Structure and Evolution of the Three Dimensional Solar Wind

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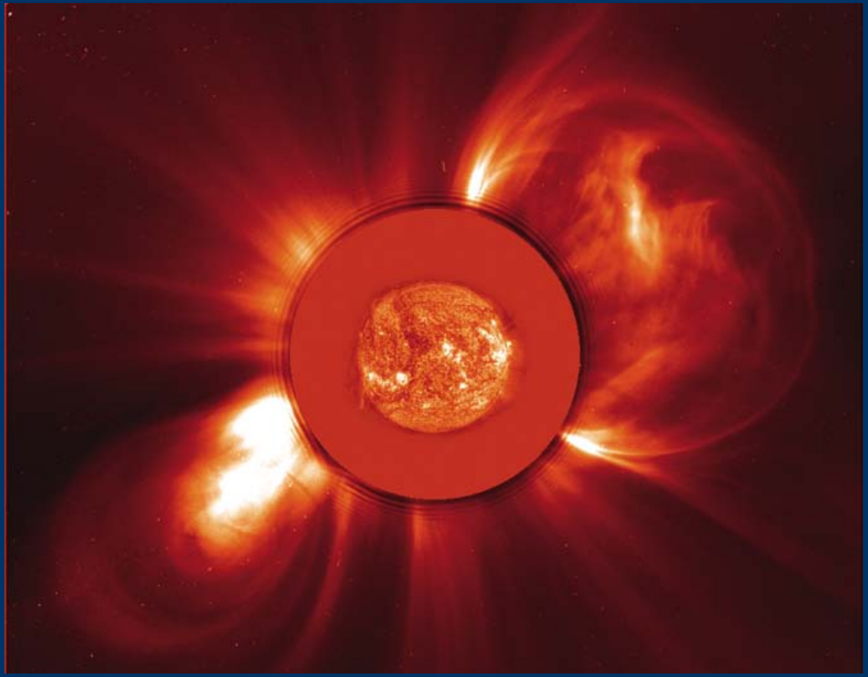
Heliophysics Summer School, 30 July, 2011

The Solar Origin of the Solar Wind



Parker’s Isothermal Solar Wind Model

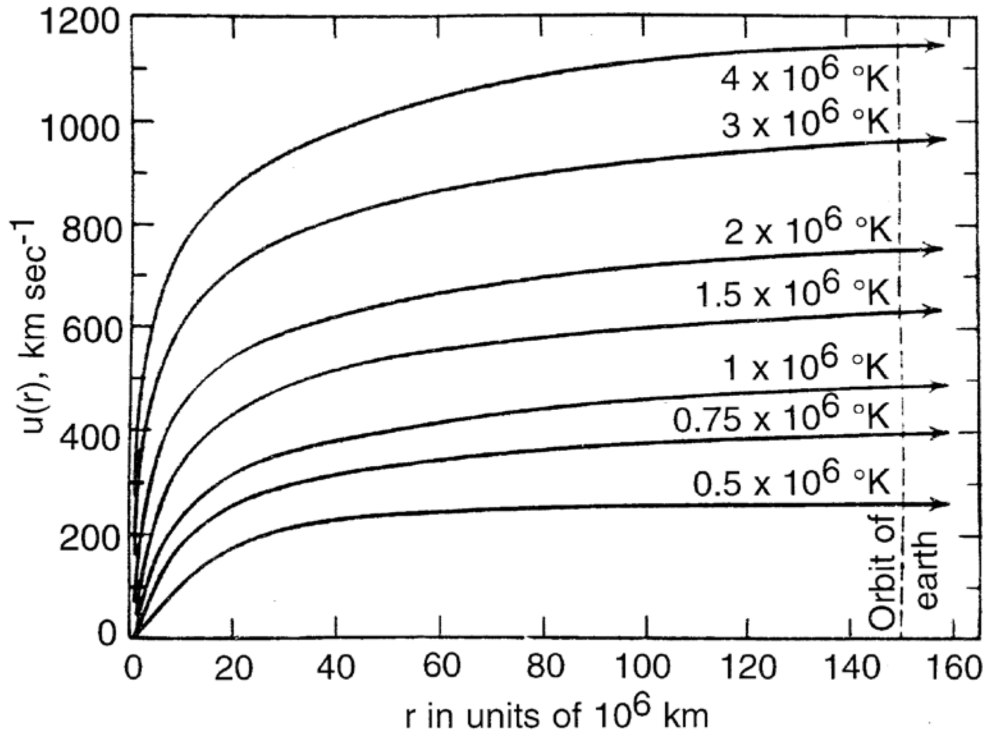
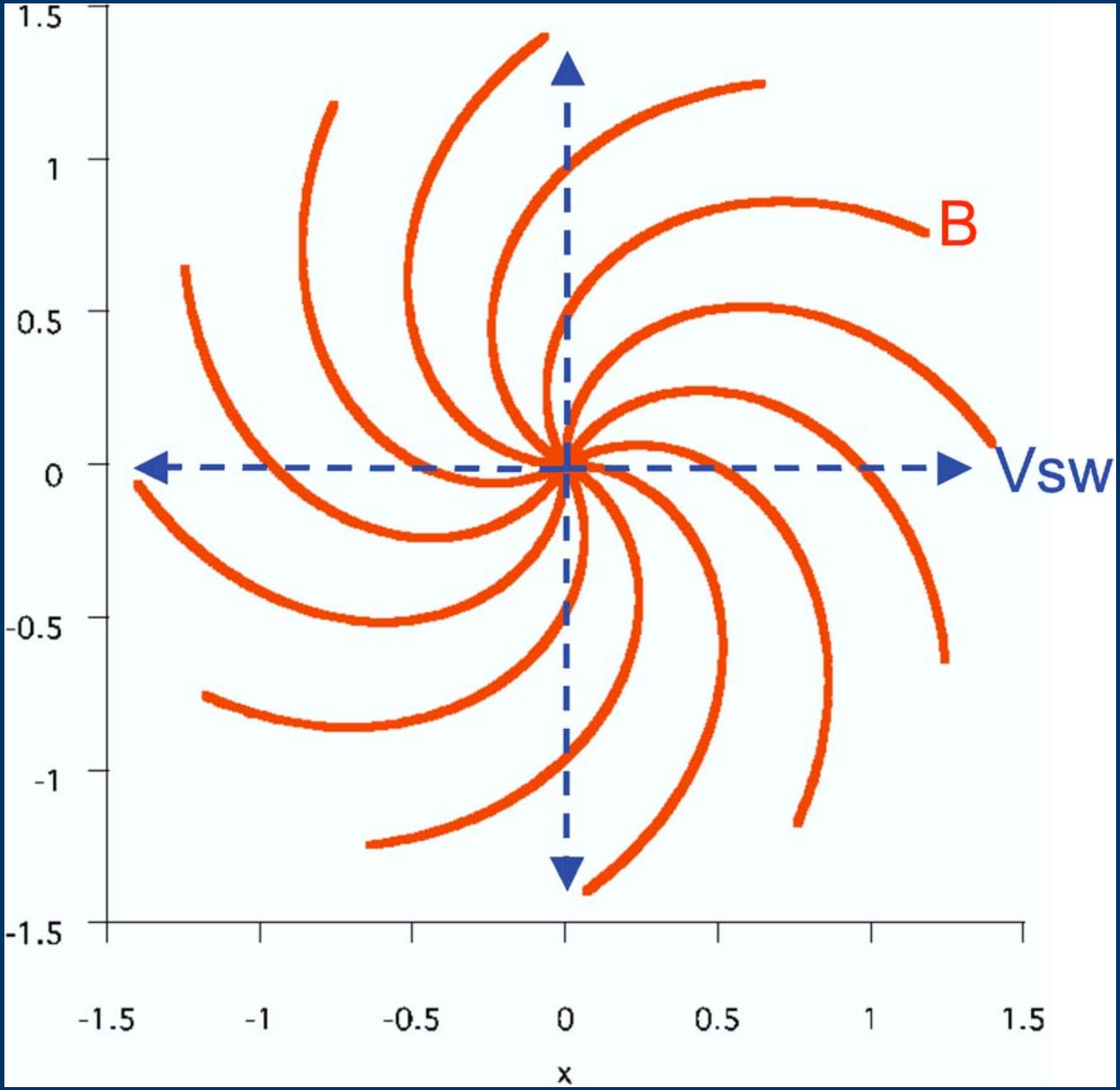


FIGURE 1 E. N. Parker’s original solutions for solar wind flow speed as a function of heliocentric distance for different coronal temperatures. Subsequent work has demonstrated that the simple relationship between coronal temperature and solar wind speed illustrated here is incorrect. [From E. N. Parker (1963). “Interplanetary Dynamical Processes.” Interscience, New York. Copyright © 1963. Reprinted with permission of John Wiley & Sons, Inc.]

Parker's Model of the Heliospheric Magnetic Field



Axes are heliocentric distance in units of AU.

The Variable Solar Wind at 1 AU

Table 1. Statistical Properties of the Solar Wind at 1 AU

Parameter	Mean	STD	Most Probable	Median	5-95% Range
n ($/cm^3$)	8.7	6.6	5.0	6.9	3.0 – 20.0
V_{sw} (km/s)	468	116	375	442	320 – 710
B (nT)	6.2	2.9	5.1	5.6	2.2 – 9.9
A(He)	0.047	0.019	0.048	0.047	0.017 – 0.078
T_p ($x10^5$K)	1.2	0.9	0.5	0.95	0.1 – 3.0
T_e ($x10^5$K)	1.4	0.4	1.2	1.33	0.9 – 2.0
T_α ($x10^5$K)	5.8	5.0	1.2	4.5	0.6 – 15.5
T_e/T_p	1.9	1.6	0.7	1.5	0.37 – 5.0
T_α/T_p	4.9	1.8	4.8	4.7	2.3 – 7.5
nV_{sw} ($x10^8/cm^2s$)	3.8	2.4	2.6	3.1	1.5 – 7.8
C_s (km/s)	63	15	59	61	41 – 91
C_A (km/s)	50	24	50	46	30 - 100

n is proton density, V_{sw} is solar wind speed, B is magnetic field strength, A(He) is He^{++}/H^+ ratio, T_p is proton temperature, T_e is electron temperature, T_α is alpha particle temperature, C_s is sound speed, C_A is Alfven speed.

Commonly Observed Ionization States in the Solar Wind

He^{2+}

C^{5+}, C^{6+}

O^{6+} to O^{8+}

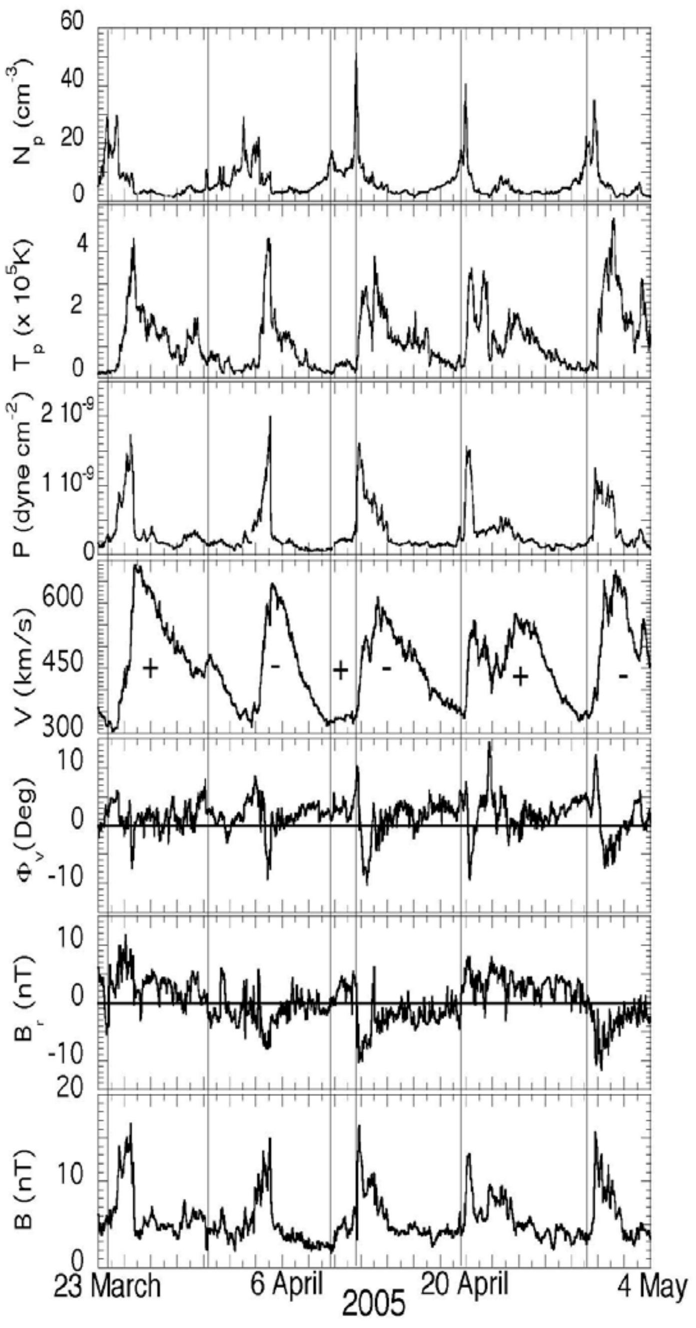
Si^{7+} to Si^{10+}

Fe^{8+} to Fe^{14+}

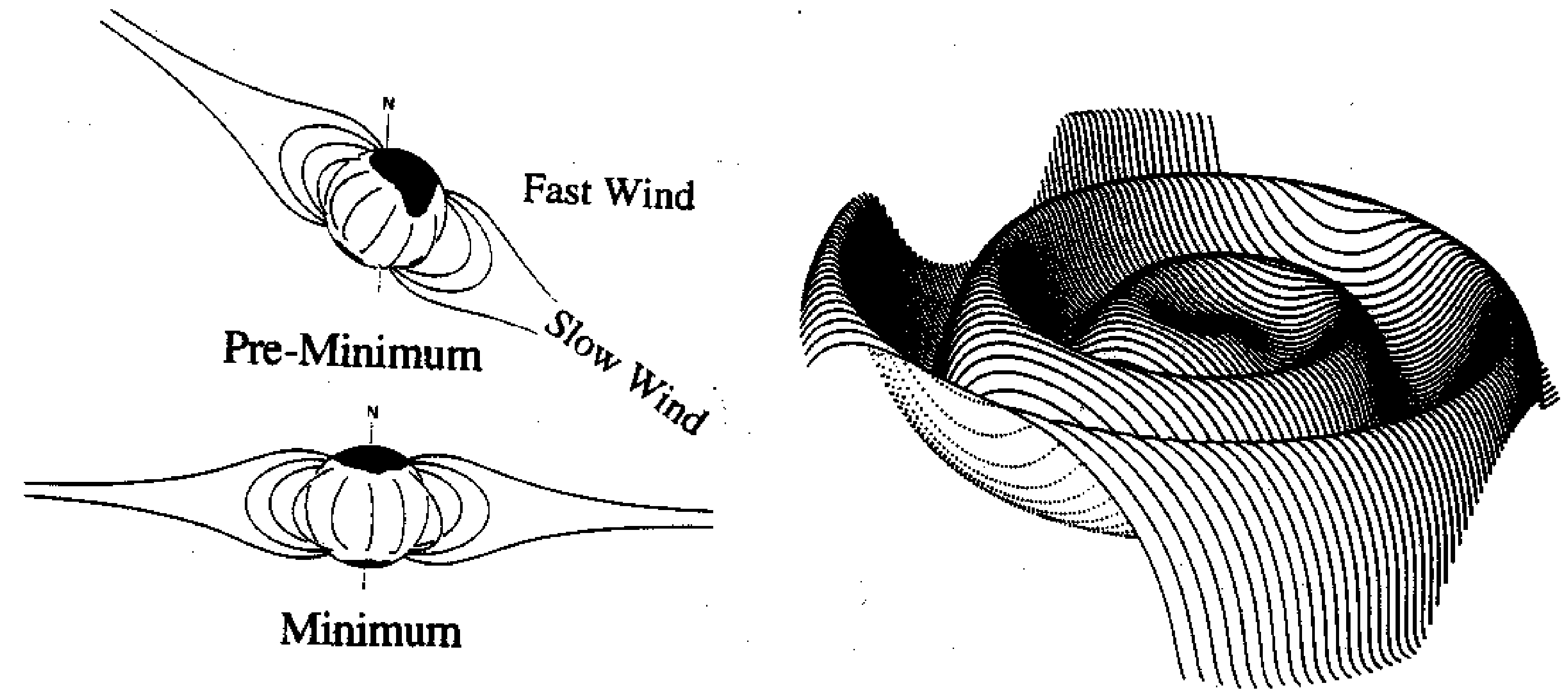
Unusual ionization states in portions of ICMEs:

He^{+} and Fe^{16+}

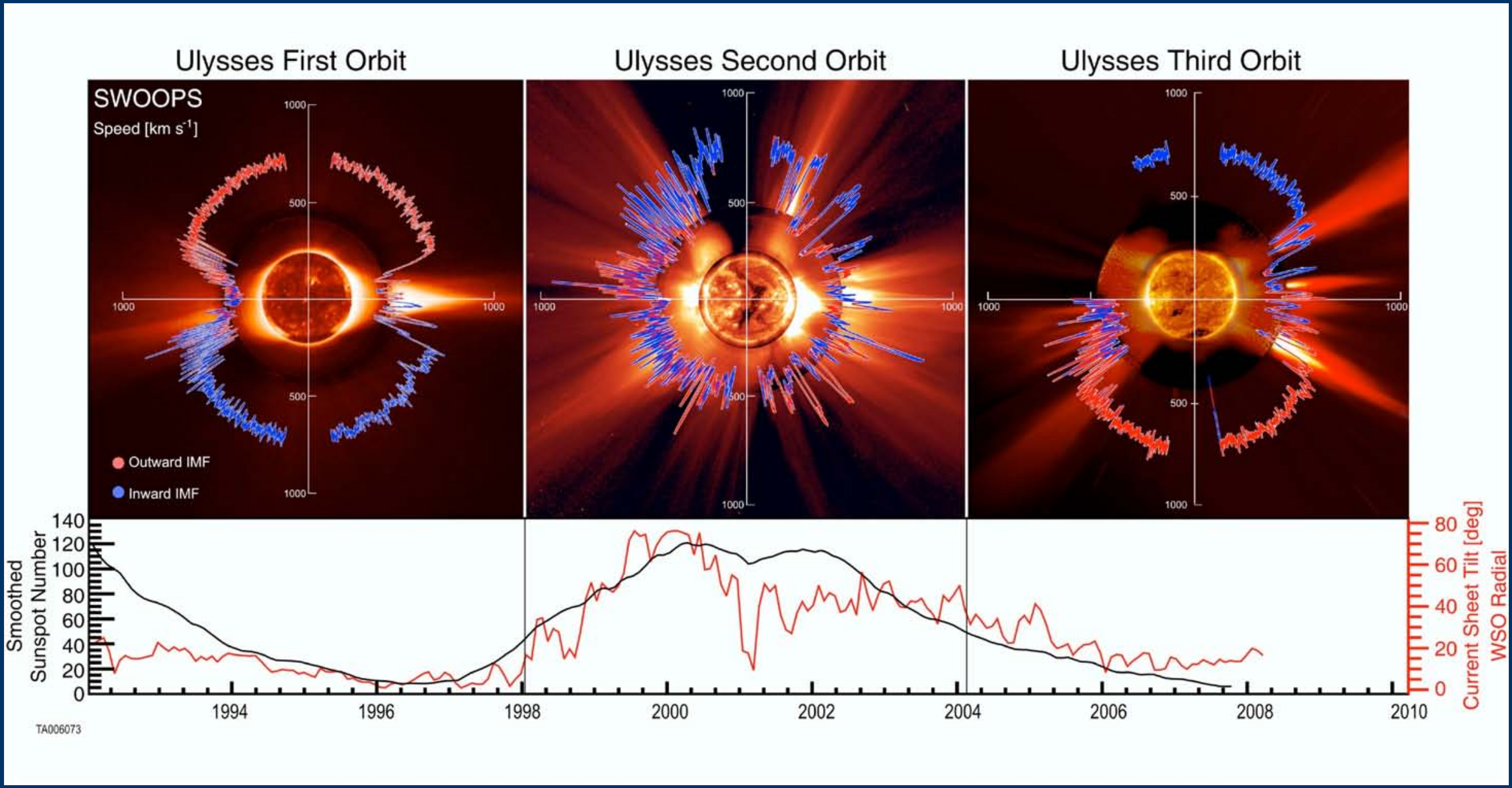
Coronal and Solar Wind Stream Structure



The Heliospheric Current Sheet and the Solar Dipole

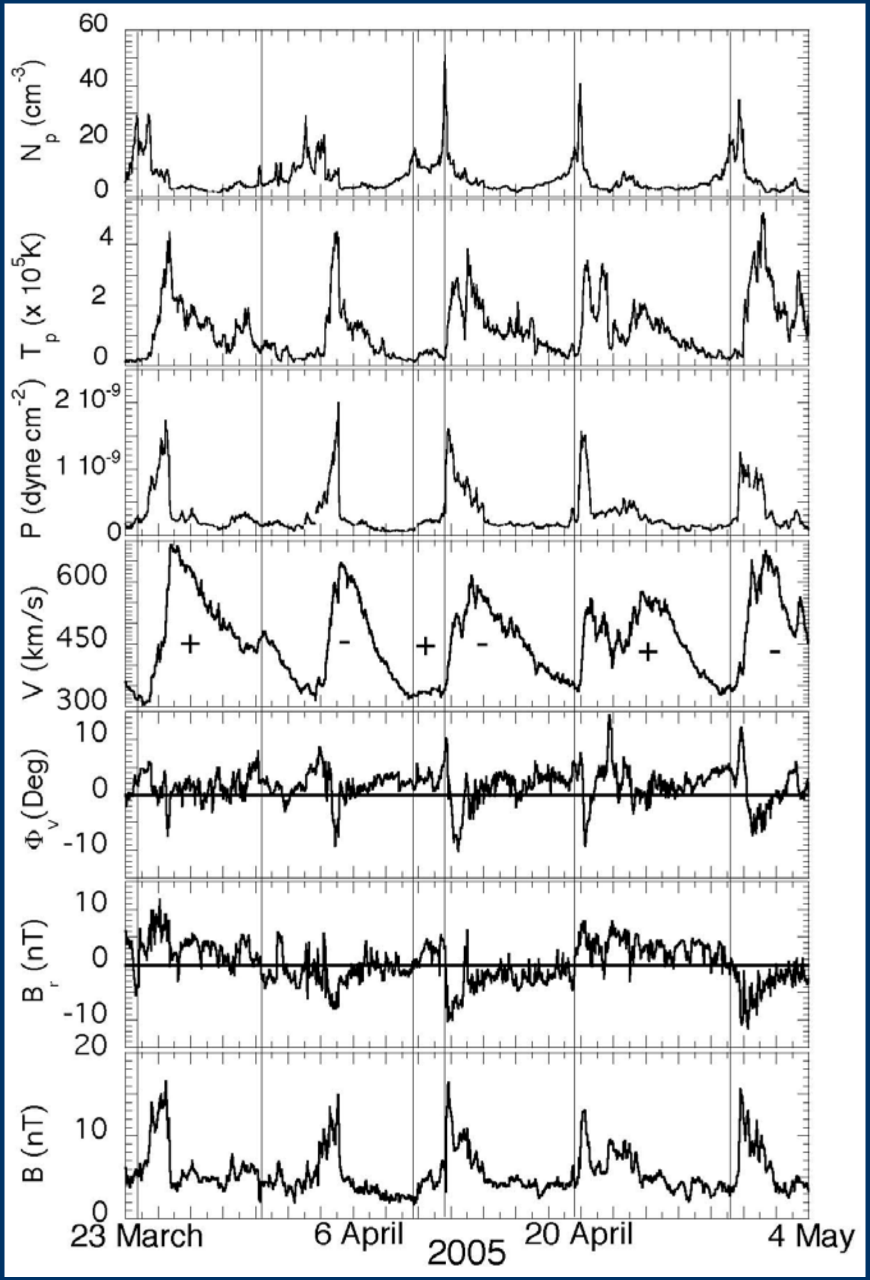


Solar Latitude and Solar Cycle Effects: Ulysses



Characteristics of Solar Wind Stream Structure

1-hr averaged data



Np (cm^{-3})

Tp (K)

P (dyne cm^{-2})

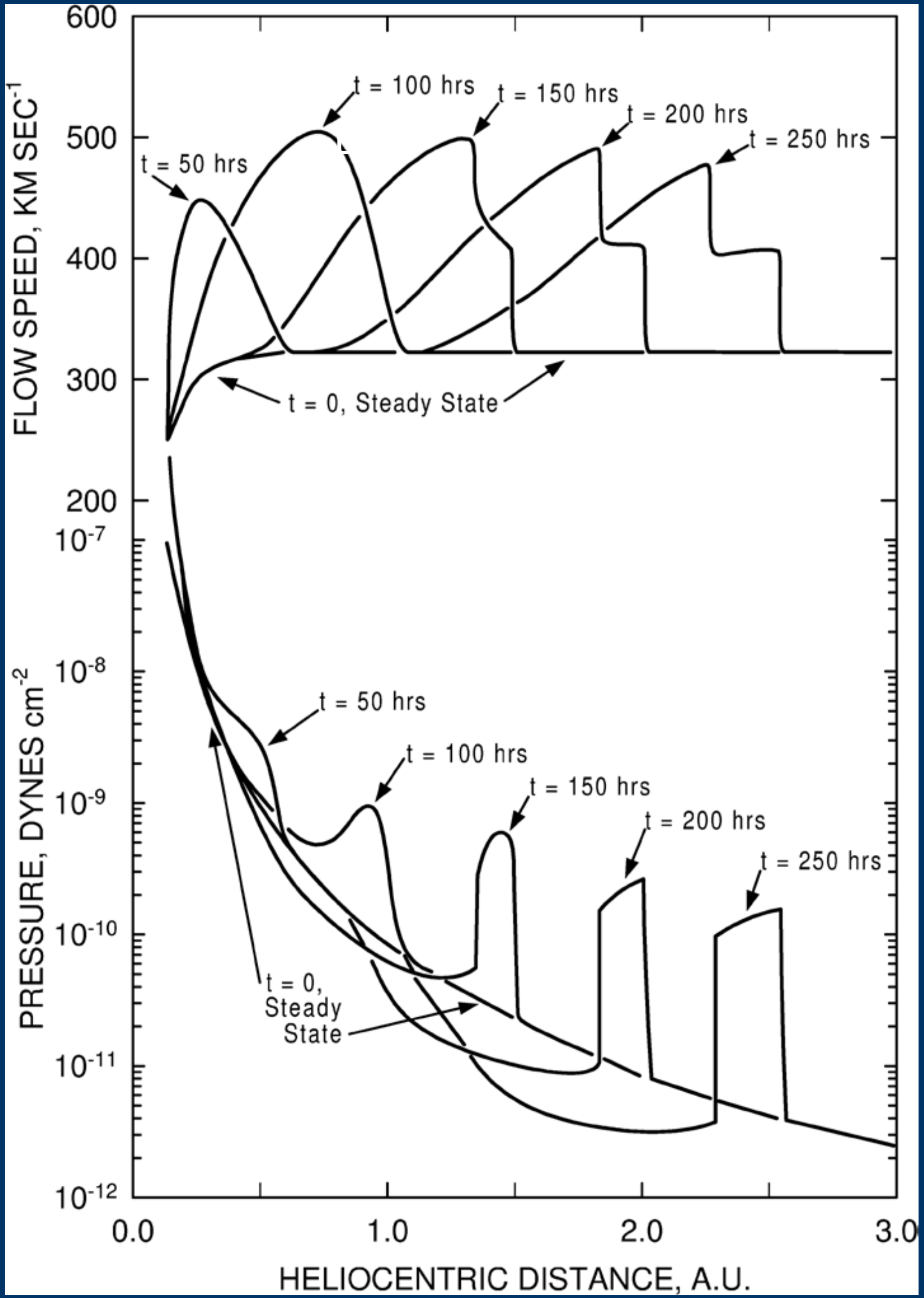
V (km s^{-1})

Phi (Deg)

Br (nT)

|B| (nT)

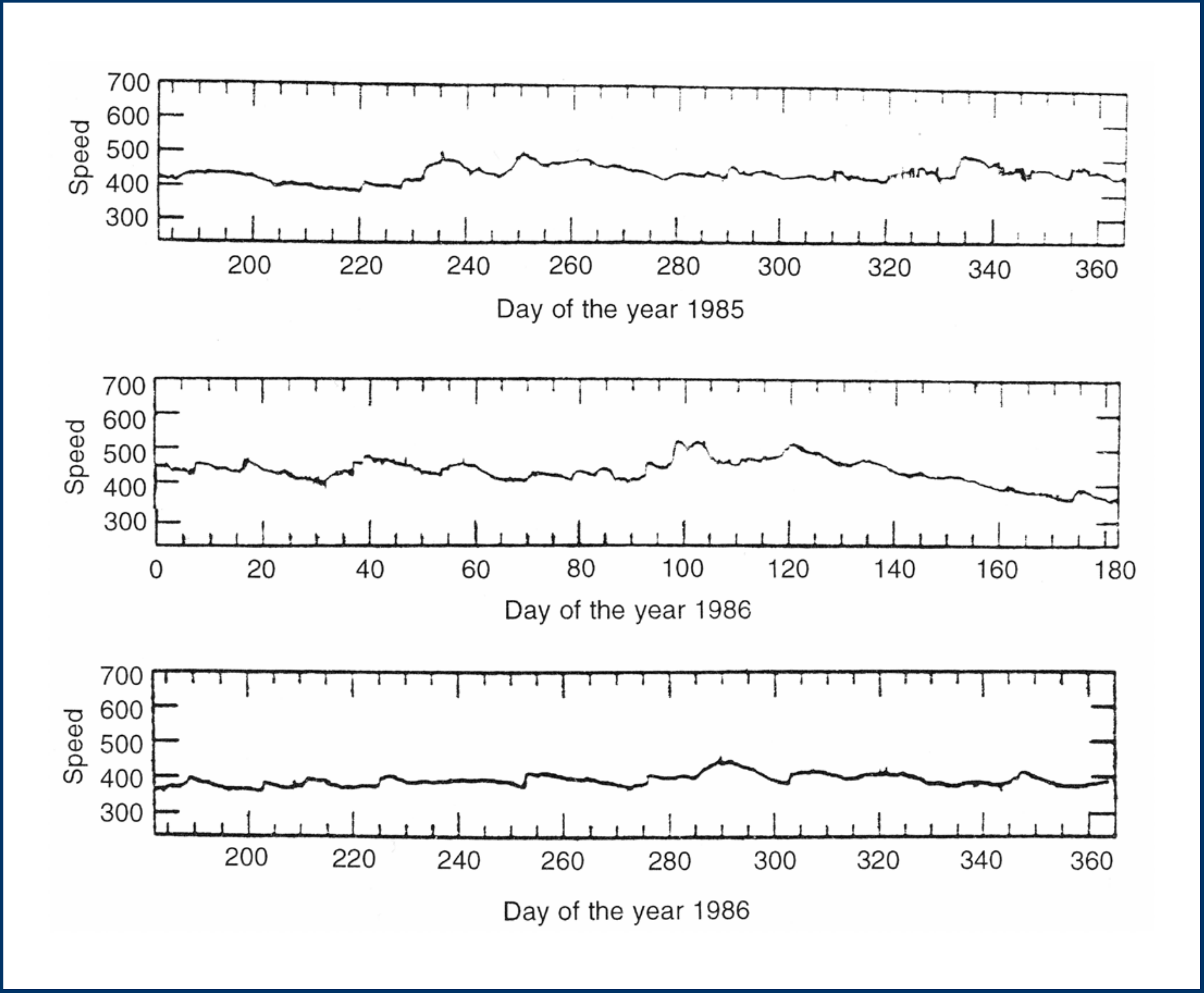
Evolution of Stream Structure with Heliocentric Distance



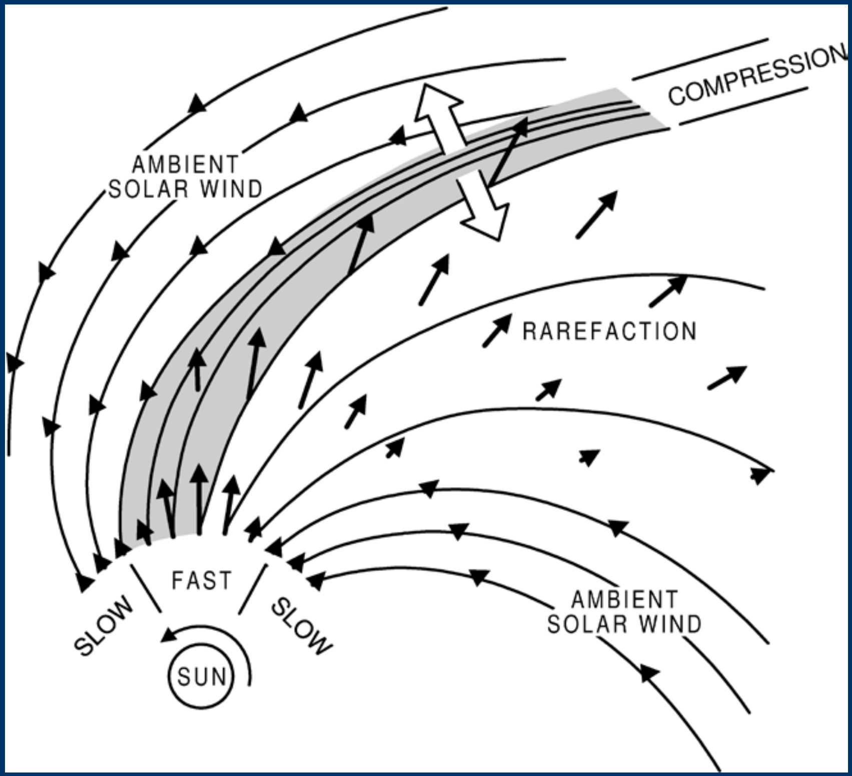
1-D Compressible Fluid Simulation

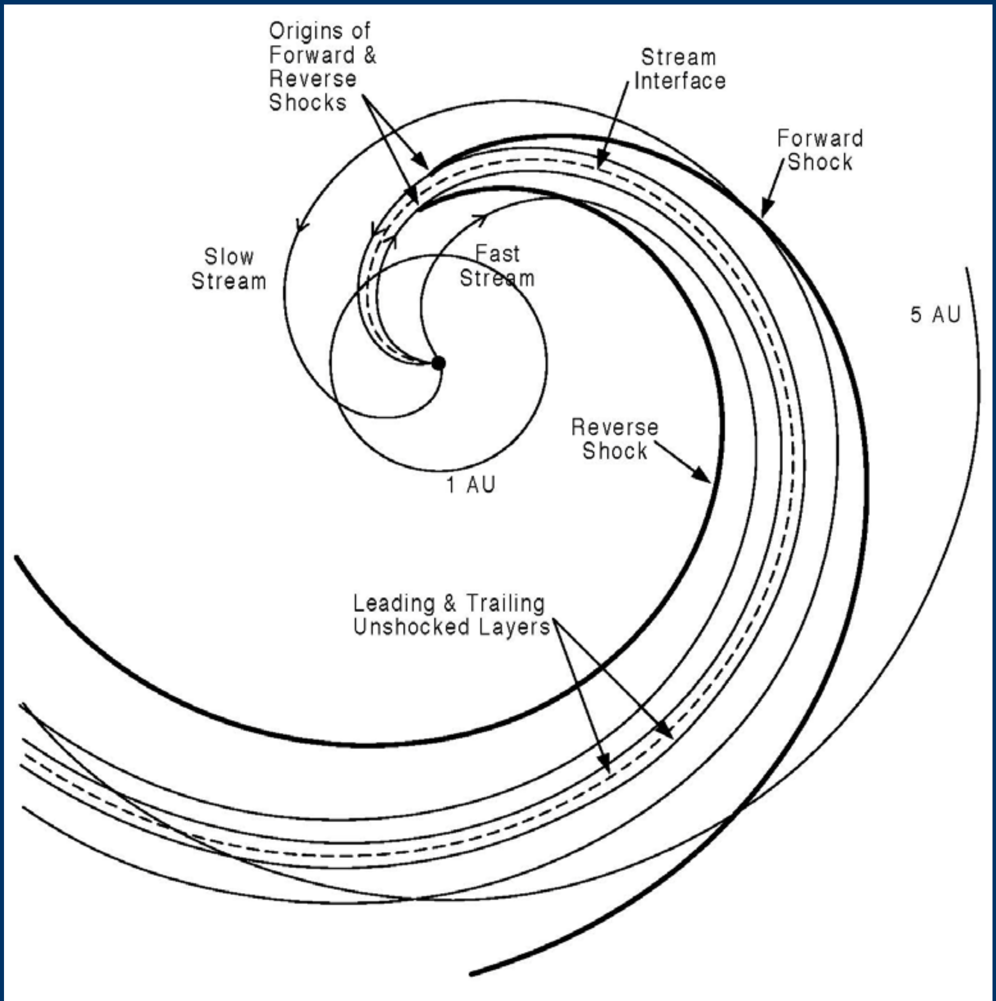
Damped High-Speed Streams in the Outer Heliosphere

Voyager 2 data obtained at ~18 AU



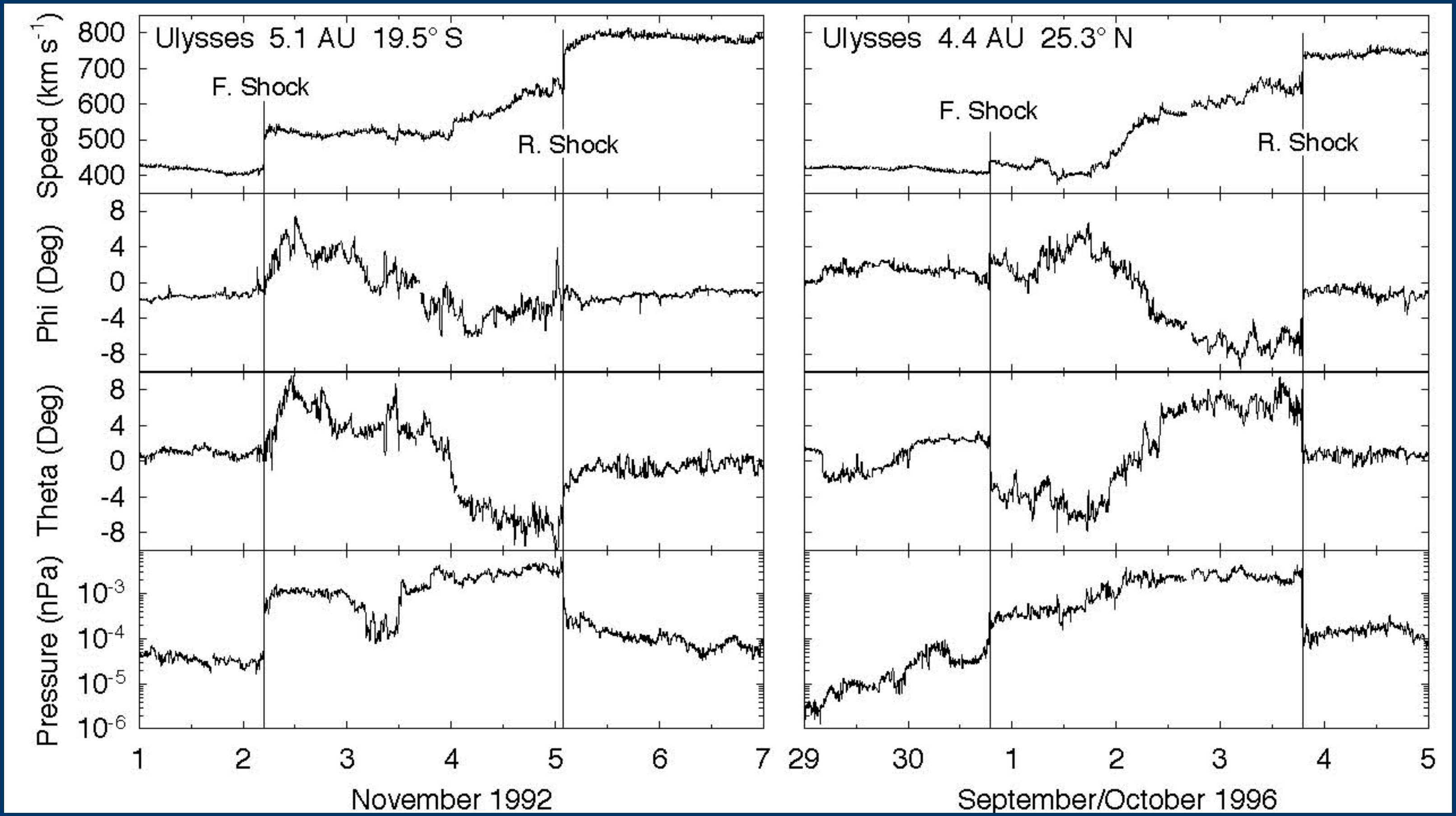
Stream Evolution in Two Dimensions



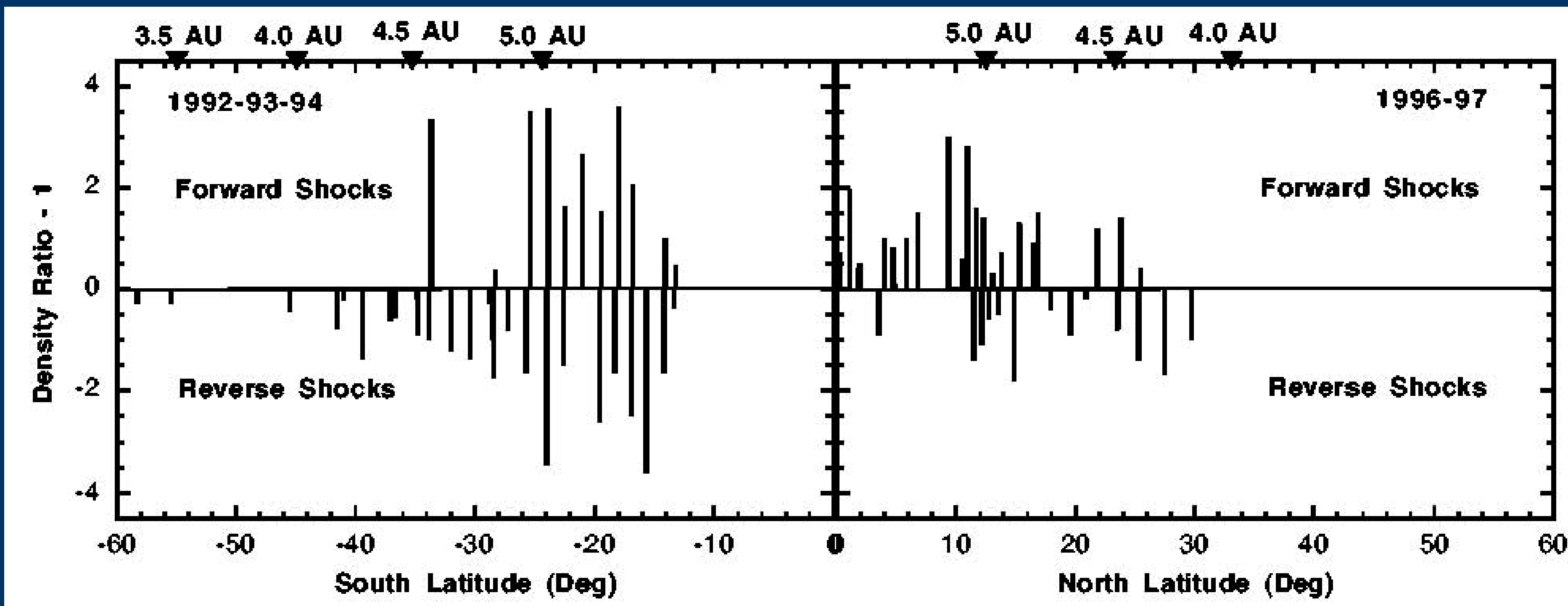


Flow Deflections in CIRs Observed by Ulysses in the Opposite Solar Hemispheres

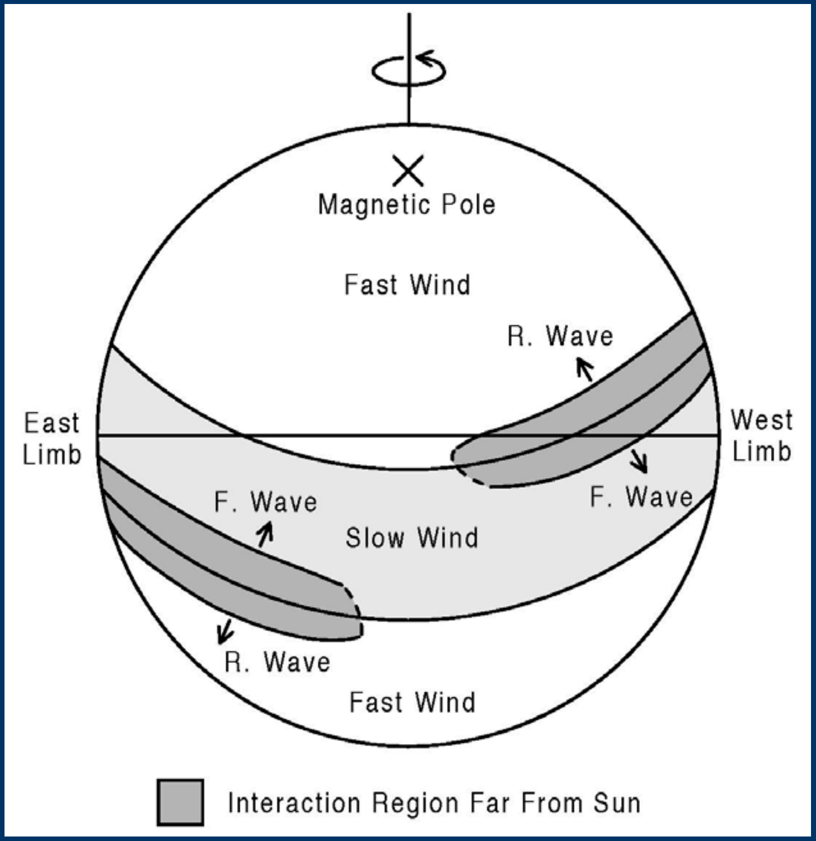
Flow Angles Relative to Radial →

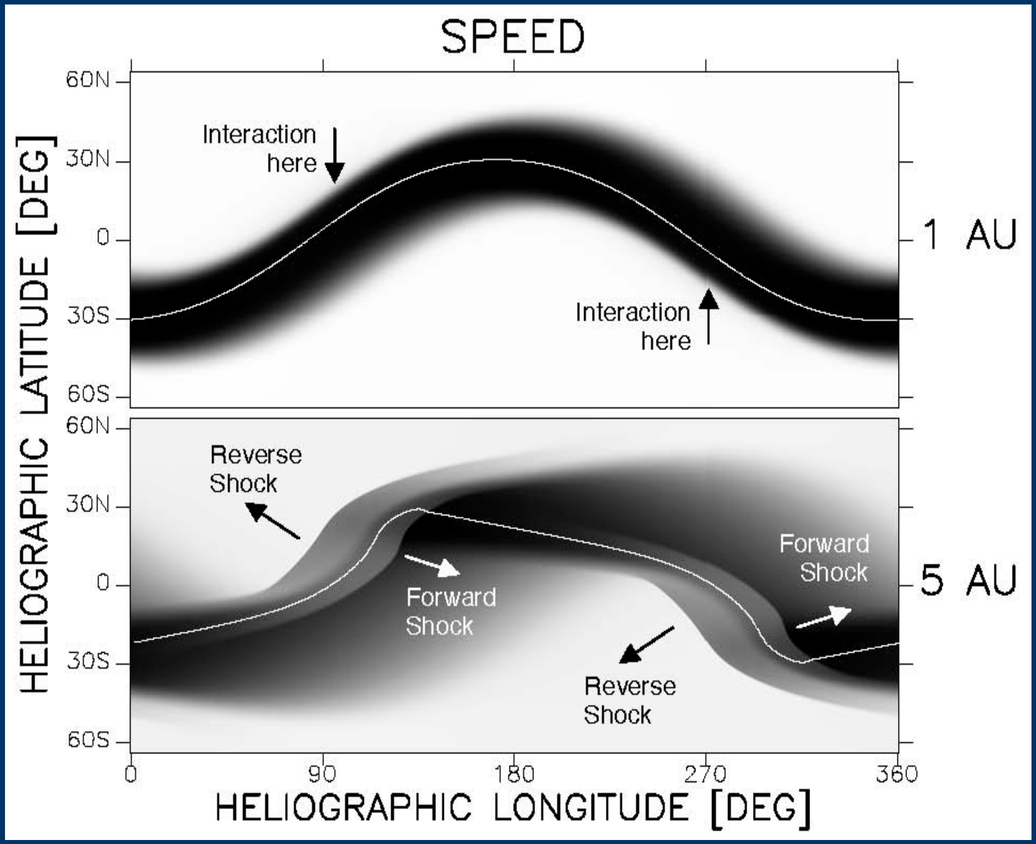


Forward and Reverse Shocks Observed by Ulysses During its First Solar Orbit

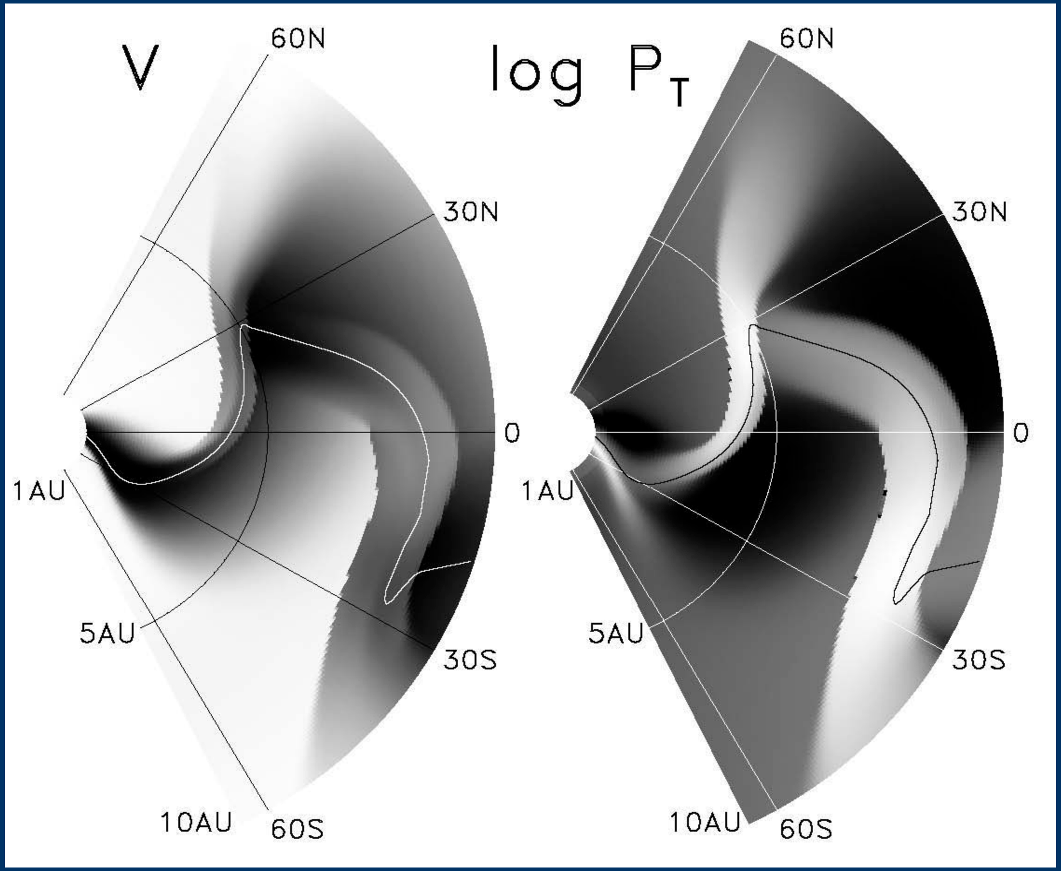


Corotating Interaction Regions in 3D



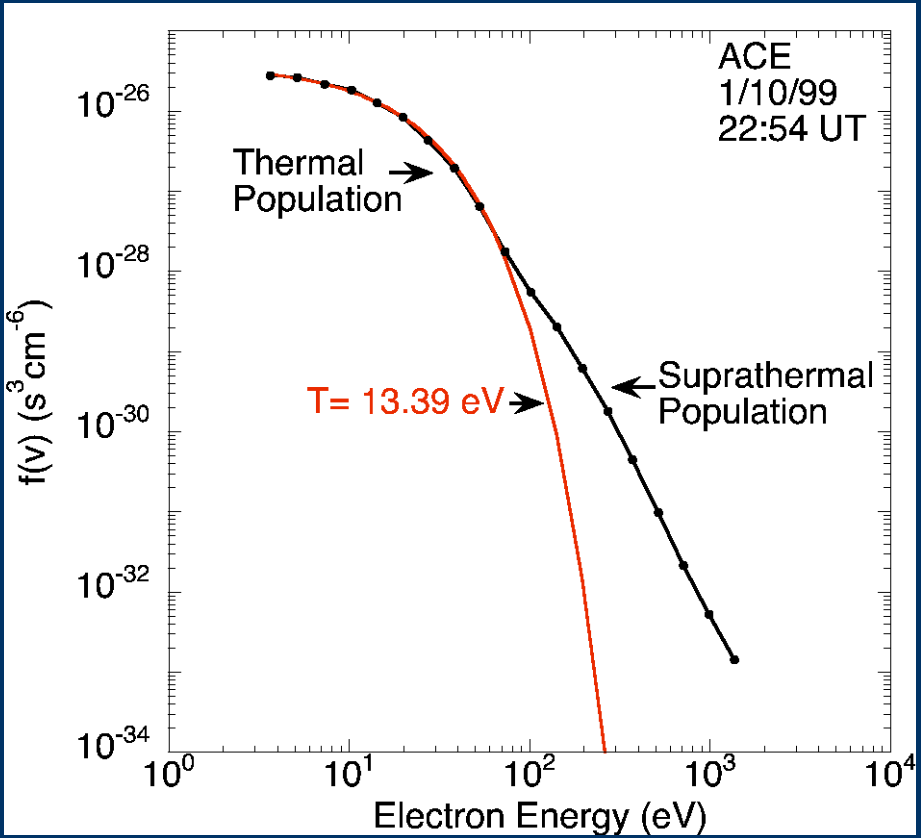


A Meridional Cut Through Stream Structure at a Fixed Longitude

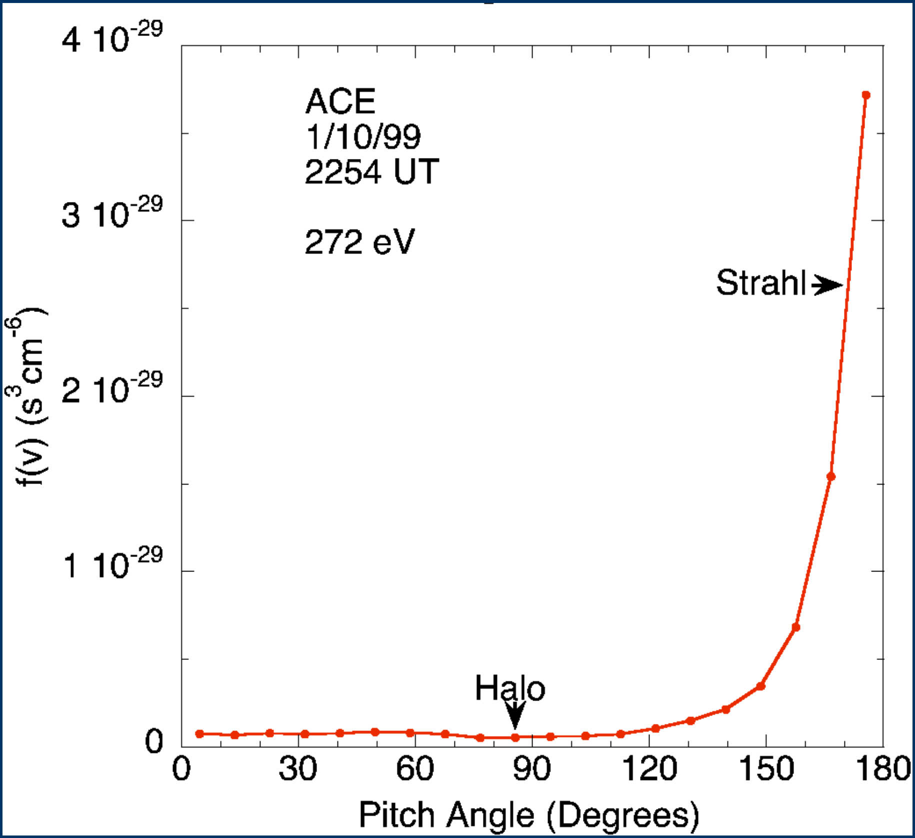


Solar Wind Electrons

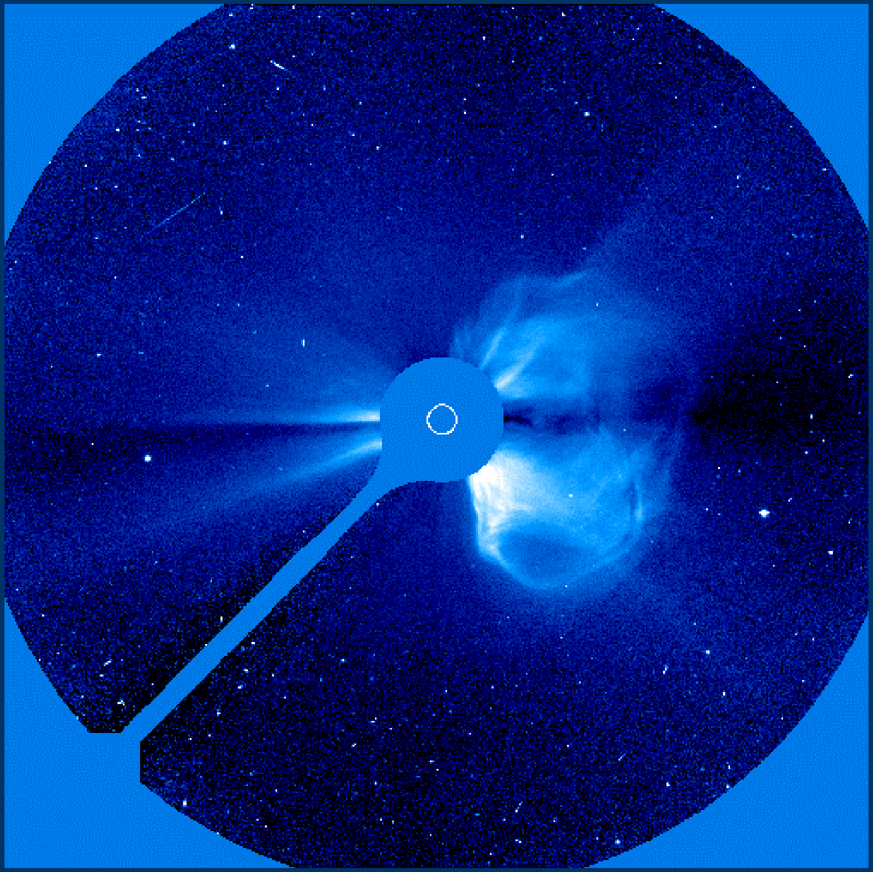
Integrated ver all look directions

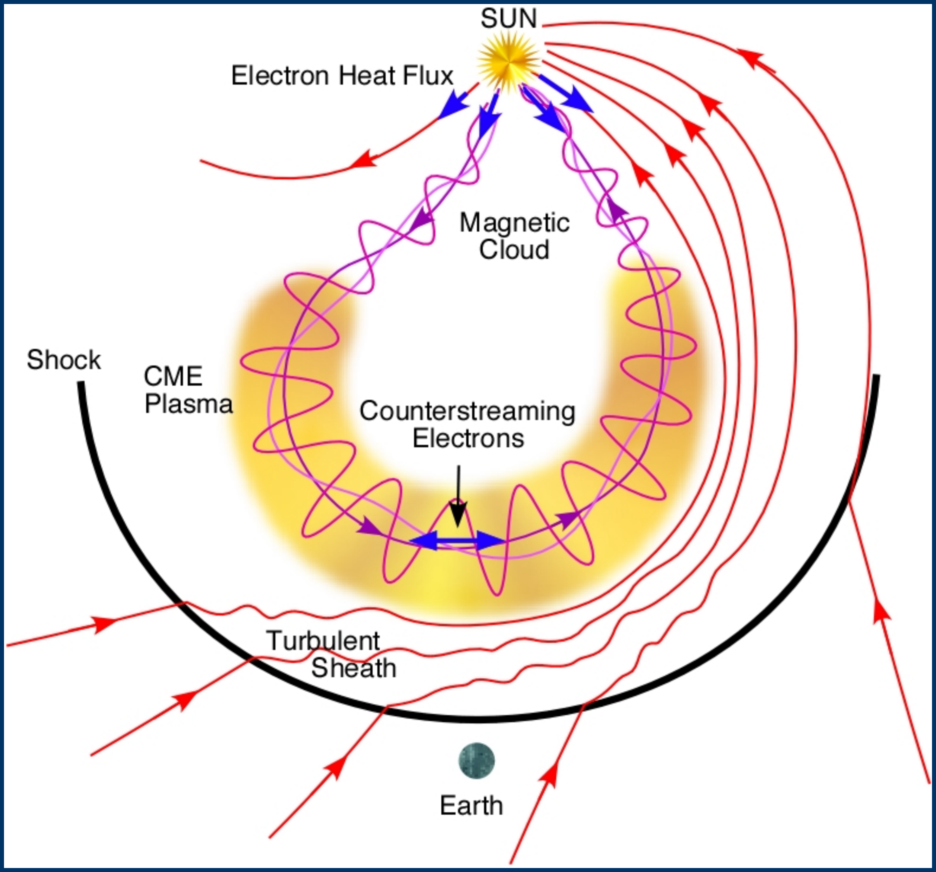


Suprathermal Pitch Angle Distribution

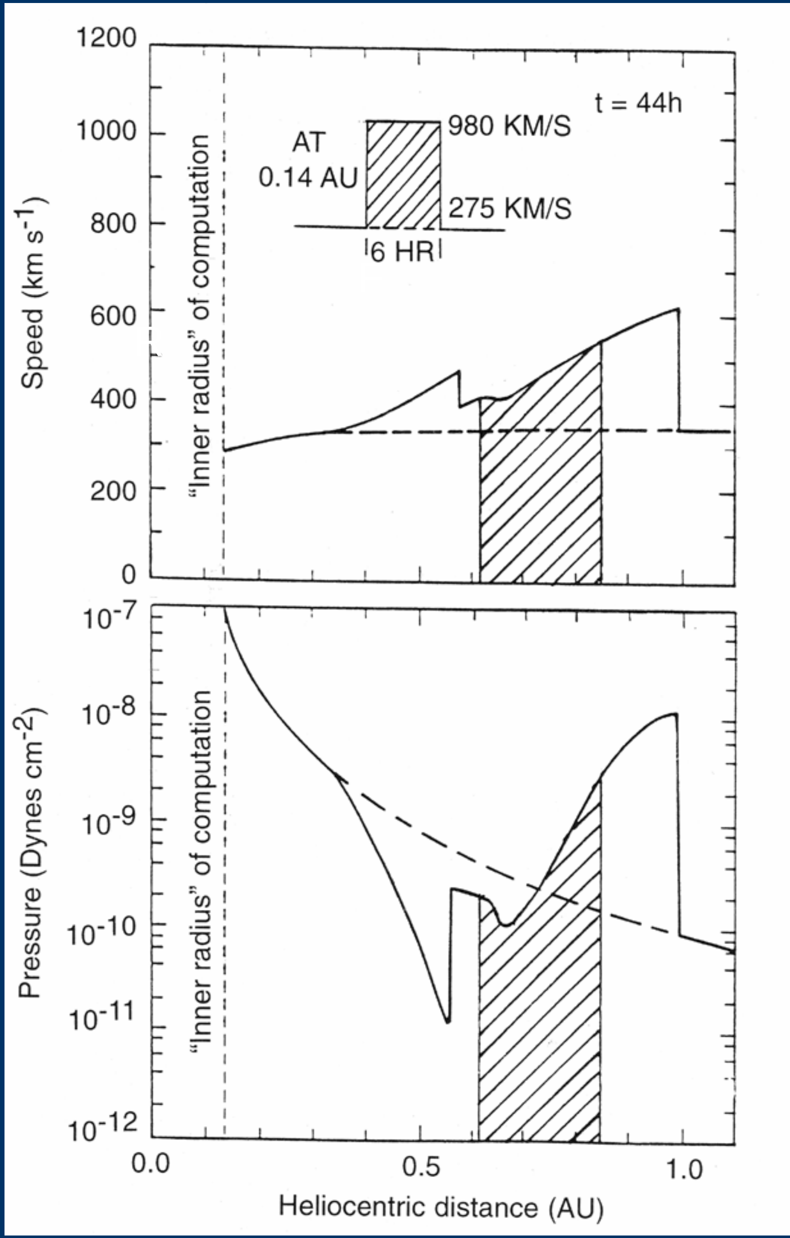


Coronal Mass Ejections and Transient Solar Wind Disturbances



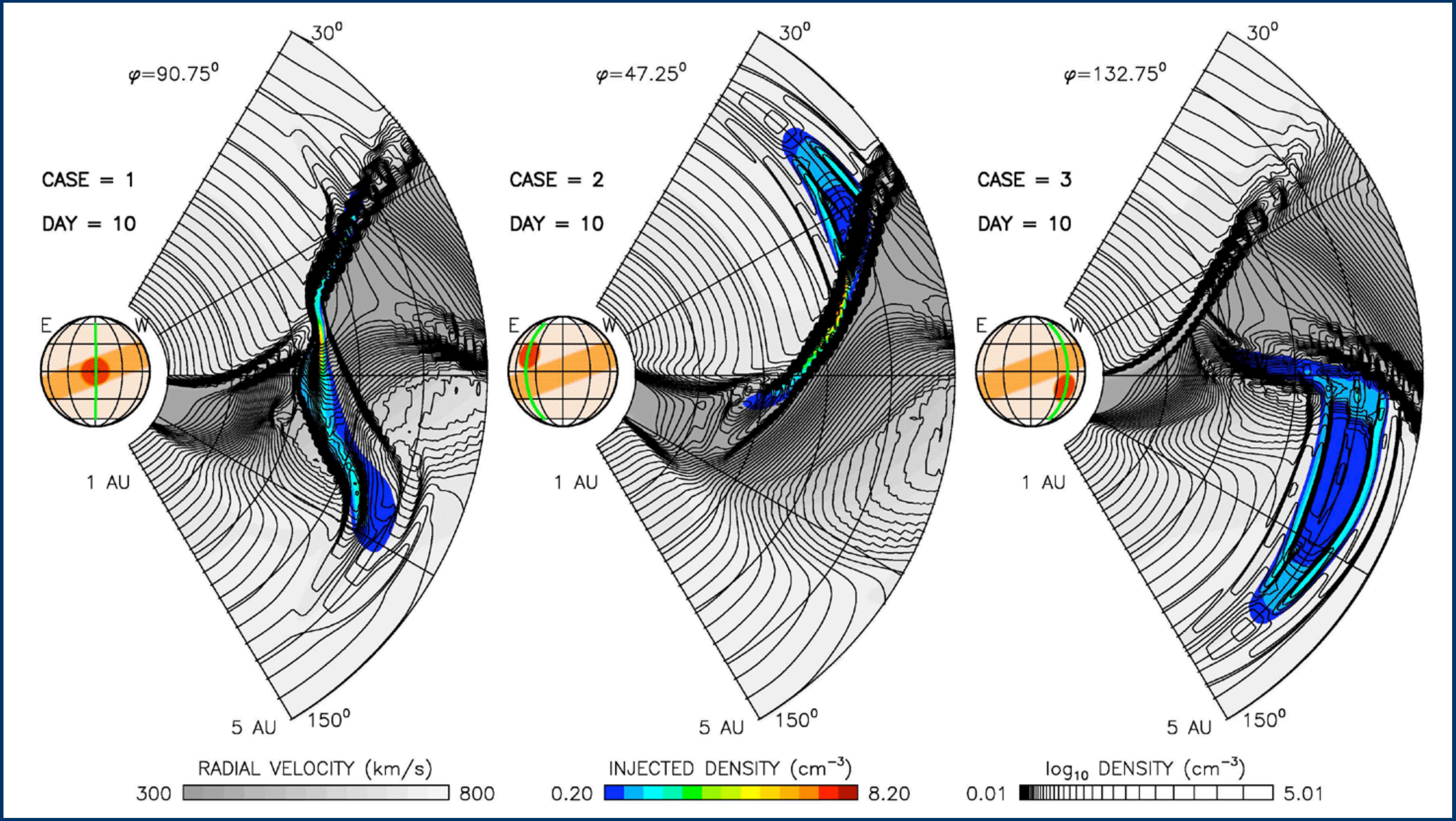


A Simple 1D Fluid Simulation of a Solar Wind Disturbance Driven by a Fast CME



Shown at time when leading edge of disturbance reaches 1 AU.

3D Simulation of CME-Driven Disturbances in a Simply Structured, Tilted Dipole Solar Wind



Colors indicate the CME material injected into the simulations

CMEs in the Solar Wind

List 1. Characteristics of Interplanetary Coronal Mass Ejections (ICMEs) at 1 AU

Common signatures:

- Counterstreaming (along the field) suprathermal electrons (energy > 70 eV)
- Counterstreaming (along the field) energetic (energy > 20 keV) protons
- Helium abundance enhancement
- Anomalously low proton and electron temperatures
- Strong magnetic field
- Low plasma beta
- Low magnetic field strength variance
- Anomalous field rotation (flux rope)
- Anomalous ionic composition (for example, Fe^{16+}, He^{+})
- Cosmic ray depression

Average radial thickness: 0.2 AU

Range of speeds: 300 - 2000 km/s

Single point occurrence frequency:

- ~72 events/yr at solar activity maximum
- ~8 events/yr at solar activity minimum

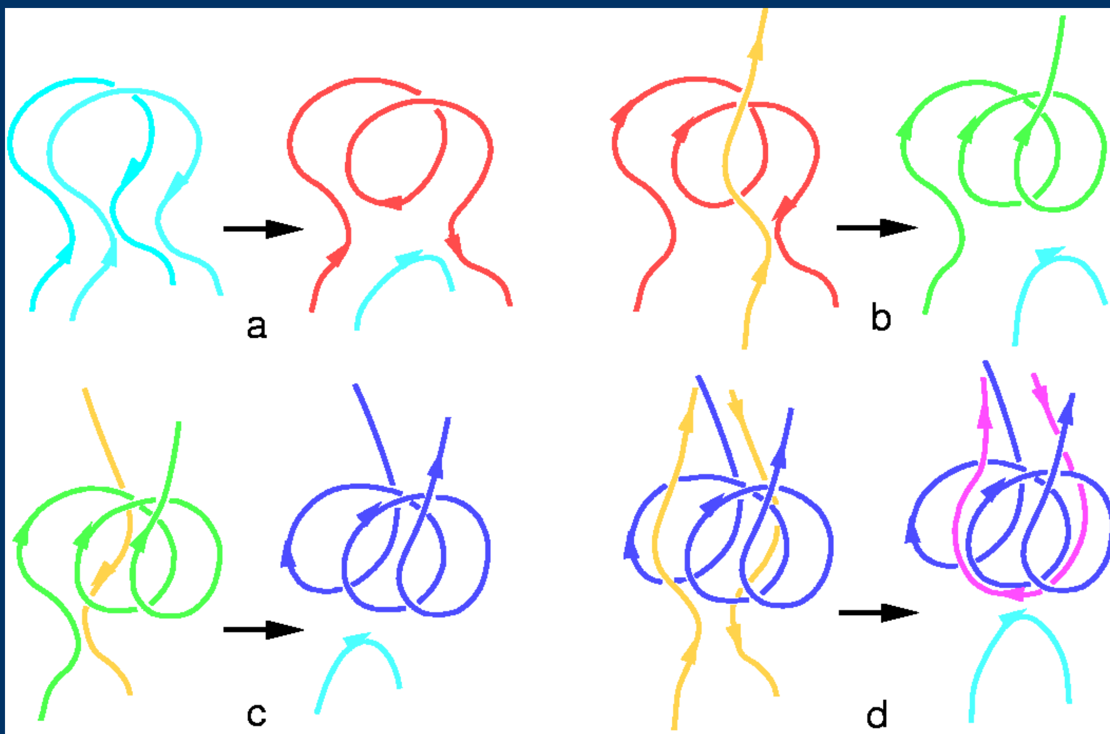
Magnetic field topology: Predominantly closed magnetic loops rooted in Sun

Fraction of events driving shocks: ~1/3

Fraction of earthward-directed events producing large geomagnetic storms: ~1/6

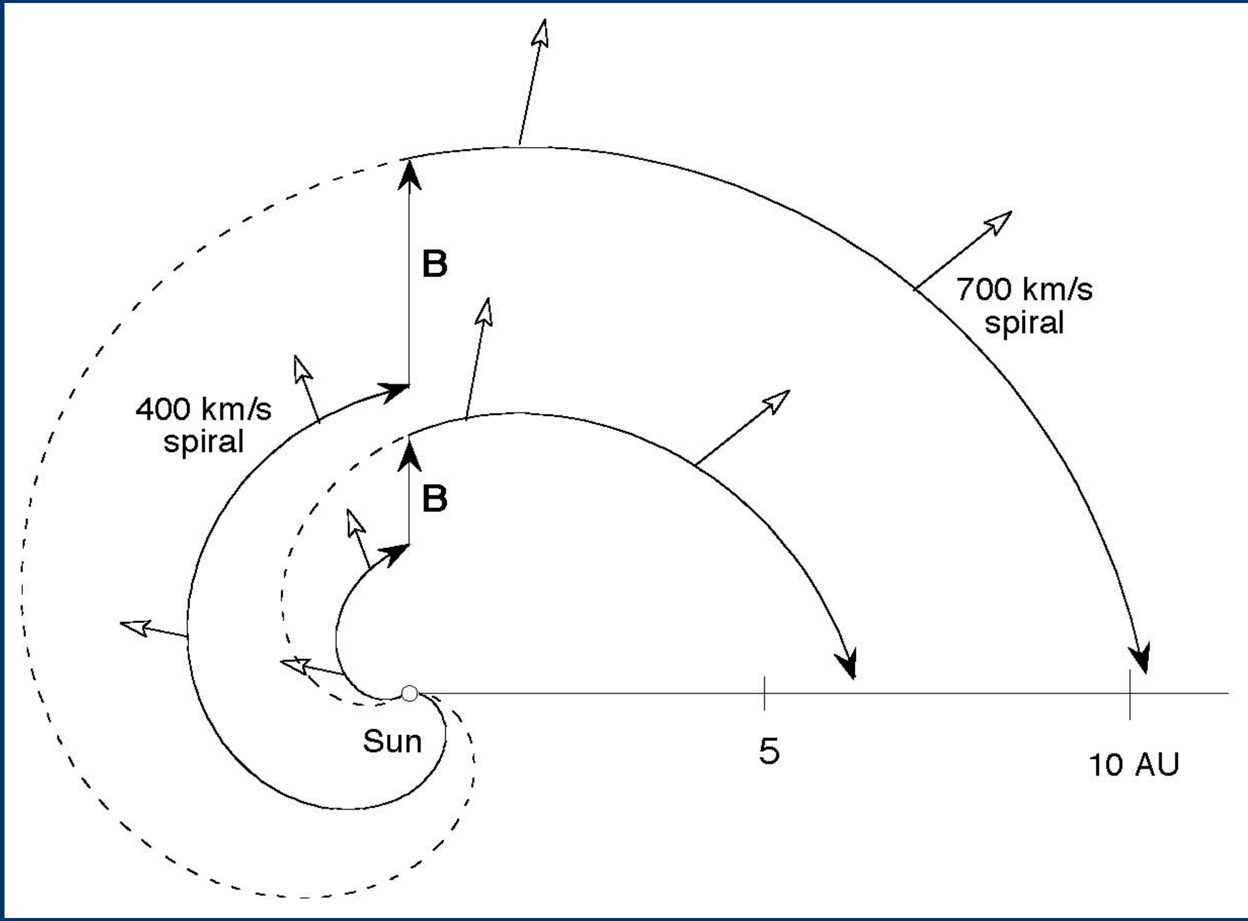
The Magnetic Field Topology of CMEs and the Problem of Magnetic Flux Balance

3D magnetic reconnection within the magnetic legs of a CME



Possible mixture of resulting field topologies

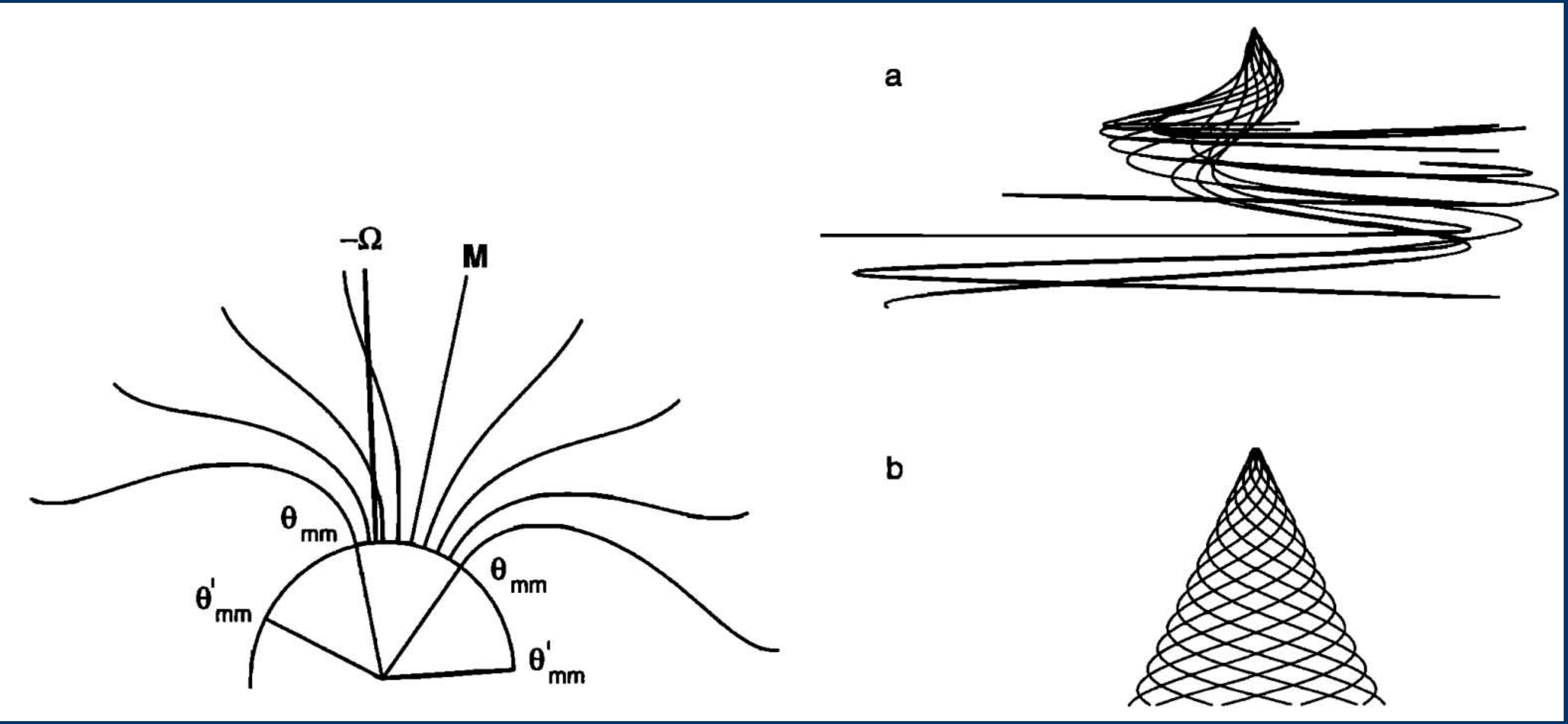
Sketch Illustrating Effect of Suddenly Decreasing the Speed of the Solar Outflow on a Particular Field Line



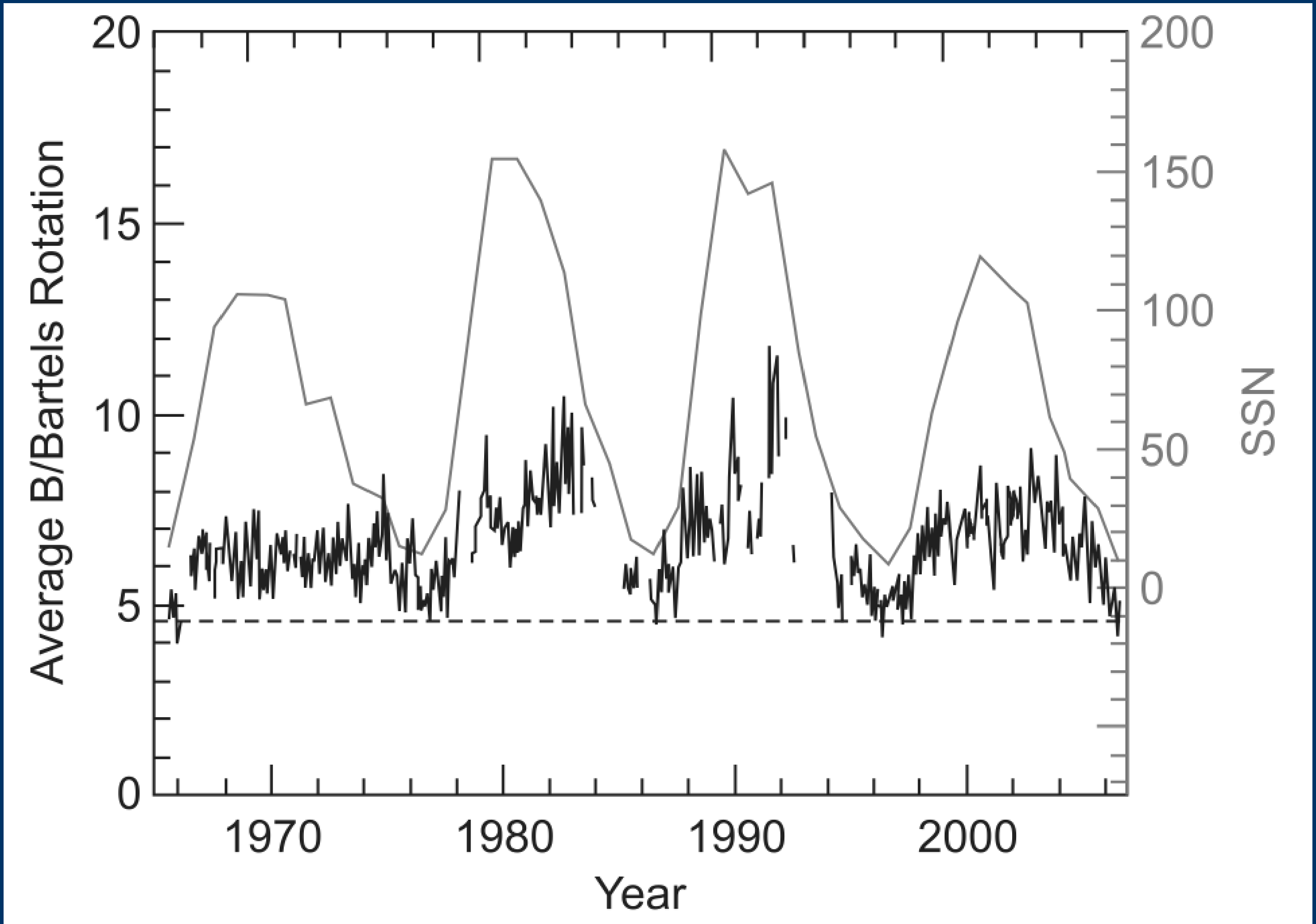
This sketch ignores dynamic effects associated with the rarefaction produced by a sudden drop in speed.

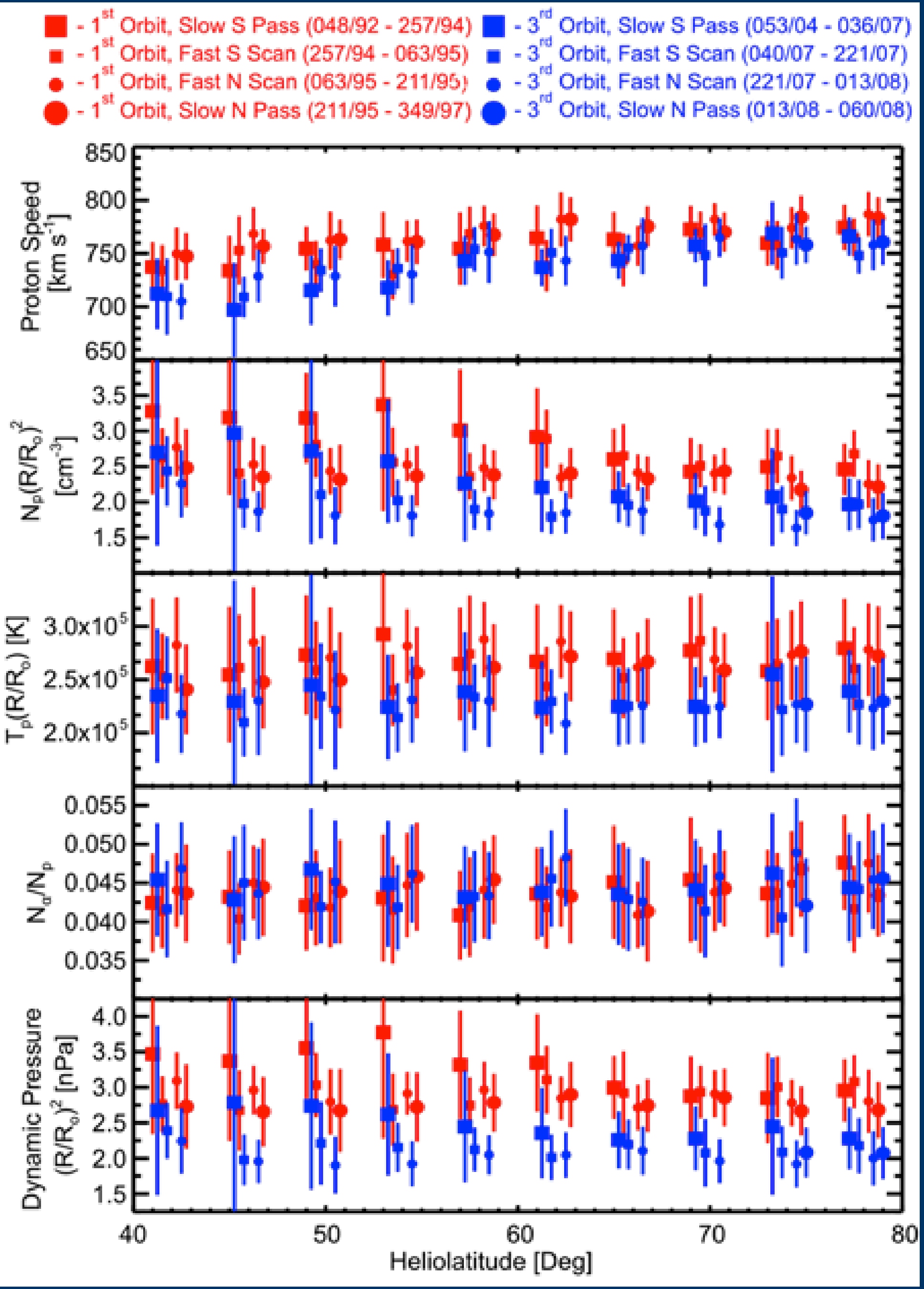
Field Lines Resulting From a Combination of Differential Rotation and a Rigidly Rotating Dipole

HMF lines originating from 70˚ S in Fisk's model (a) and Parker's model (b).



Variation of Solar Rotation-Averaged Magnetic Field Strength Over 4 Solar Activity Cycles

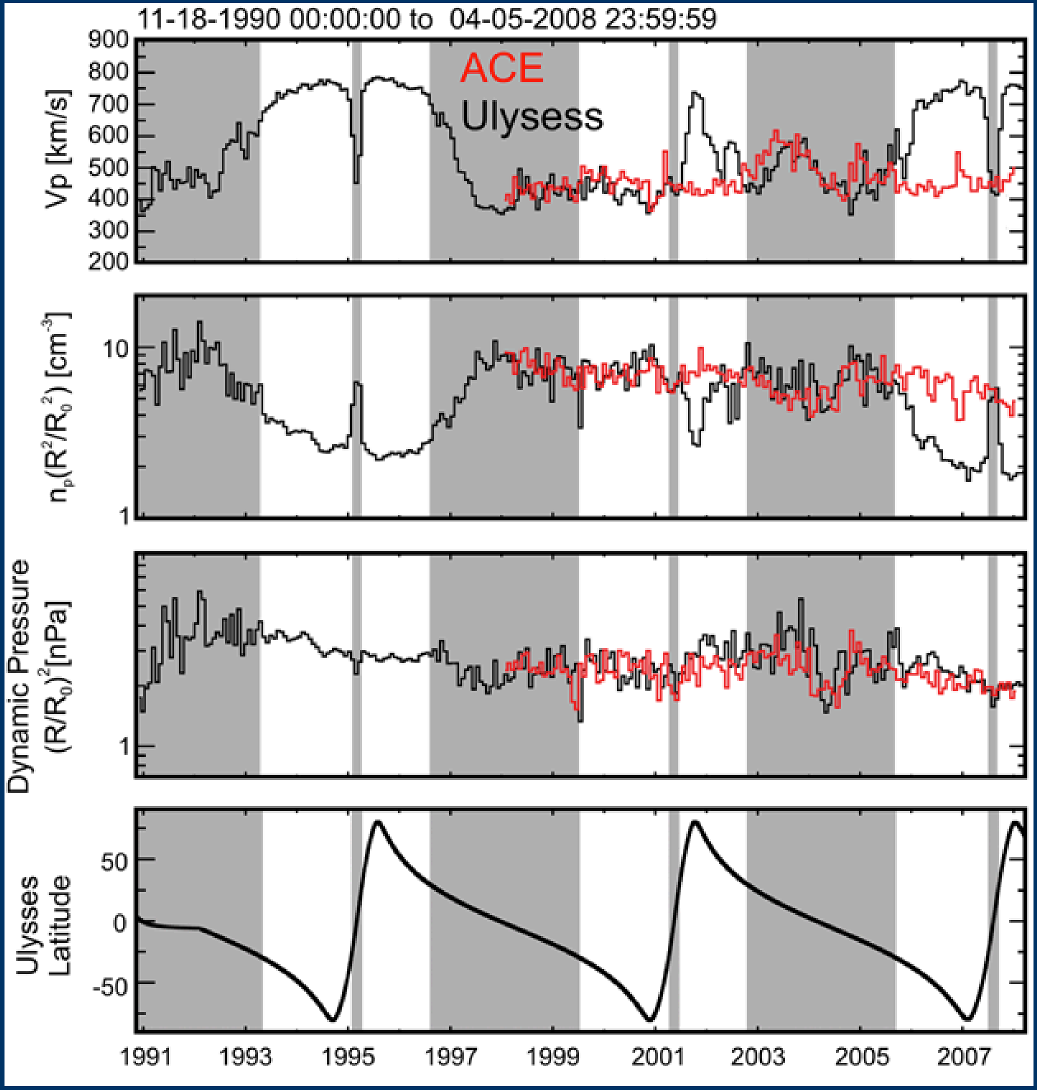




Ulysses Data

Comparison of Solar Wind Between Cycles 22 (red) and 23 (blue) as Function of Heliolatitude

Lower Particle Density and Dynamic Pressure Near Most Recent Solar Minimum



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