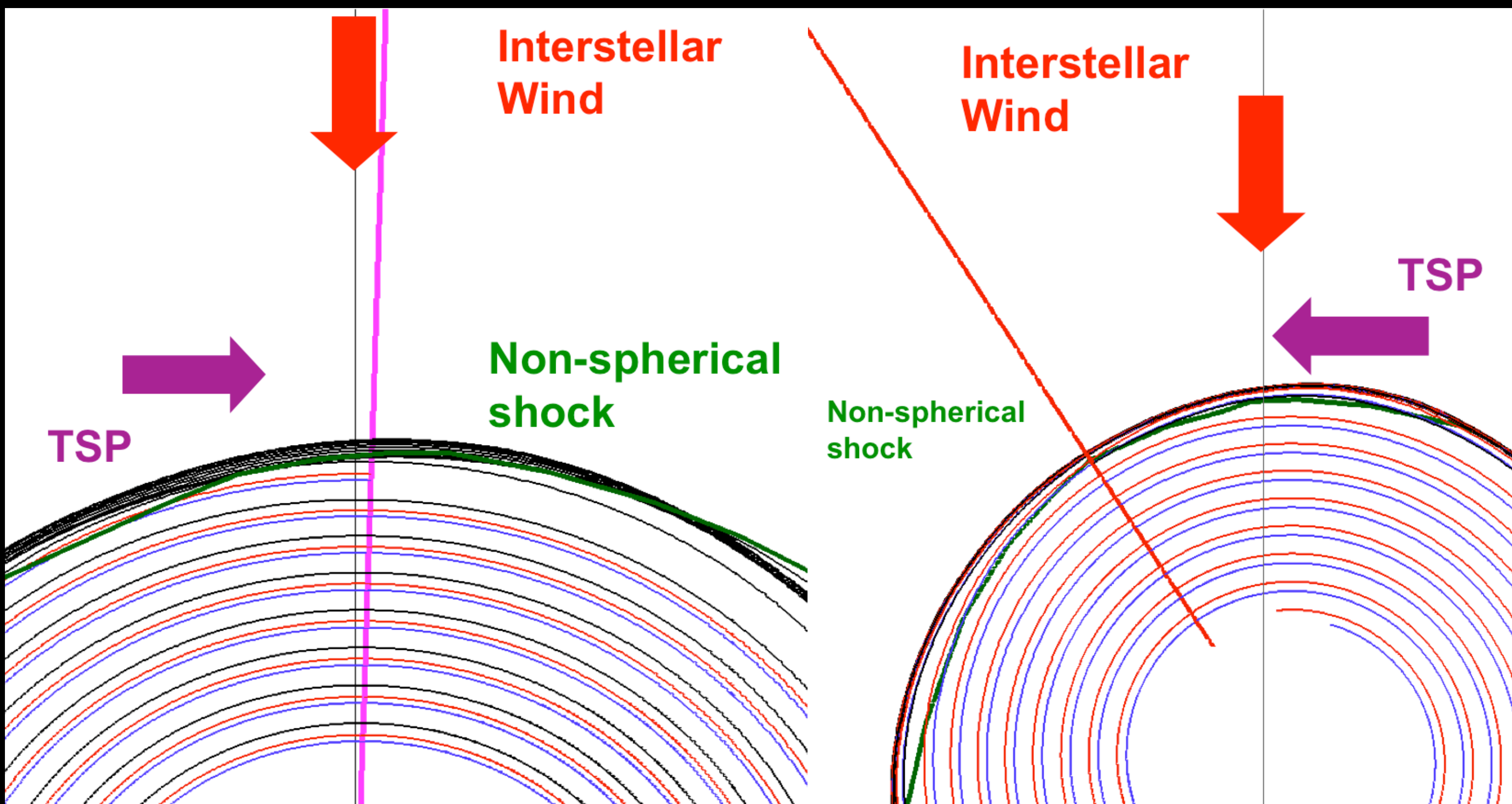


View from North
Voyager 2 trajectory
TSP
5 AU
3 AU
0 AU
Non-spherical TS

Presence of neutral H

B=4.375 μG in HDP plane
with α=20°
with Bsw

Asymmetries recovered

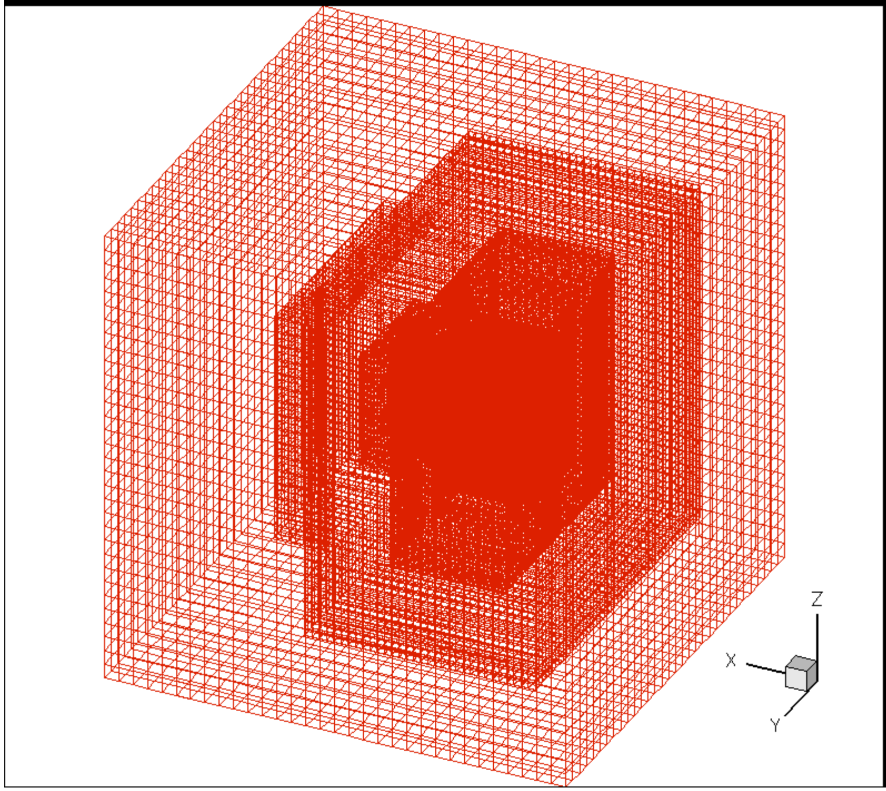


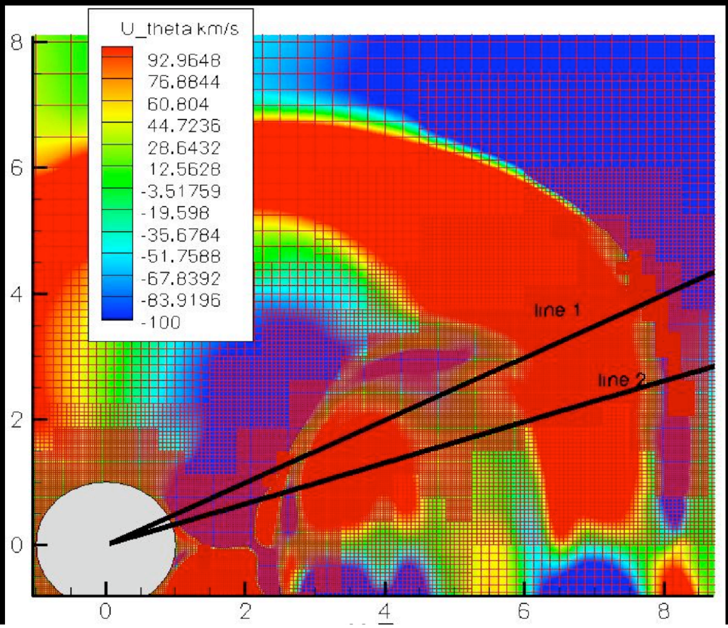
The solar magnetic field should distort the coronal shocks as they propagate in the heliosphere

The challenge is resolving the shock

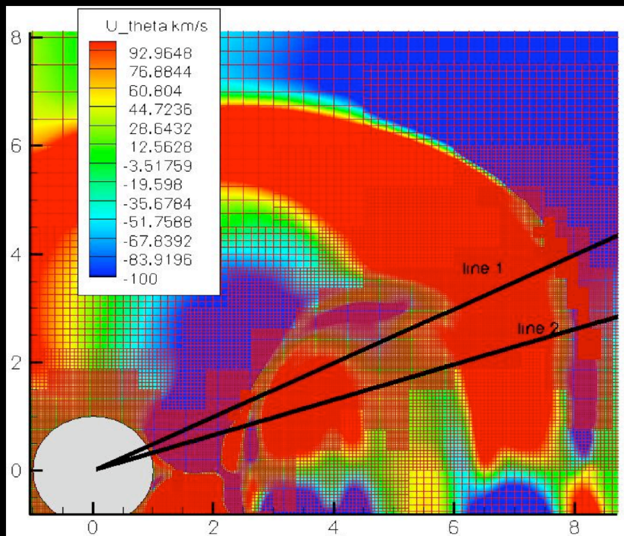
TS: static shock

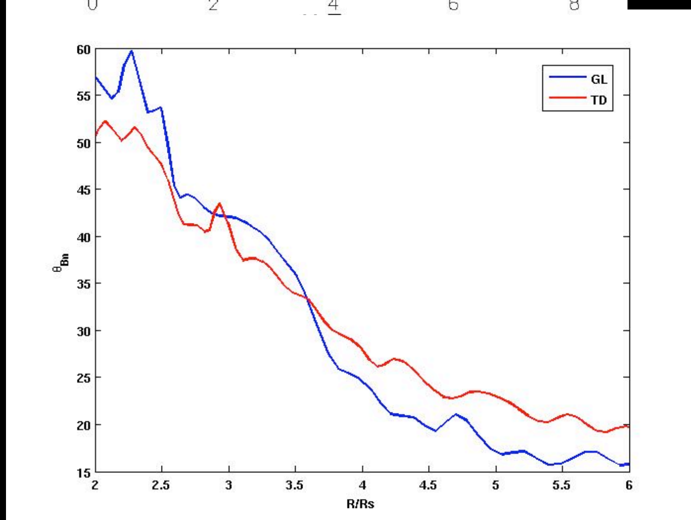
CME driven-shock is moving





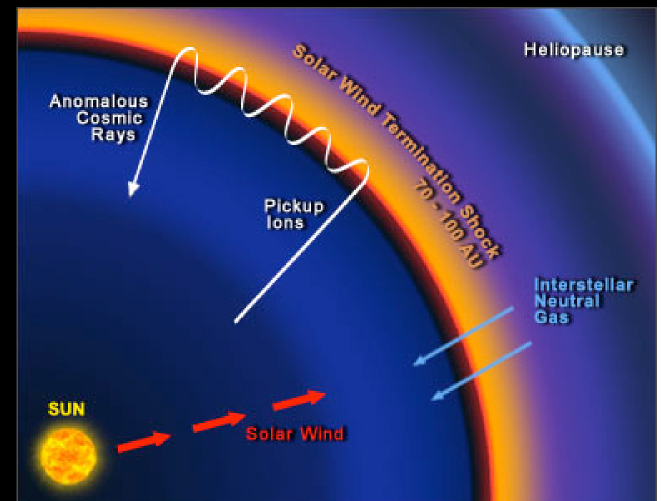
Normal to the Shock-acceleration of particles

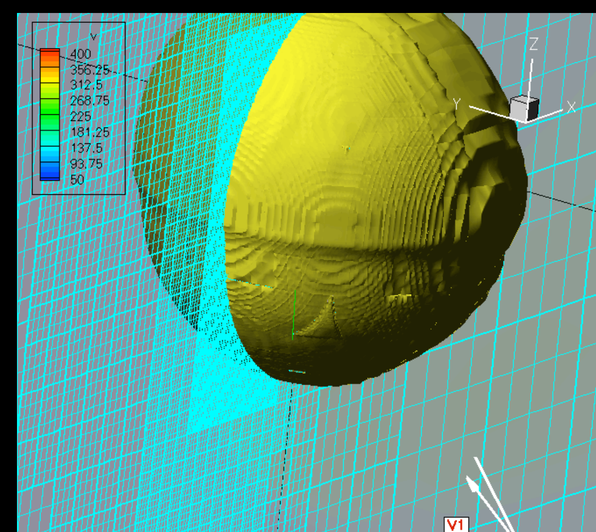




Evolution of CMEs in the Lower Corona
Loesch et al. 2008

CME: only nose is resolved (moving shock)



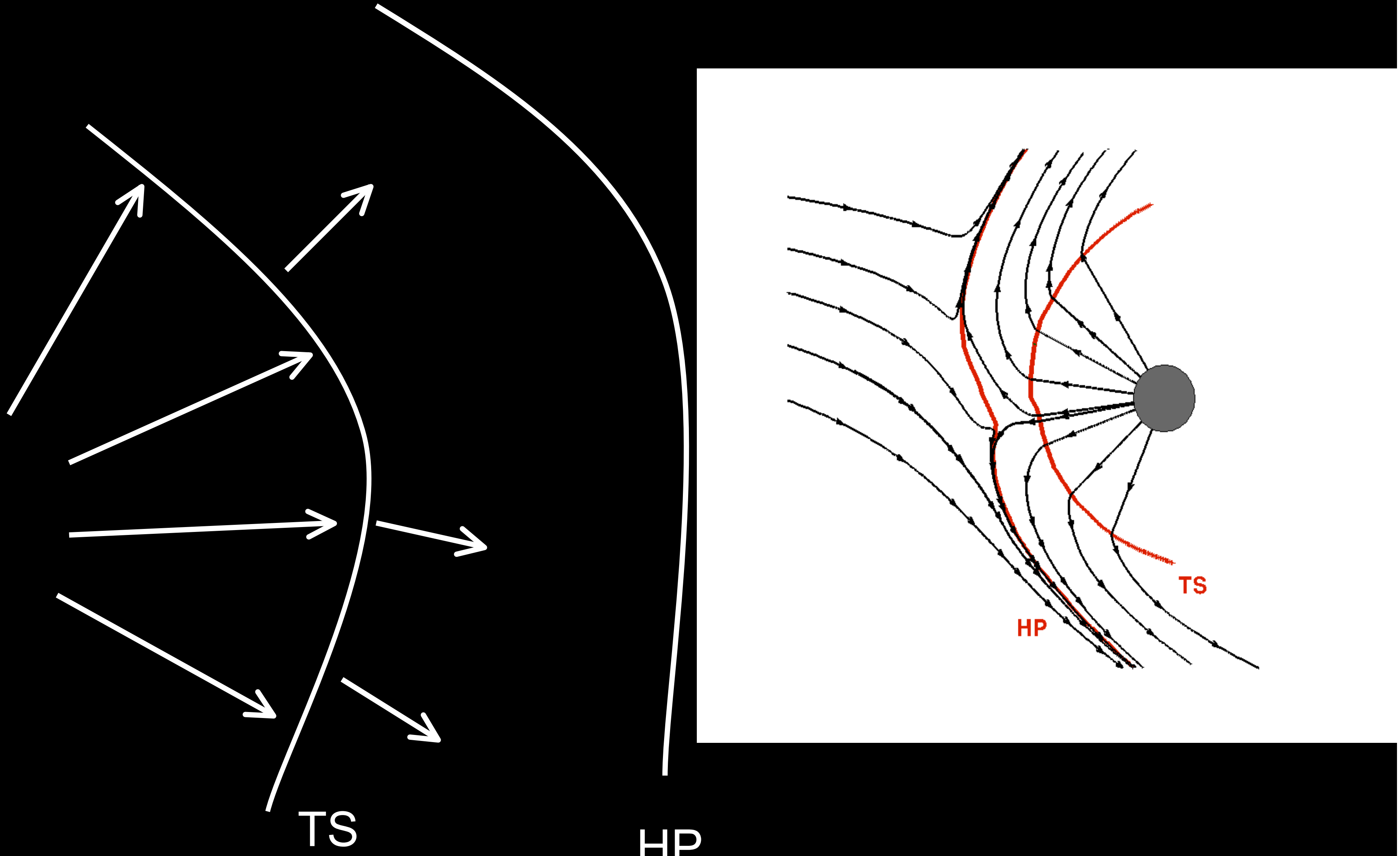


Termination Shock

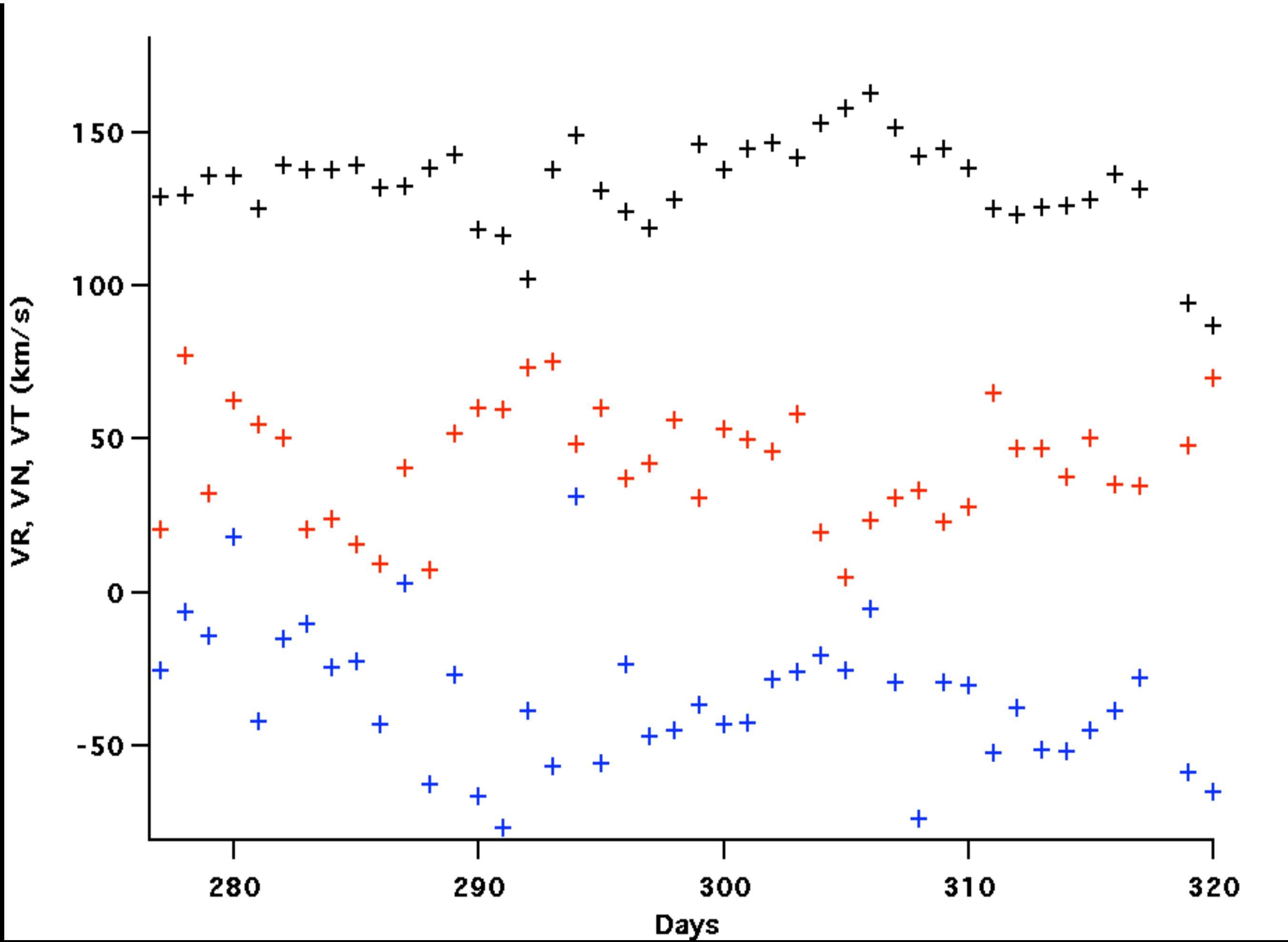
CME- and HELIO-sheaths

Flows in Helio-sheath/ Flows in CME-sheath - can we predict the structure of flux rope?

The heliosheath flows: *heliospheric compass*



Opher *et al.* 2008

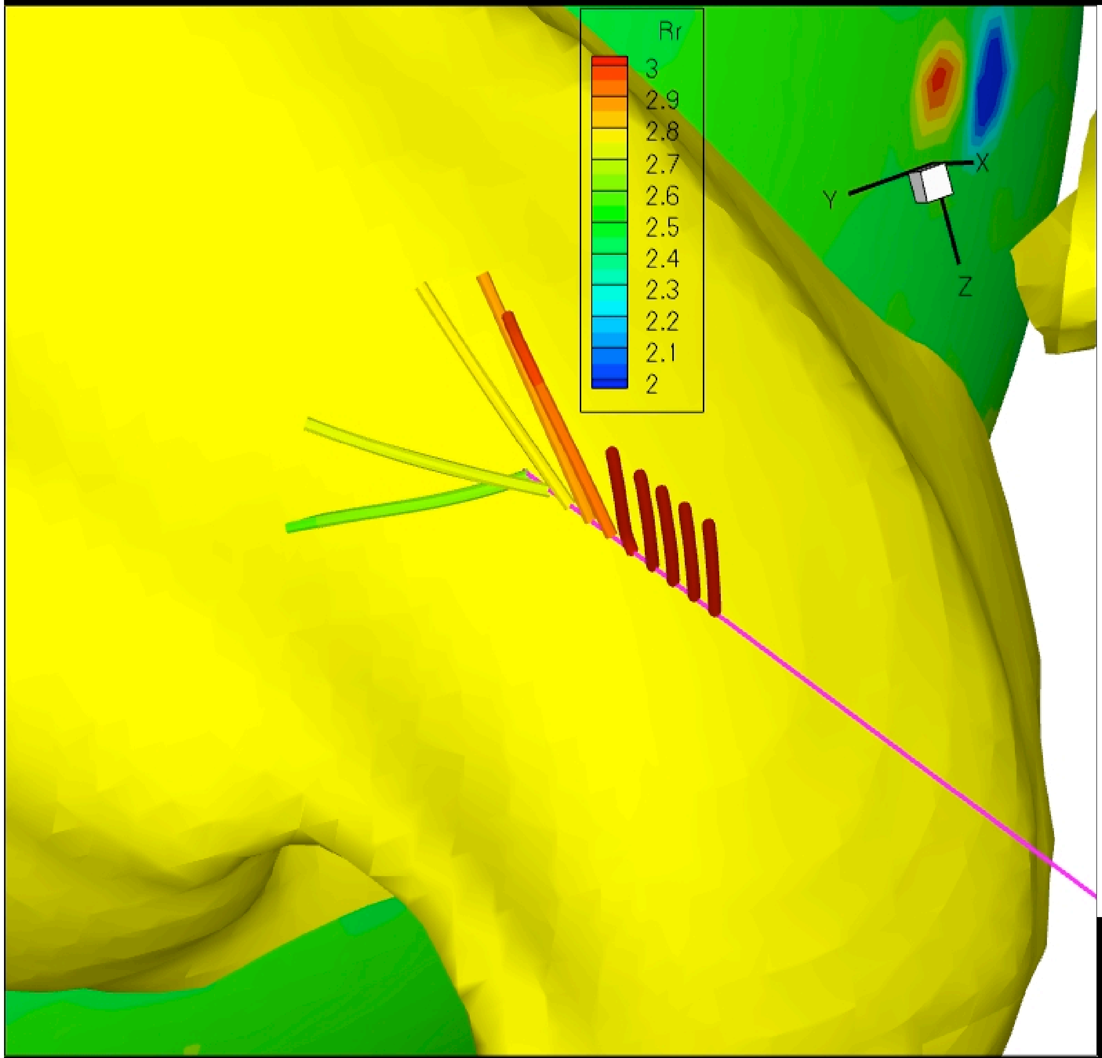


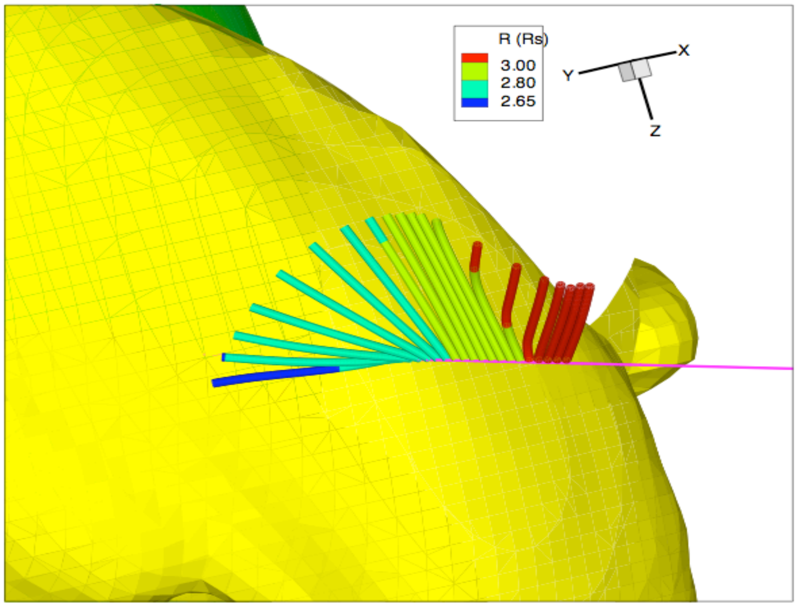
Daily Averaged

Flows from day 277-320

V_N/V_R=-0.30; V_T/V_R=0.35

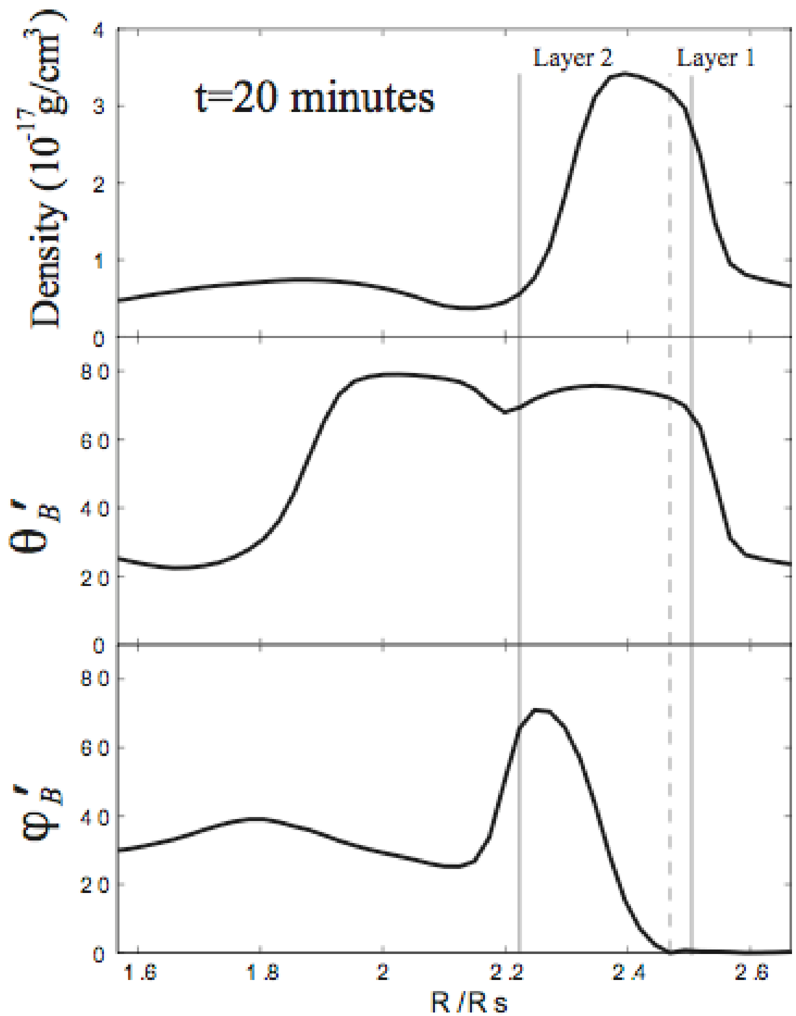
Evolution of Field Lines in the sheath

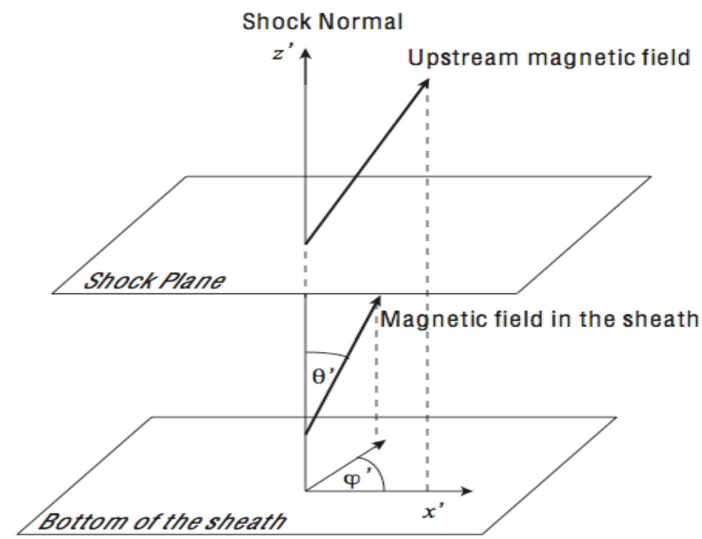




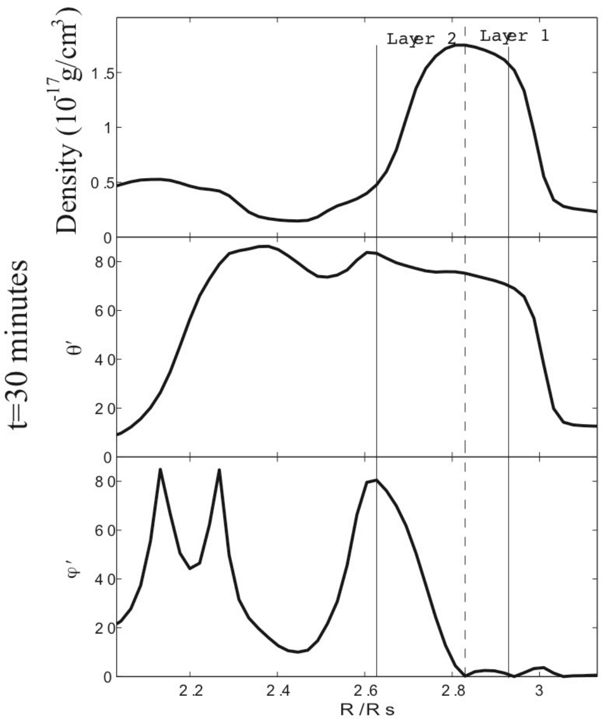
Liu, Opher, Gombosi ApJ (2008b)

The evolution of the magnetic field in the sheath

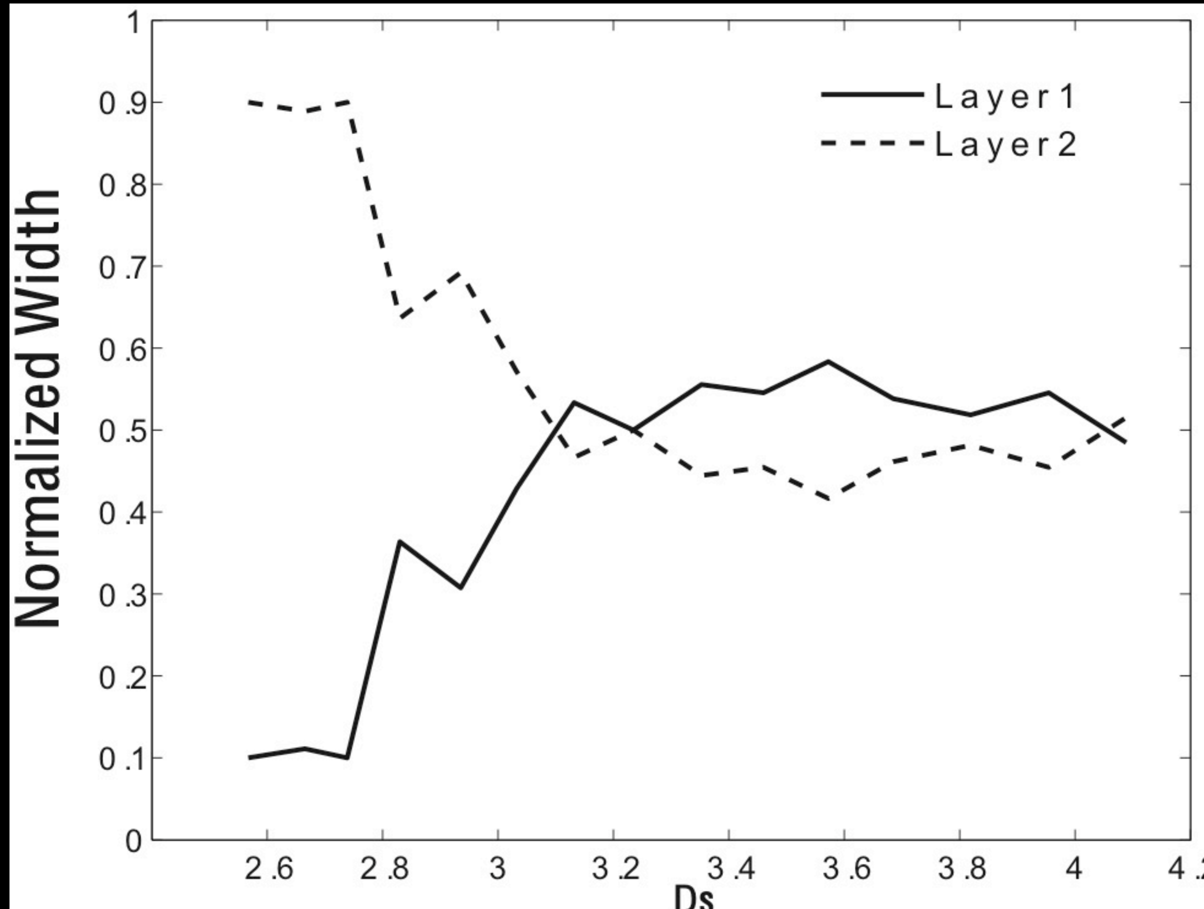




Liu et al. ApJ 2008b

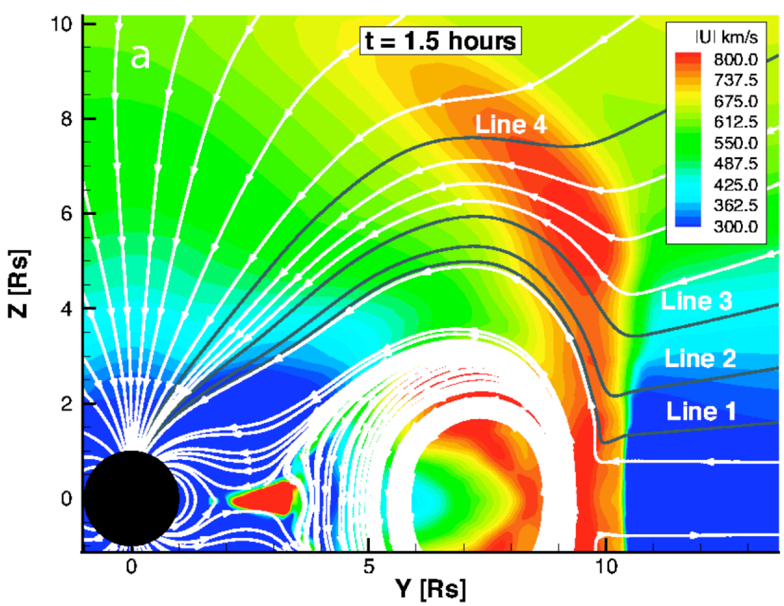


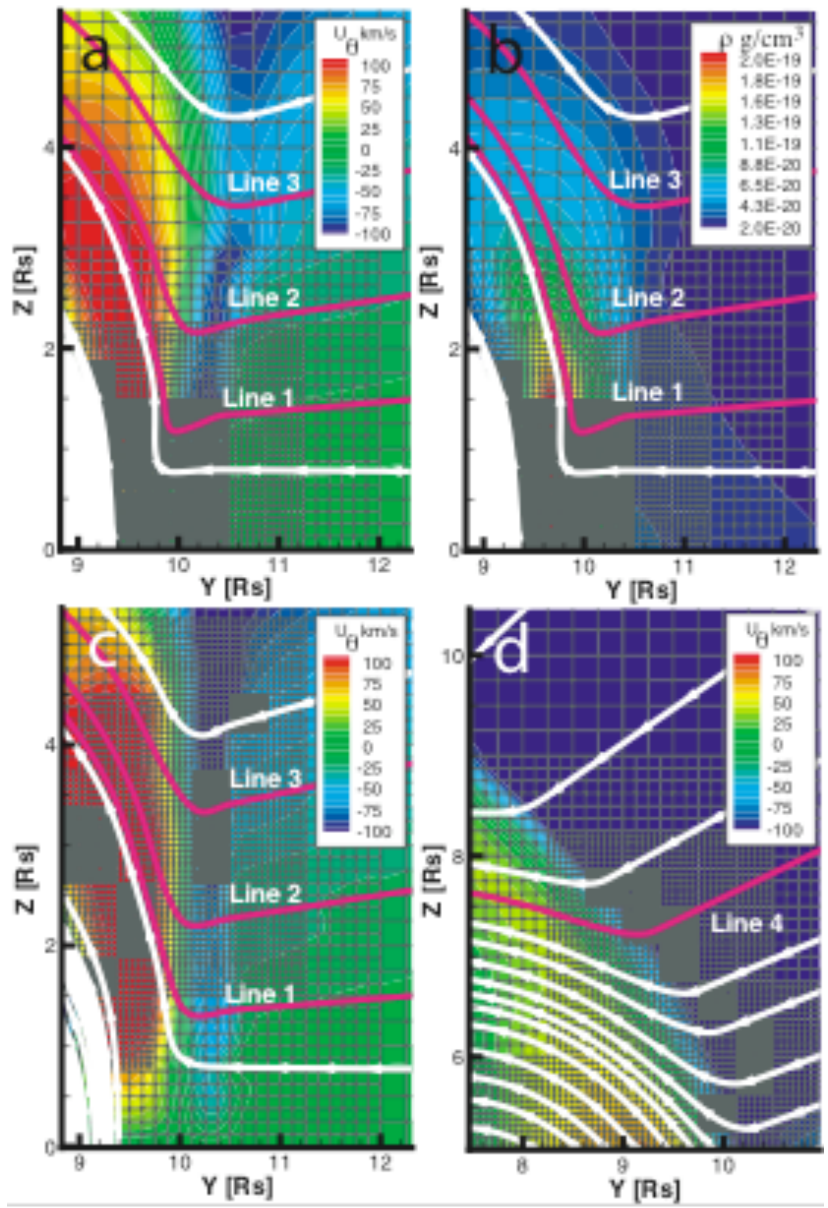
Behaviour of the Magnetic Field in the Sheath



Post-shock compression
-reconnection effects?

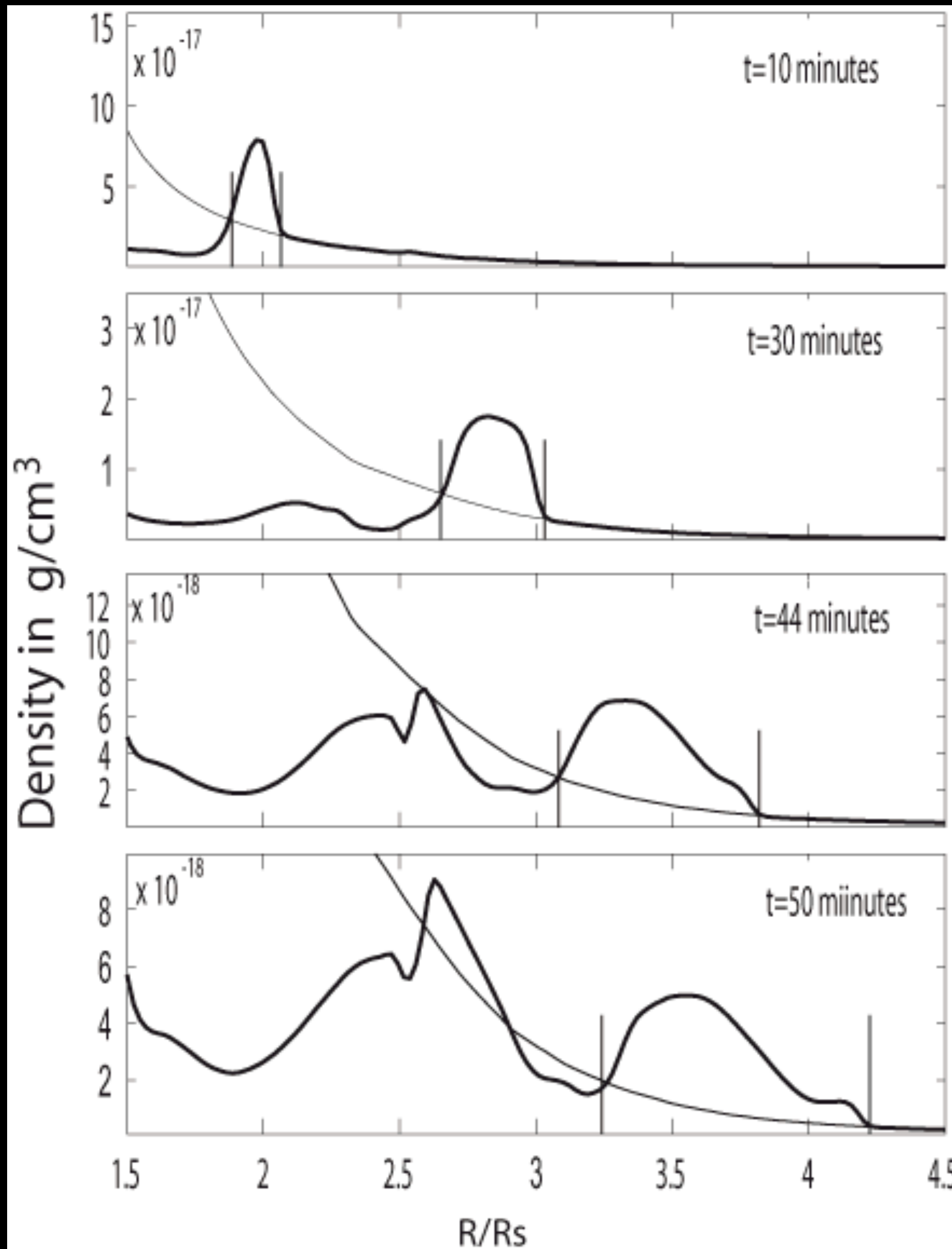
Fine Shock Structure: Flow Deflect Toward the CME behind the Shock Indentation





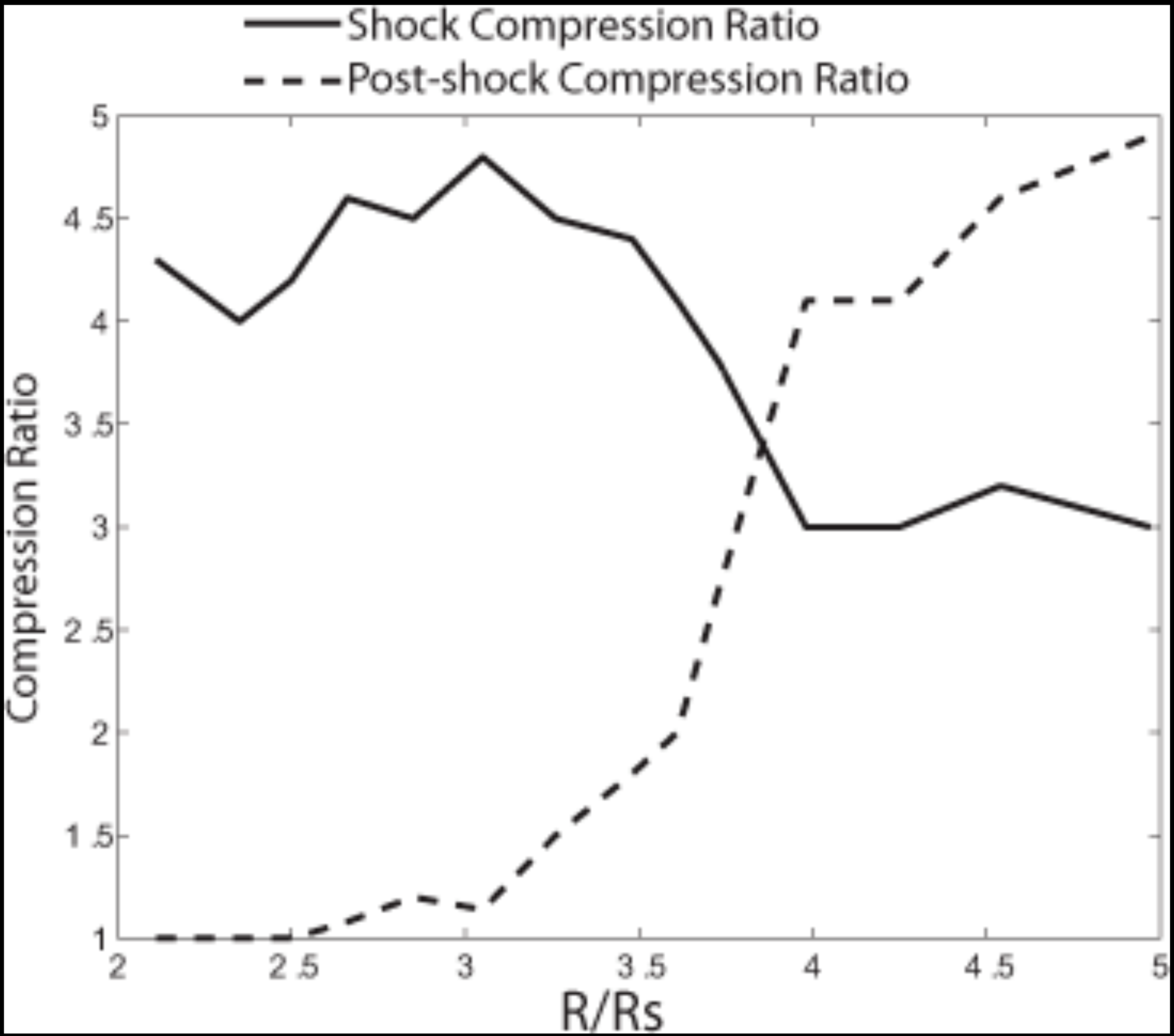
Post-shock compression

Second peak due to
Reconnection?
Reverse shock?
γ effects?



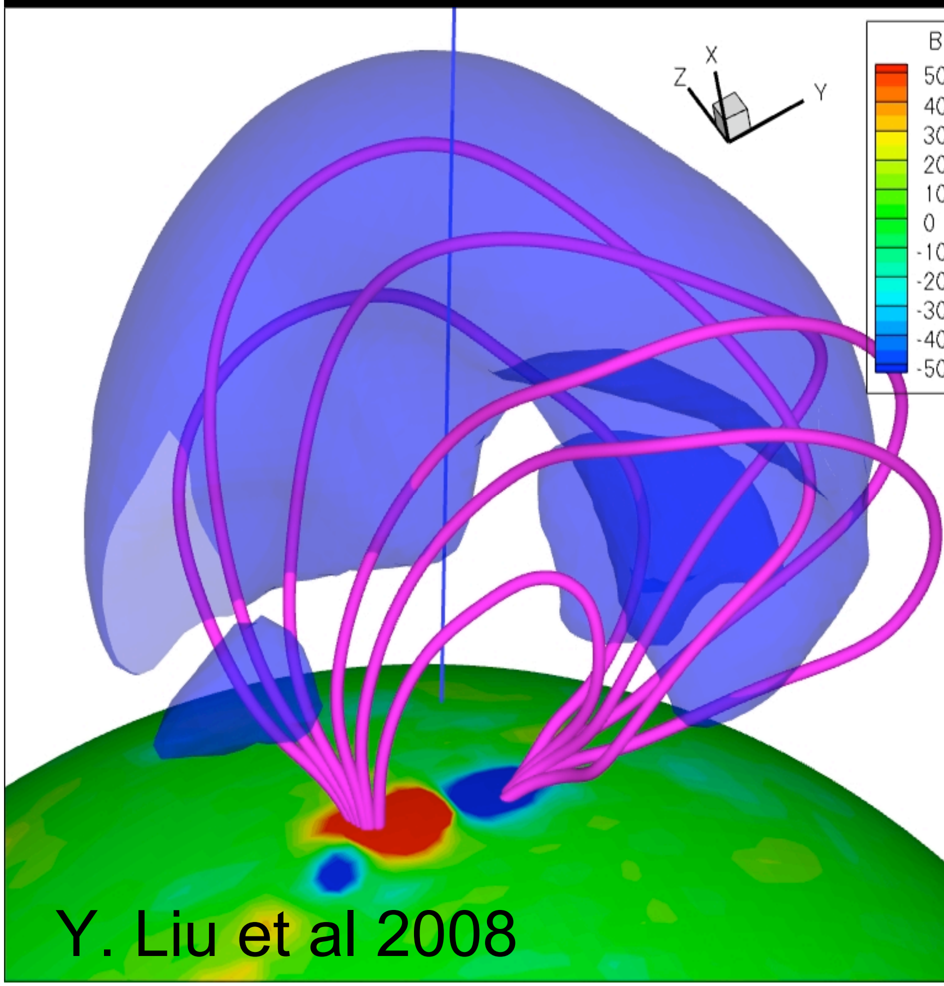
Liu et al. (2008)

Shock and Post Shock Compression Ratio

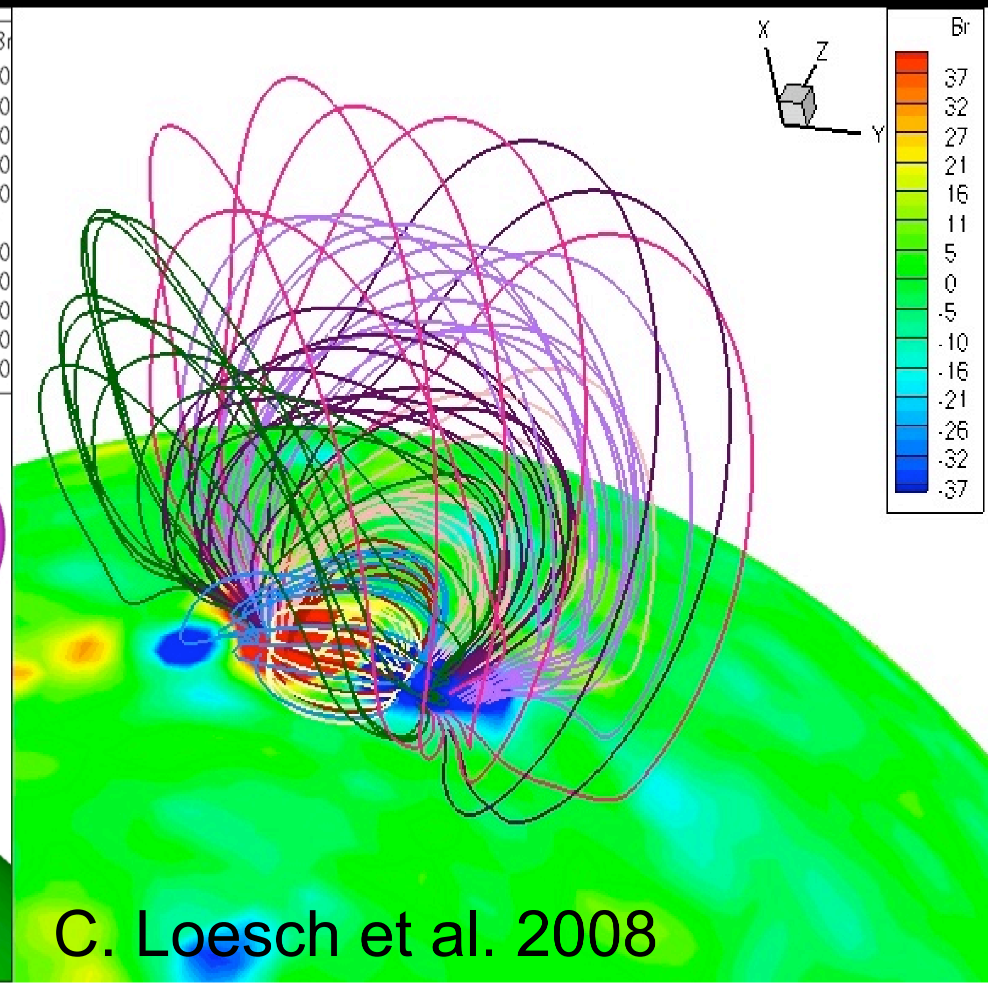


The post shock acceleration exists in 3-5 Rs

Signatures of CME Initialization in CME Evolution



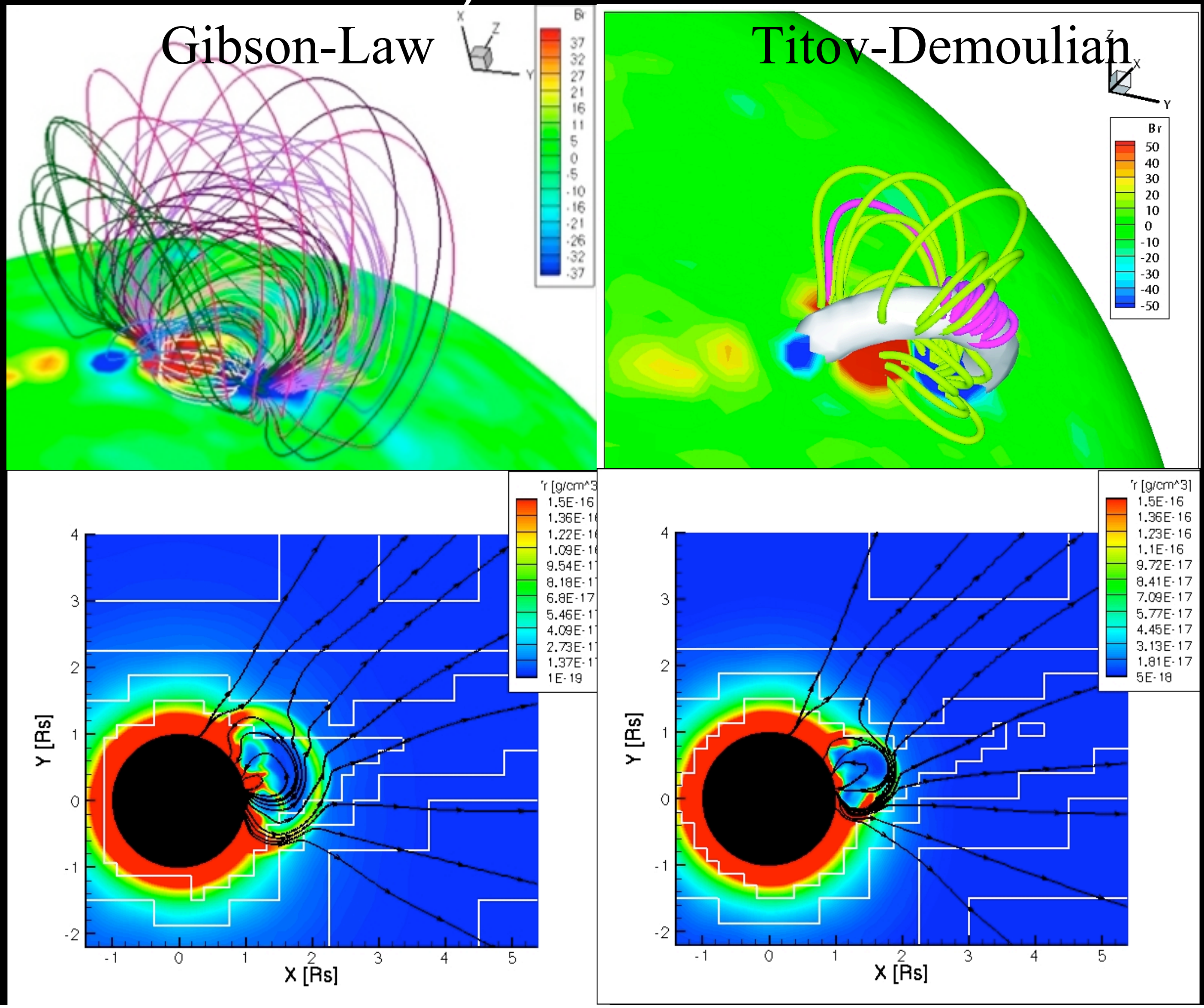
Y. Liu et al 2008



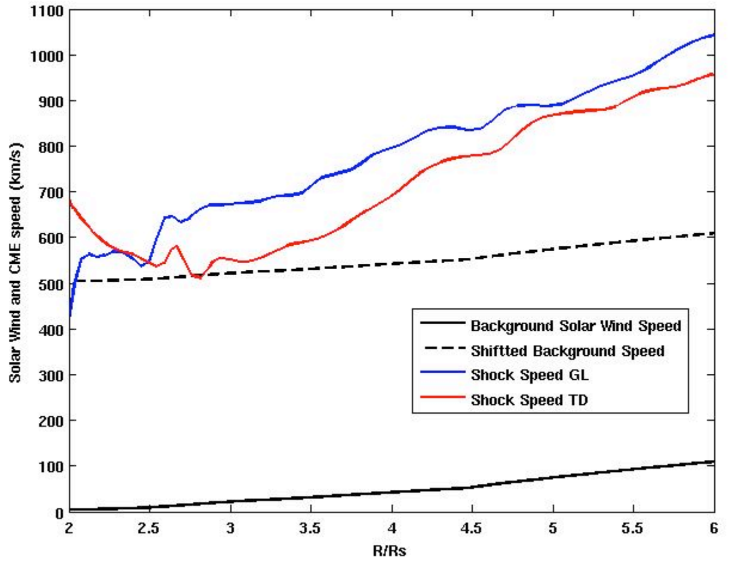
C. Loesch et al. 2008

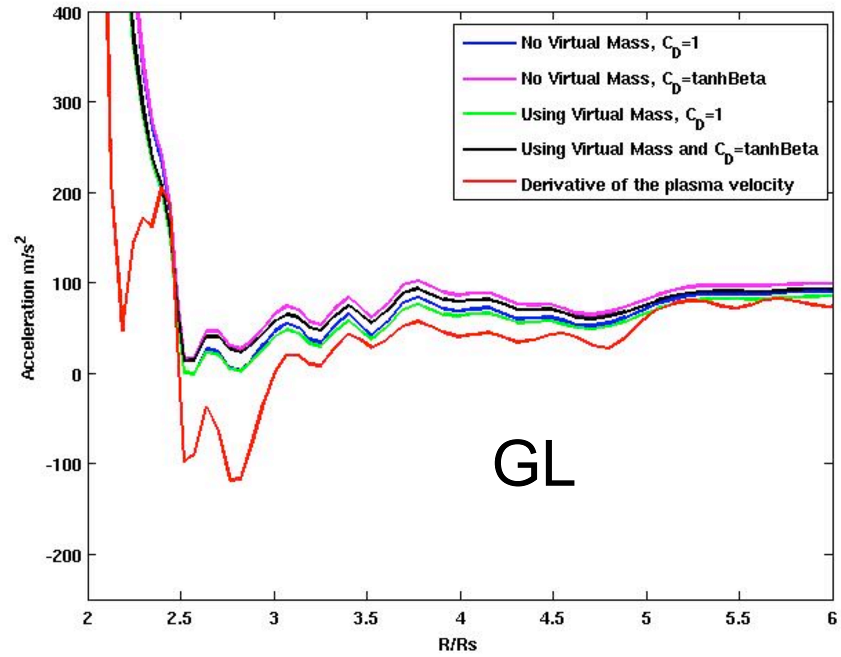
Coronal Mass Ejection in the Lower Corona: Comparison of Two Initiation Models

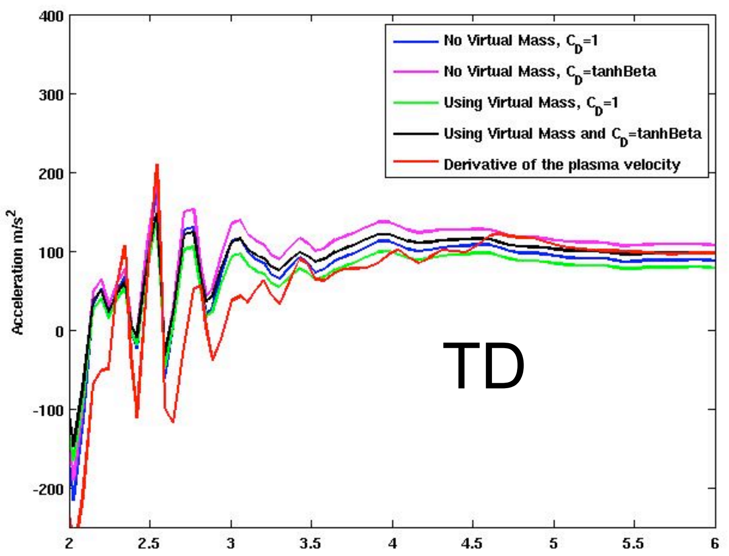
(Loesch et al. 2008)



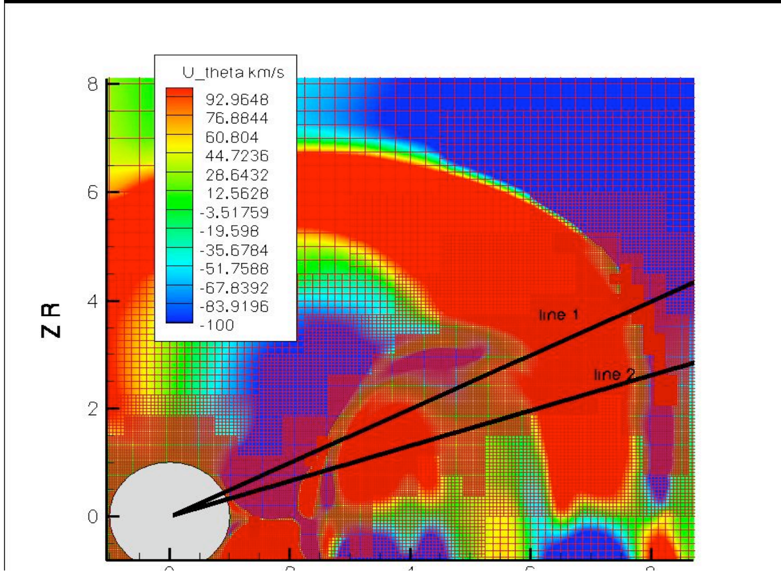
Effect of Magnetic Field in the Drag of a CME



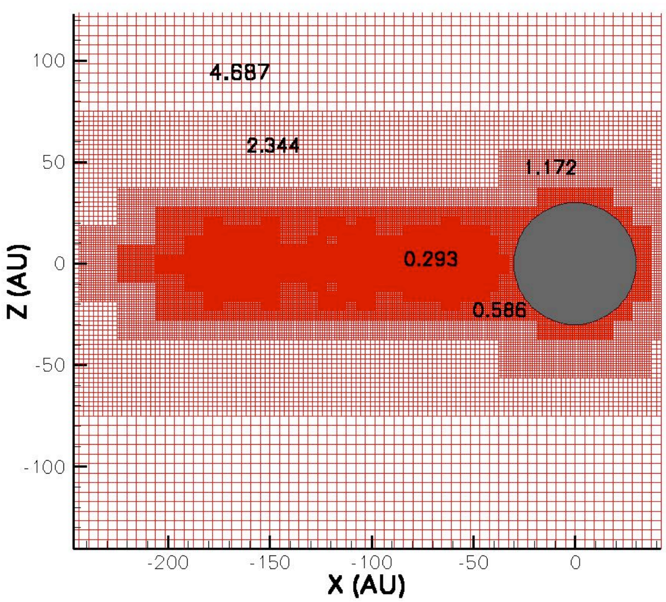




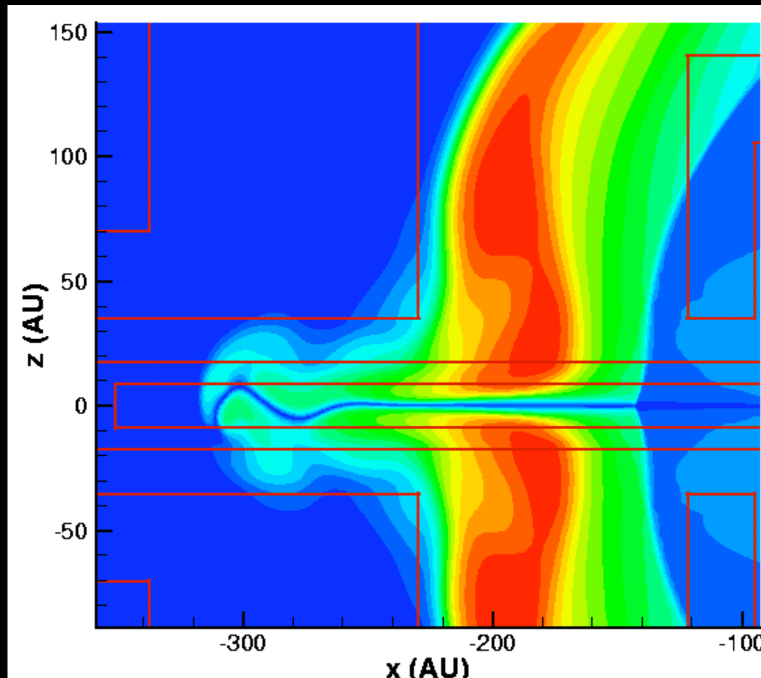
Kelvin-Helmholtz Instability at the Current Sheet



Opher et al. 2003, 2004



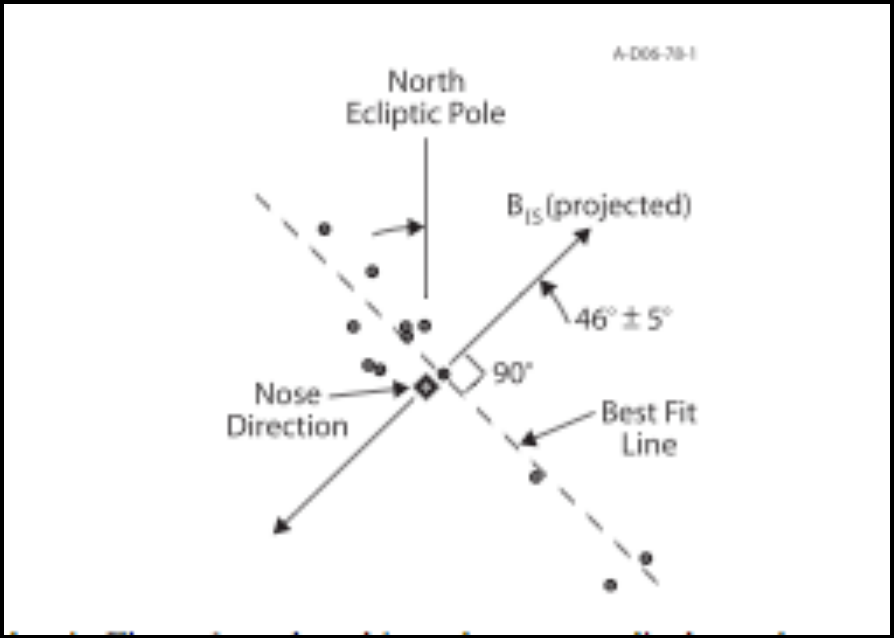
MHD instabilities at the current sheet

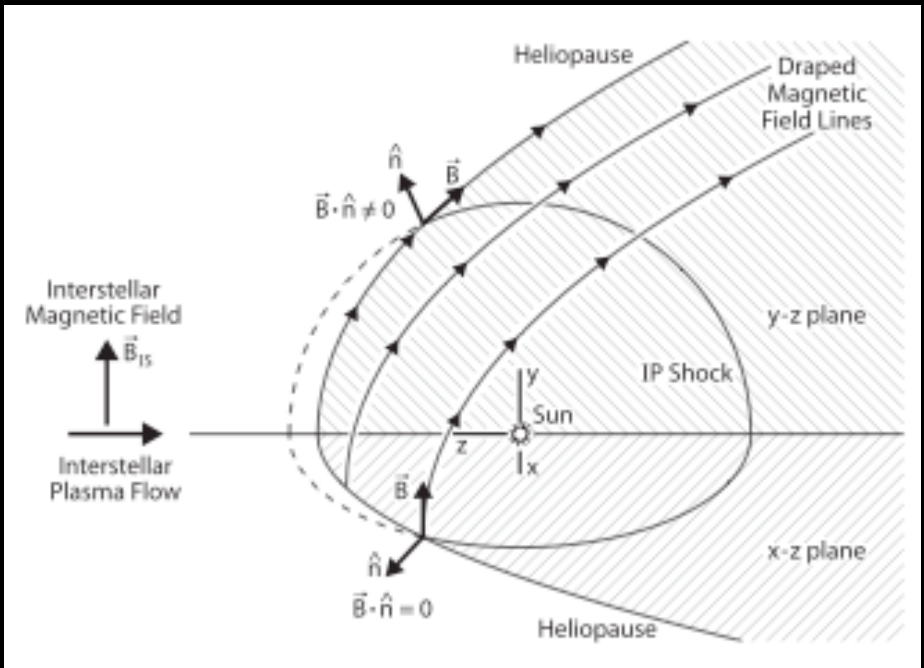


Radio Emission in Shocks
Draping of B_{ISM}

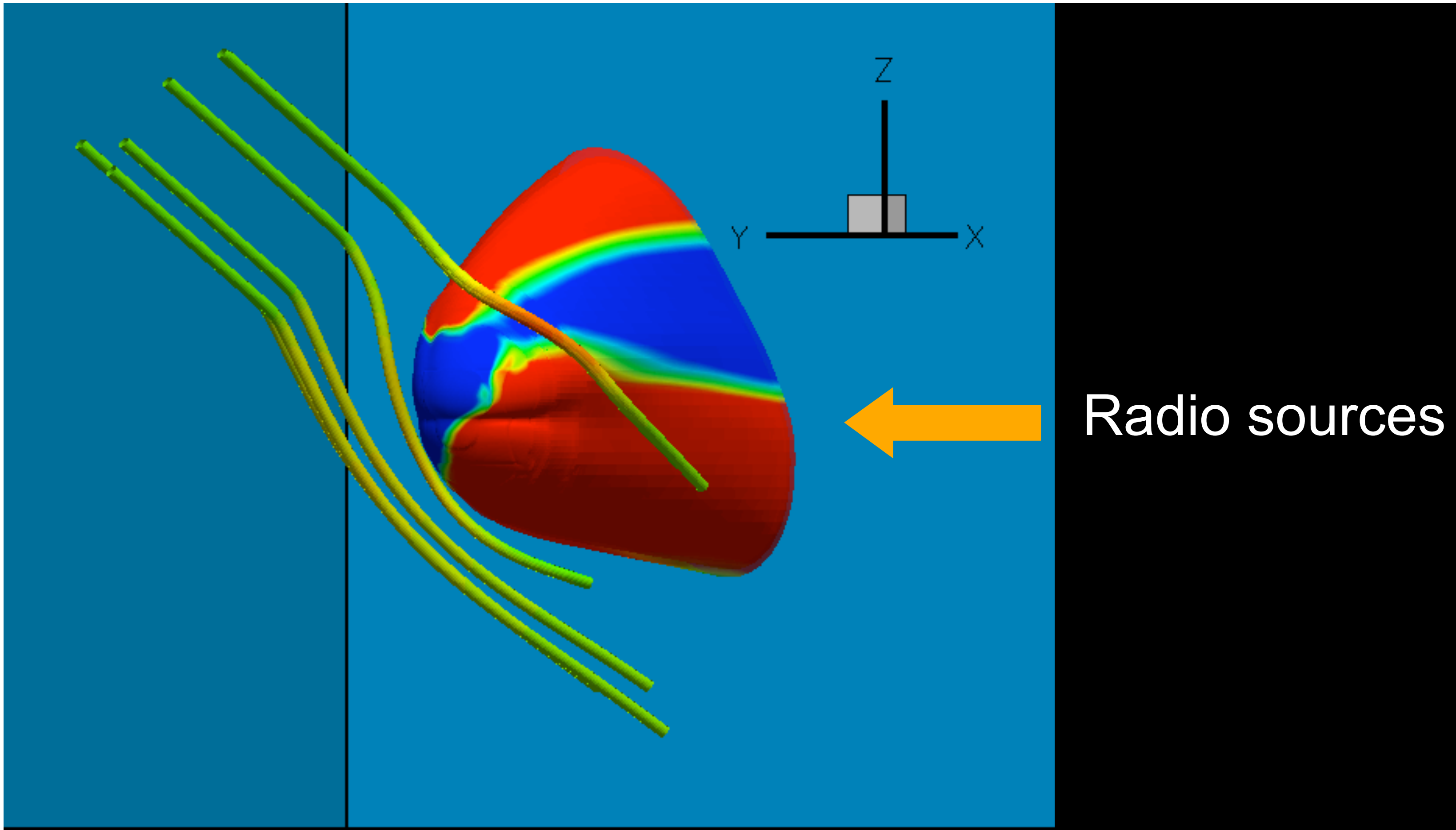
Gurnett et al. 2006: radio emission at Earth's bow shock and interplanetary shocks occurs where the magnetic field lines are tangential to the shock surfaces, or

$$B \bullet n = 0 \quad \Rightarrow B_{ISM} \bullet r = 0 \Rightarrow B_r = 0$$

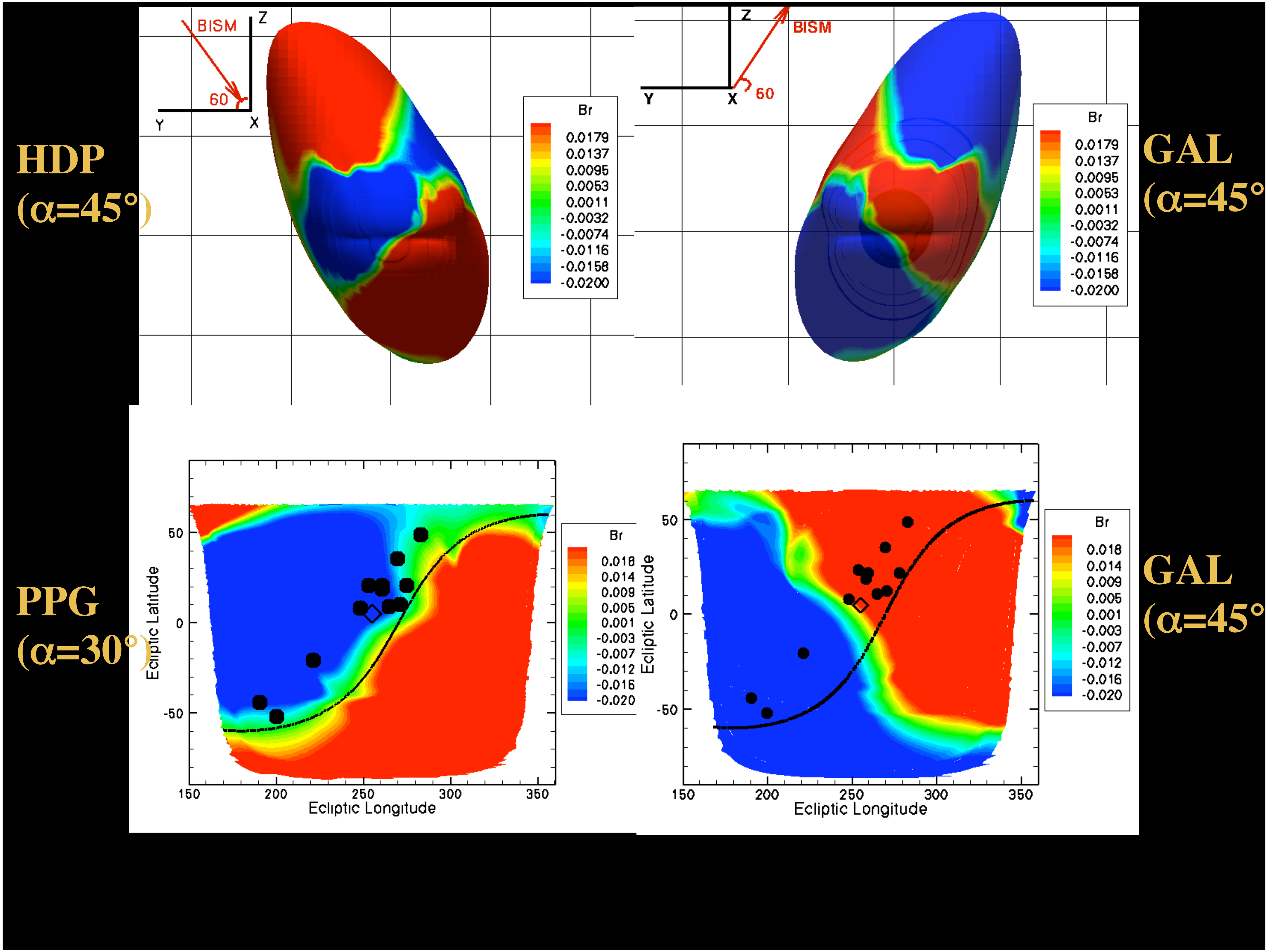




$B_{ISM} \sim 46° \pm 5°$(plane PPG)

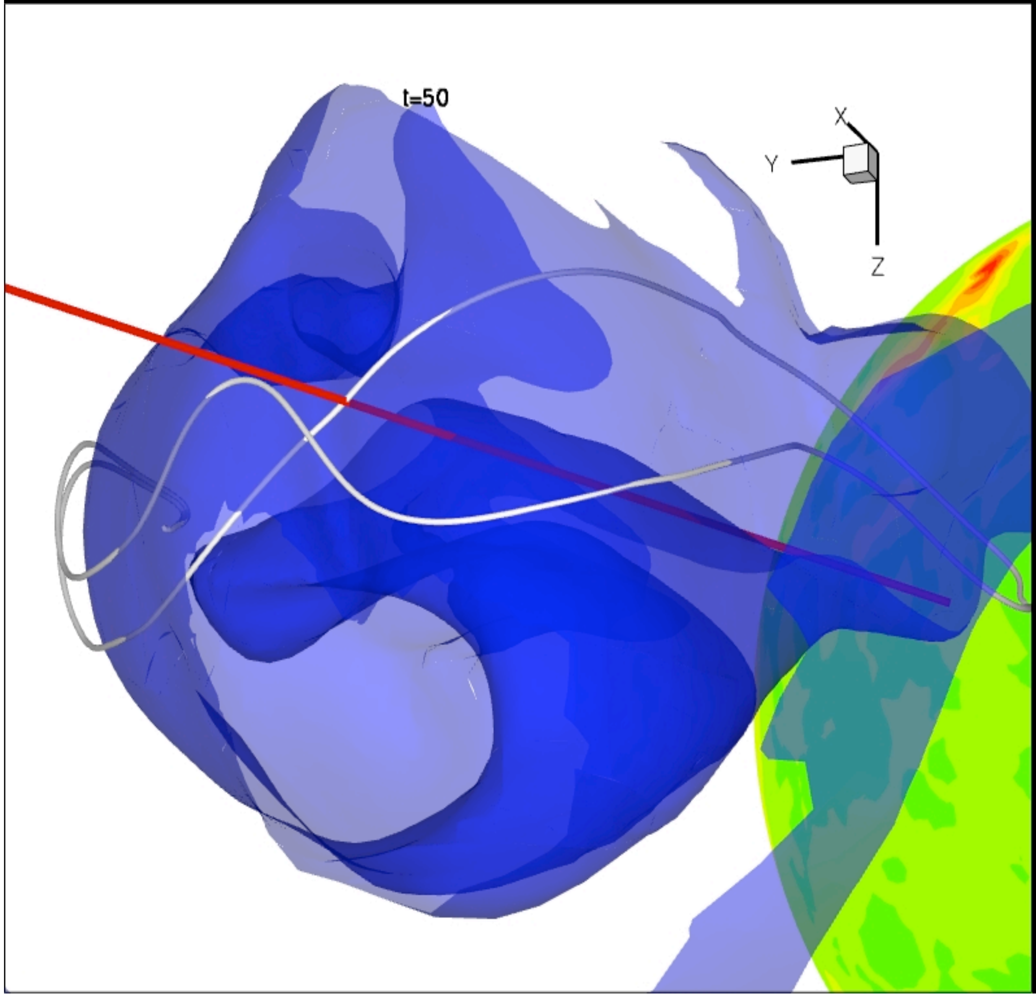


Magnetic Field in the HDP plane with α=45°
(angle between B_{ISM} and v_{ISM})



HDP
(α=45°)
GAL
(α=45°)
PPG
(α=30°)
GAL
(α=45°)
BISM
Z
Y
X
60
Br
0.0179
0.0137
0.0095
0.0053
0.0011
-0.0032
-0.0074
-0.0116
-0.0158
-0.0200
Br
0.018
0.014
0.009
0.005
0.001
-0.003
-0.007
-0.012
-0.016
-0.020
Ecliptic Latitude
Ecliptic Longitude
50
0
-50
150
200
250
300
350

Evolution of Magnetized Shocks



What is the thickness of sheath?

How magnetic effects affect shock evolution?

Which type of flows we get in shocks?

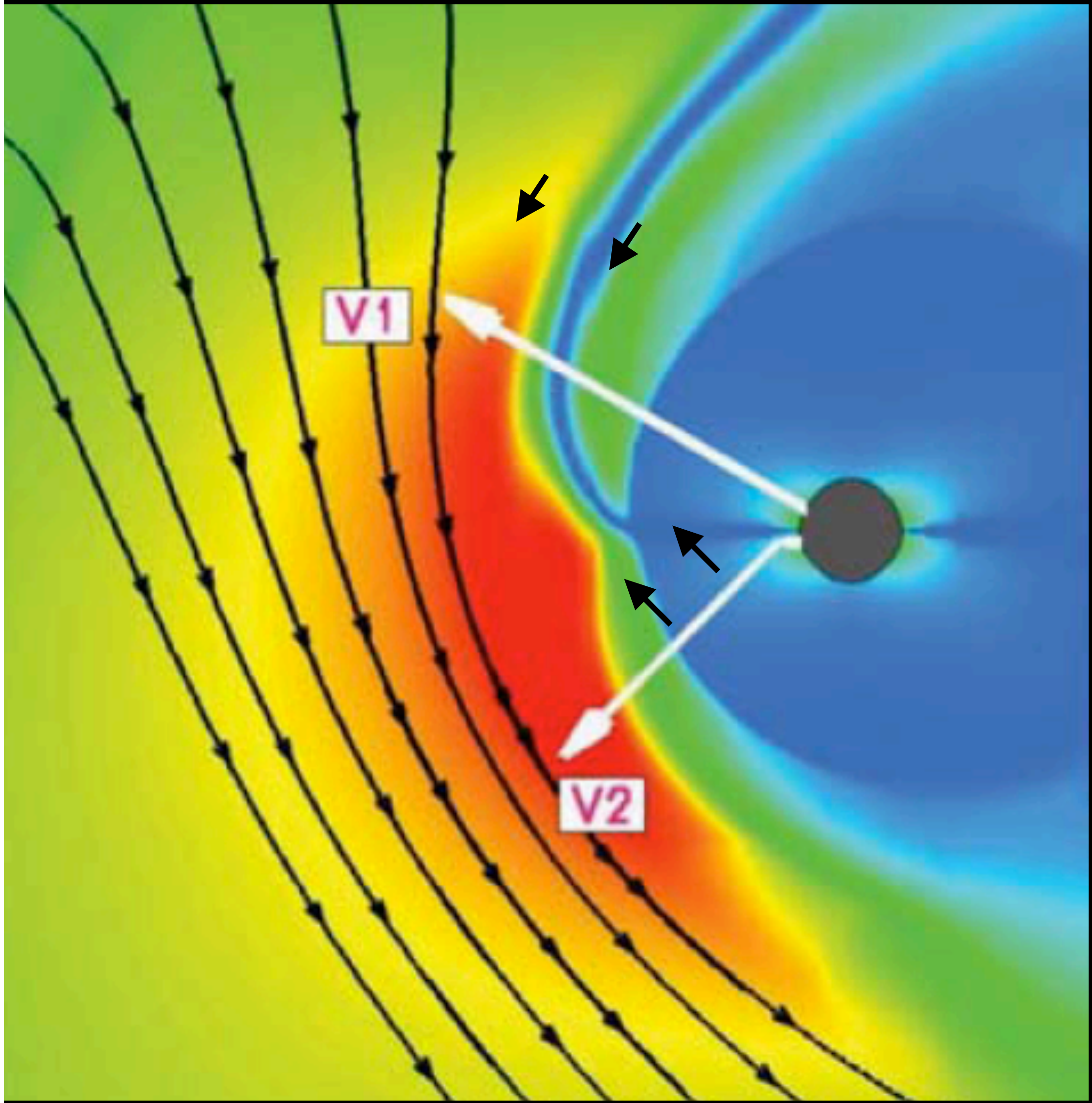
Asymmetries in shock?

MHD instabilities?

How reconnection affect shock structures?

How a structured solar wind affect the evolution of the shock?

Effect of reconnection



How reconnection in small scales affects large structures such as Heliopause, Coronal Mass Ejections

How can we best include it in Global Models? Kuzentsova? Hall MHD?