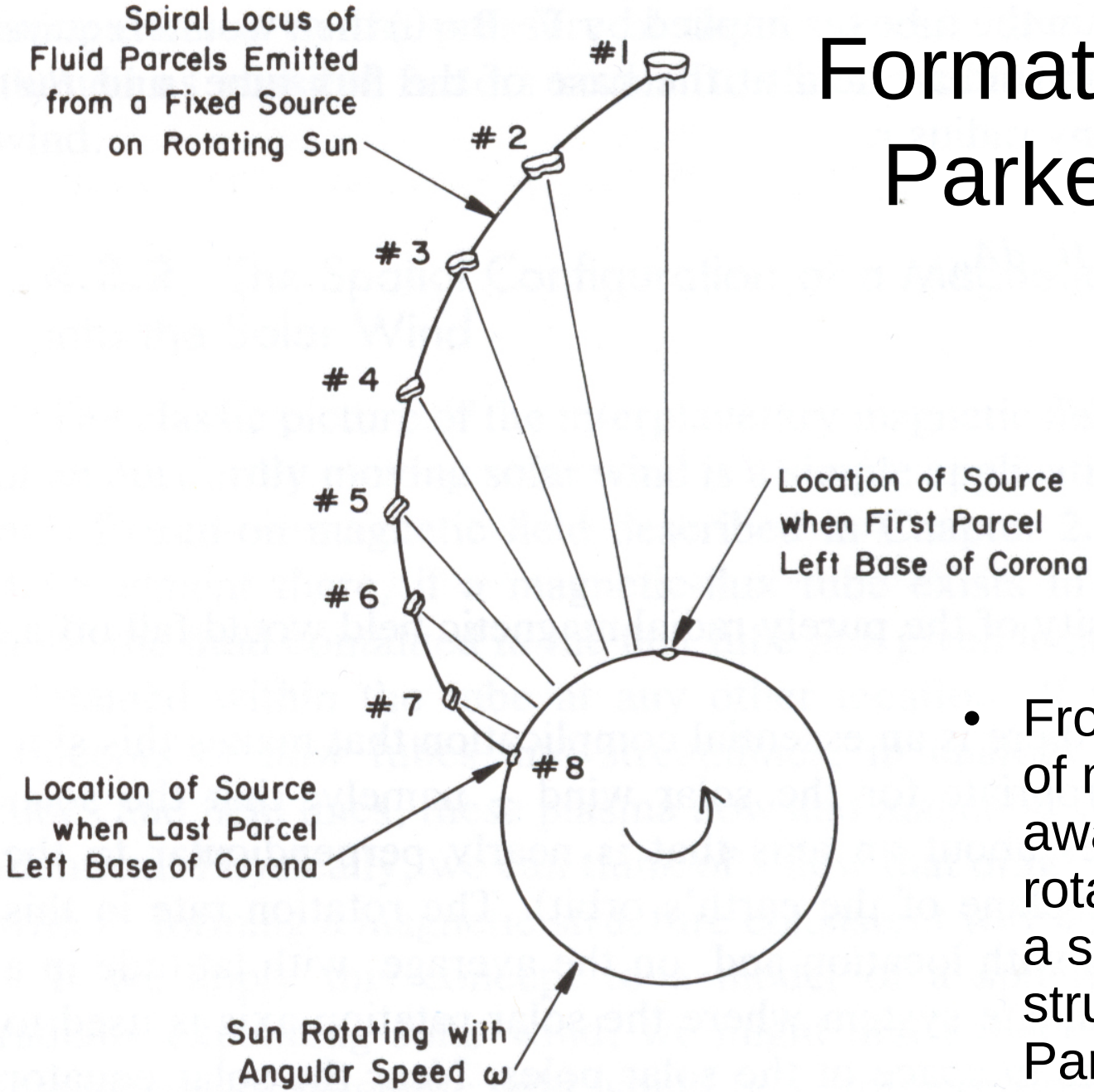
Average properties of the Solar Wind at Earth Orbit

- The solar wind is the extension of solar corona into interplanetary space:

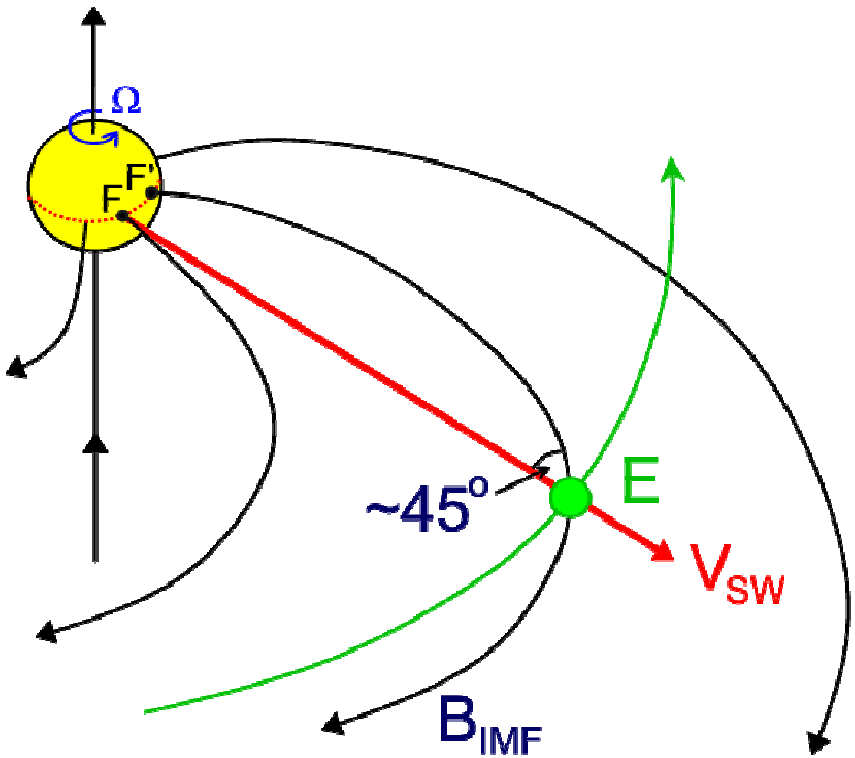
Density ~ $7 cm^{-3}$ (~ 4% He^{2+})
Speed ~ 450 km s^{-1}
Proton Temp. ~ 1.2×10^5 K
Electron Temp. ~1.4×10^5 K
B-Field Strength ~ 7 nT
$M_S \sim M_A \sim 2\text{-}10$
$\lambda_{MFP} \sim 1$ AU

Formation of the Parker Spiral



- Frozen-in transport of magnetic field away from the rotating Sun creates a spiral field structure – the Parker Spiral

Average IMF Strength and Direction



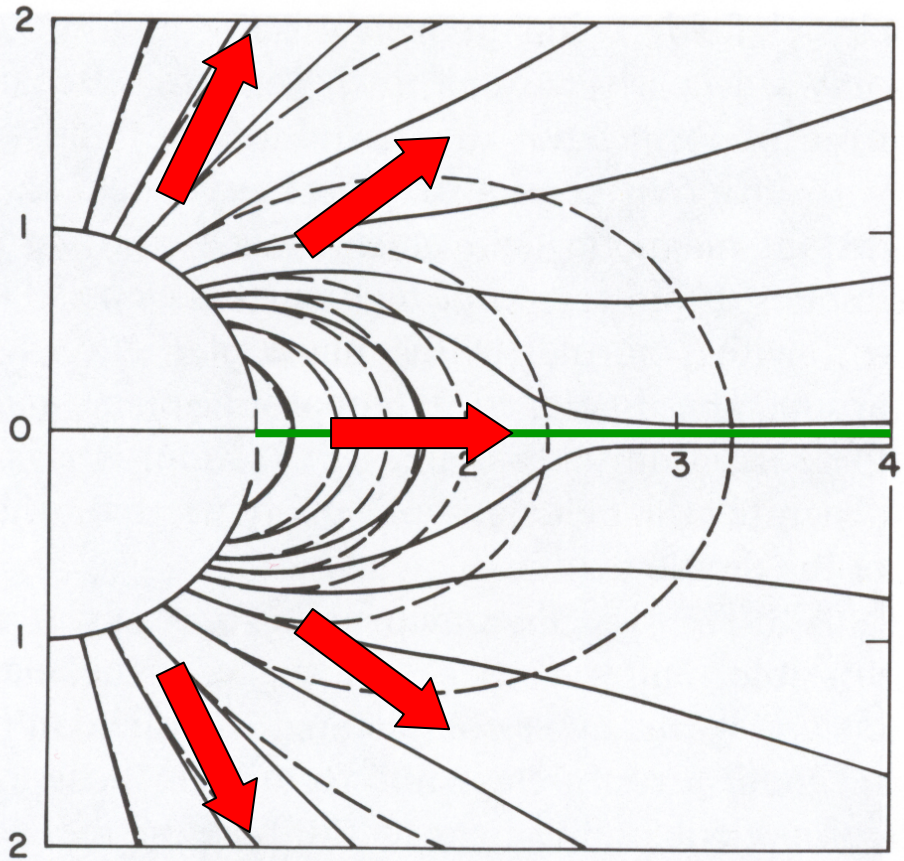
At:	Angle:	Strength:
Mercury	21°	35 nT
Earth	45°	7 nT
Mars	56°	4 nT
Jupiter	80°	1 nT
Neptune	88°	0.2 nT

6.3 Real Solar Wind Structures

- Large Scale:
  - Heliospheric Current Sheet and Sector Structure
  - Fast/Slow Streams
  - Corotating Iteraction regions (CIRs)
  - Coronal Mass Ejections
  - Magnetic Clouds
- Small Scale:
  - Waves and Turbulence
  - Discontinuities
  - Shocks

(See also last part of Chapter 4 of Kivelson and Russell.)

a) Origin of the Heliospheric Current Sheet

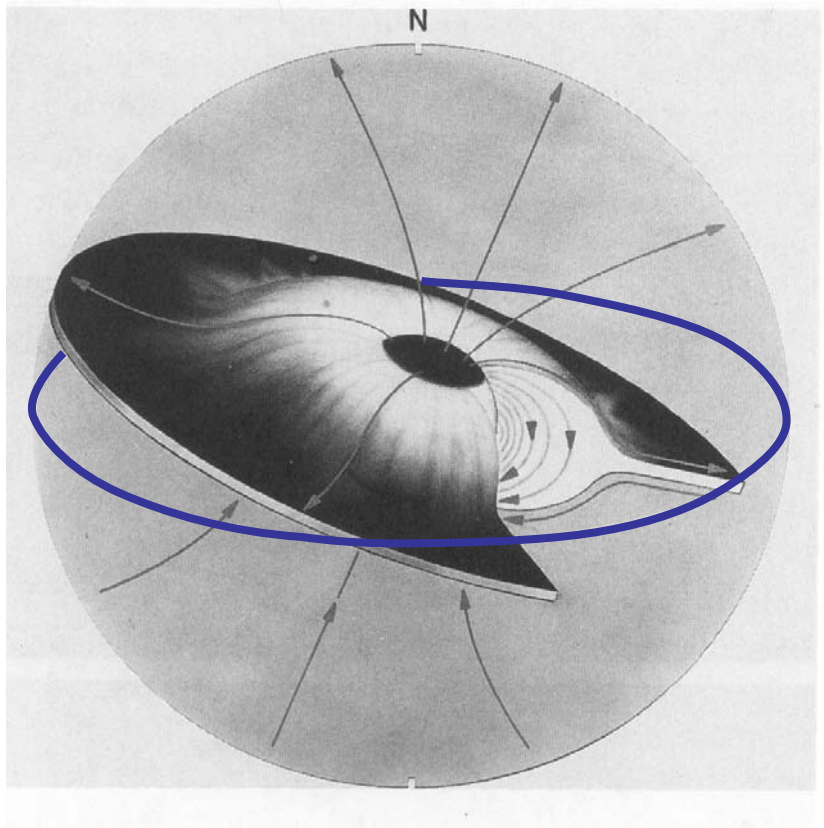


Solar wind outflow

Dipolar field structure

Extended field structure

Heliospheric Current Sheet

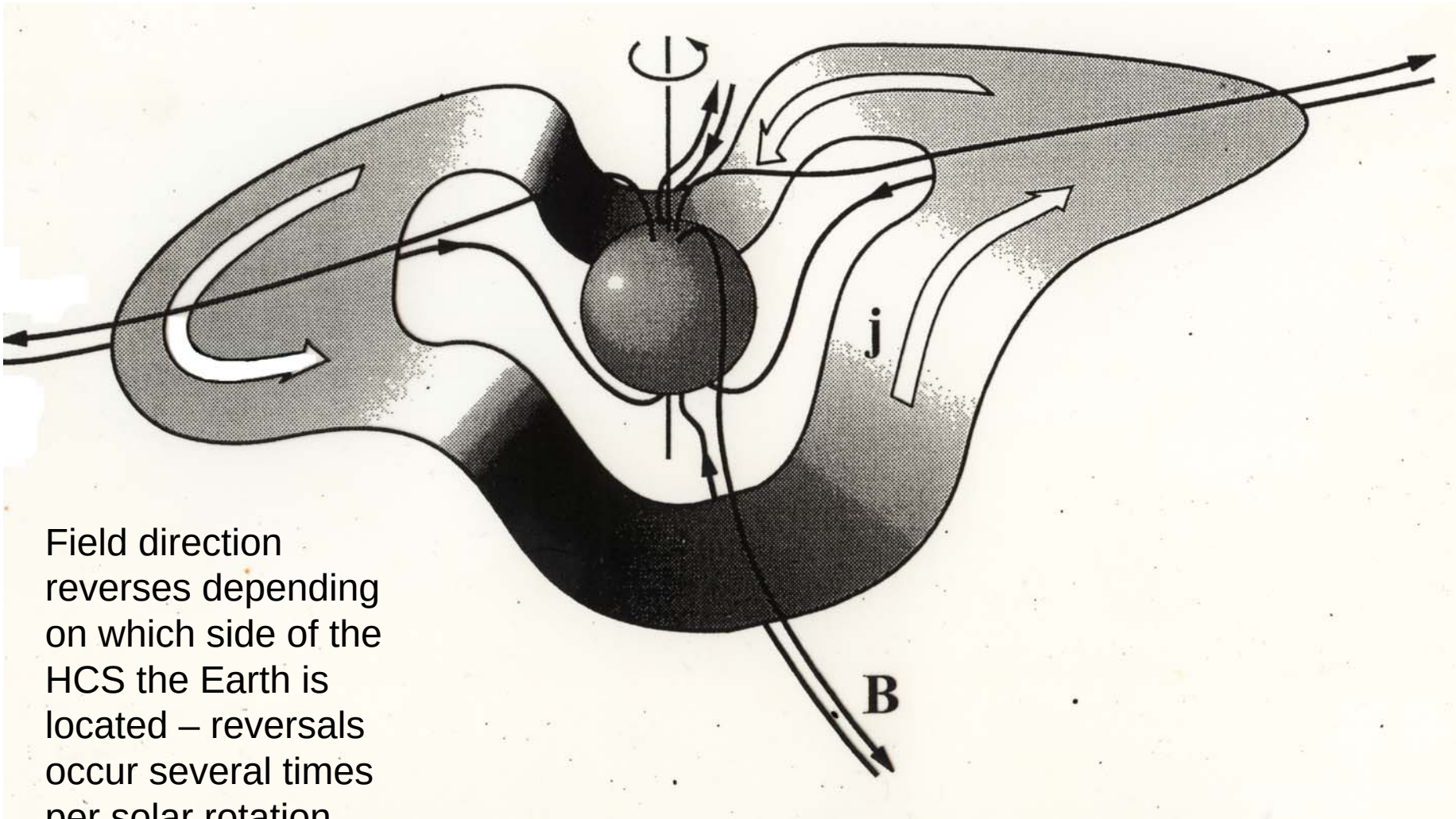


Solar magnetic field wobbles w.r.t. Earths orbital plane (——). Hence the Earth is sometimes above and sometimes below Heliospheric CS.

Sector Structure

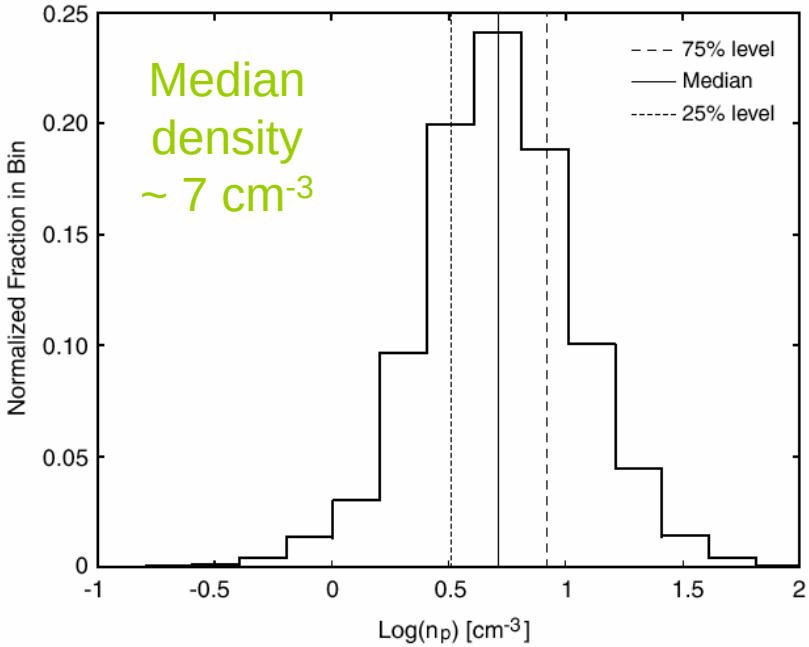
The current sheet separating magnetic field from N and S poles of Sun becomes warped – hence sometimes Earth is above the current sheet, at other times below – we see a sector structure in the B-field.

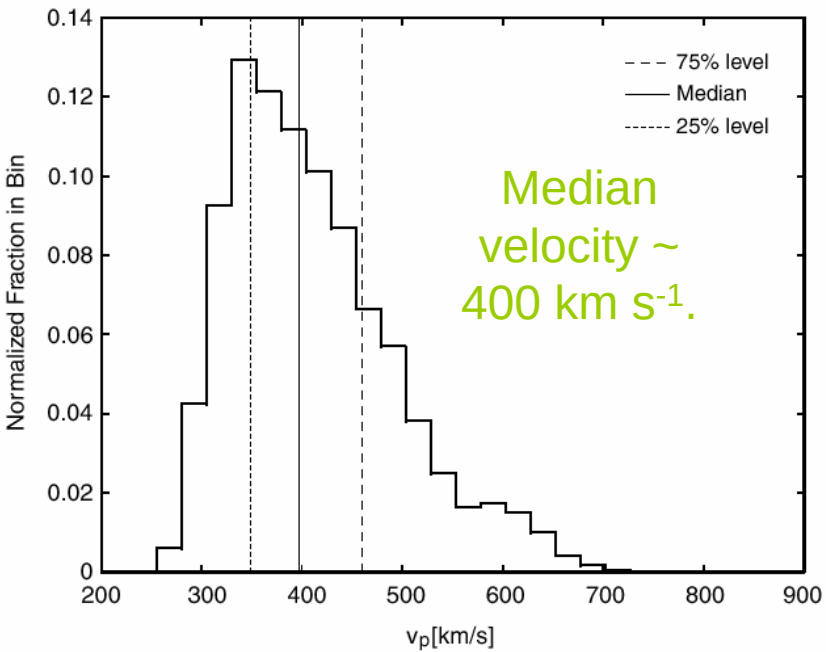
Actually more complicated still…

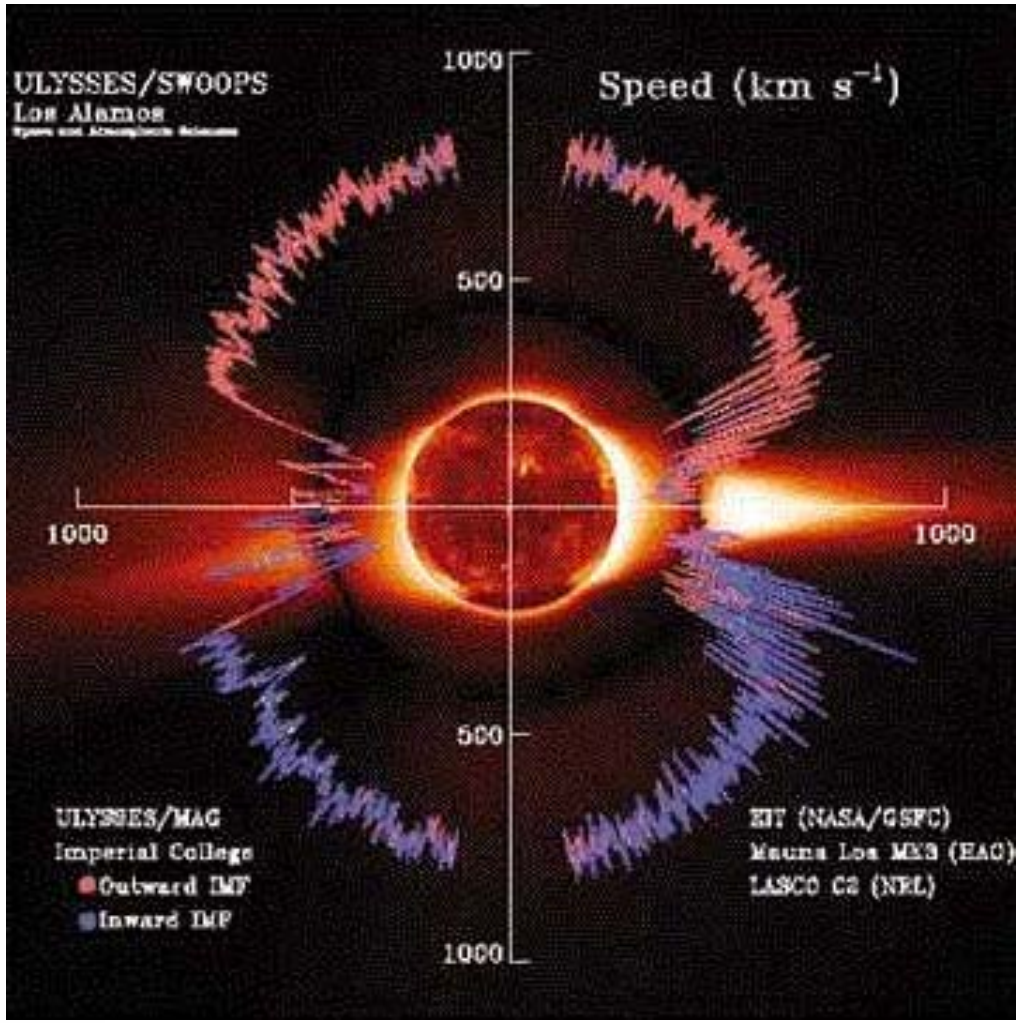


Field direction reverses depending on which side of the HCS the Earth is located – reversals occur several times per solar rotation.

b) 2-speed Solar Wind

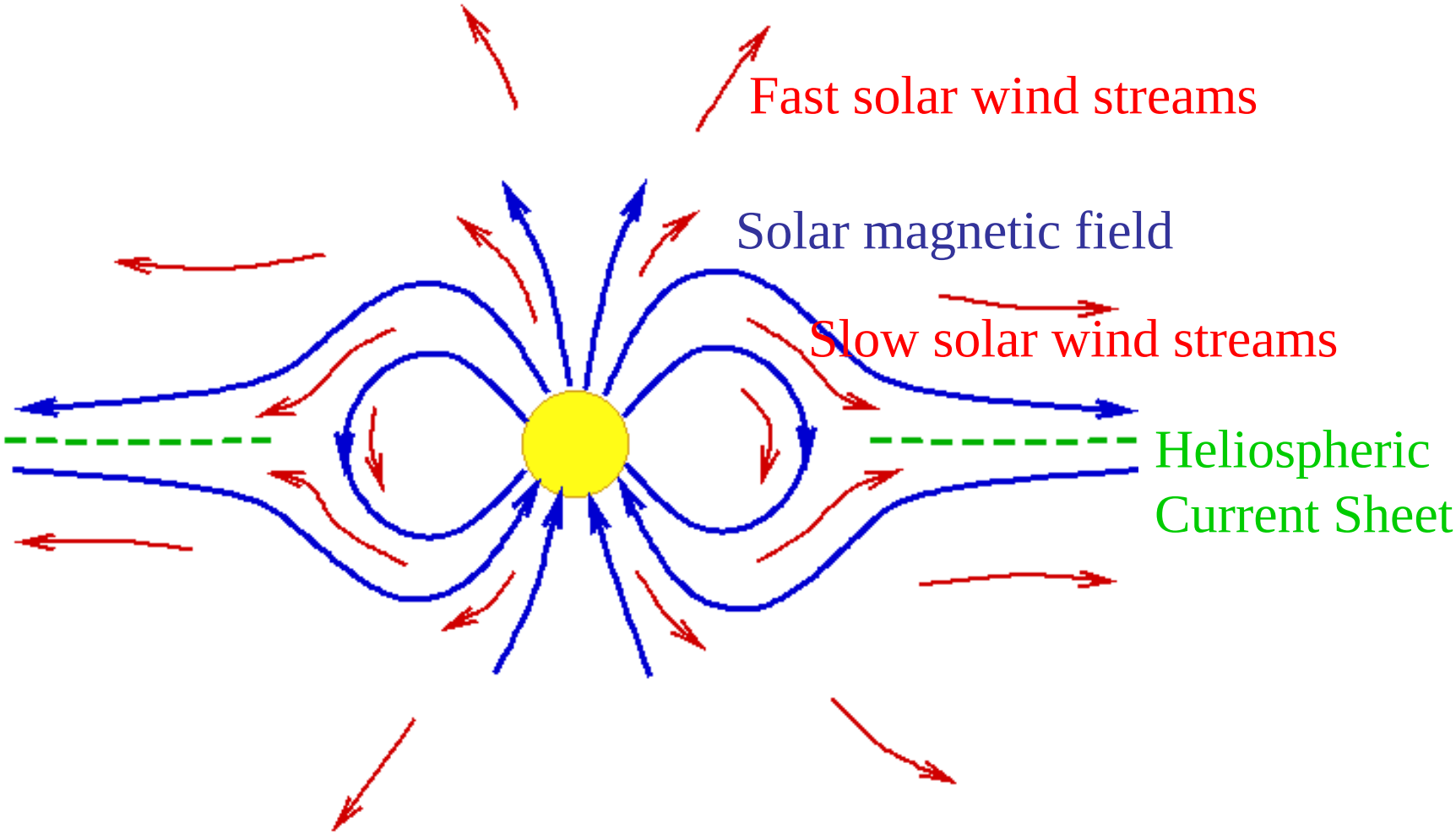


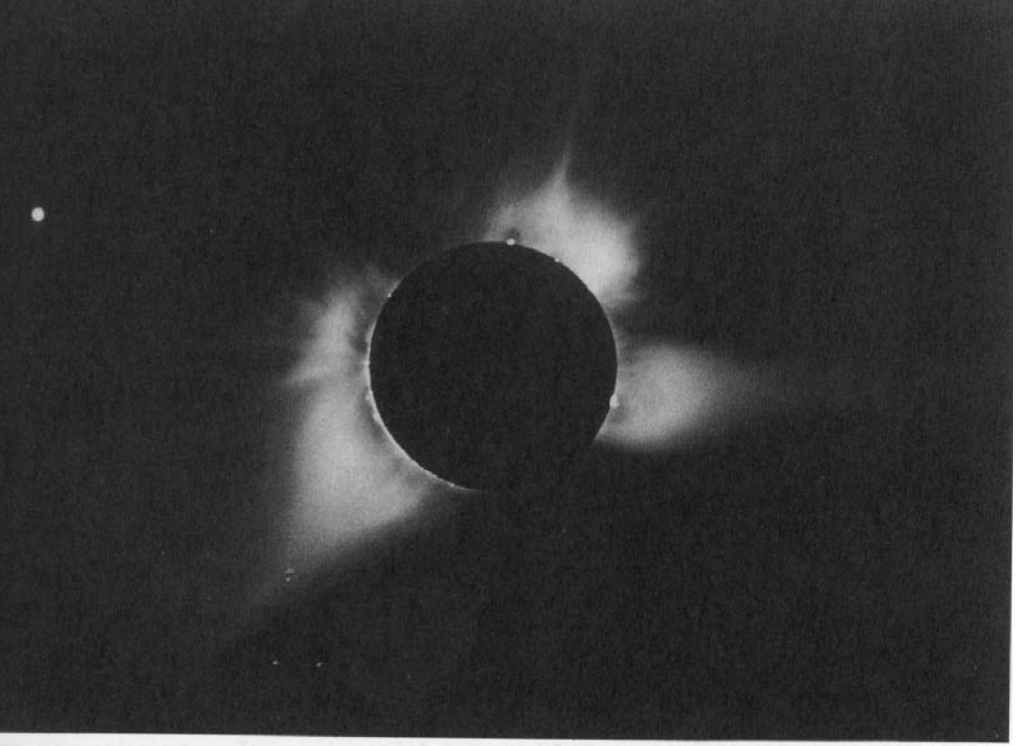


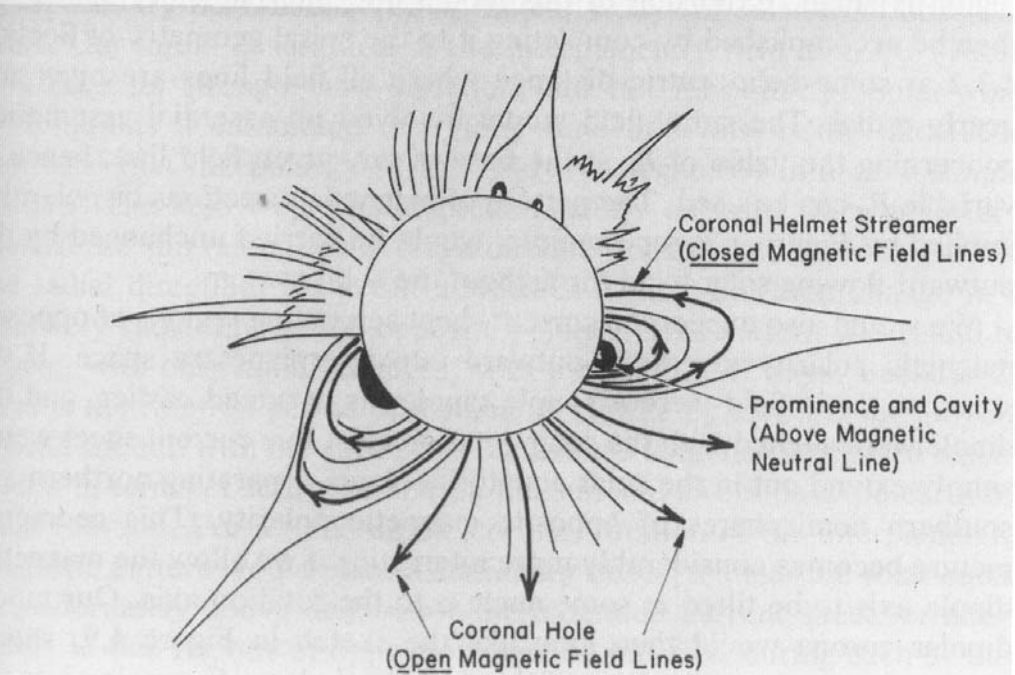


Above plot shows solar wind speed measured during an orbit over the poles of the Sun – solar wind emitted from polar coronal holes is much faster, averaging 800 km s^{-1}.

Large-Scale Magnetic Structure of the Outer Corona



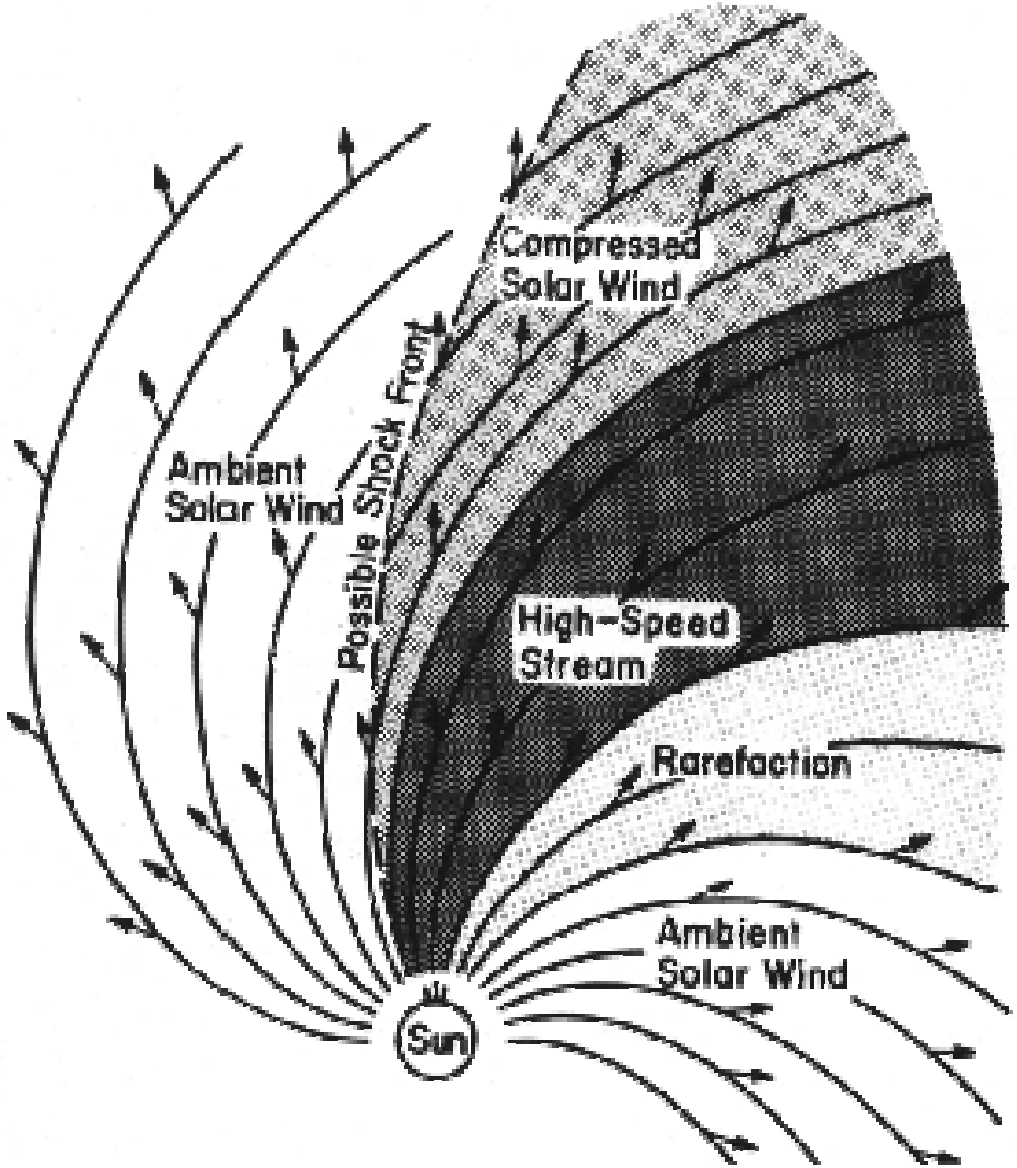




Real Coronal Structure

- The real Sun is a complicated and disordered mix of open and closed field lines;
- ‘Coronal Holes’ appear dark and are the origin of fast solar wind
- Brighter regions, indicating higher plasma density, are the source of slow solar winds

c) Co-rotating interaction regions



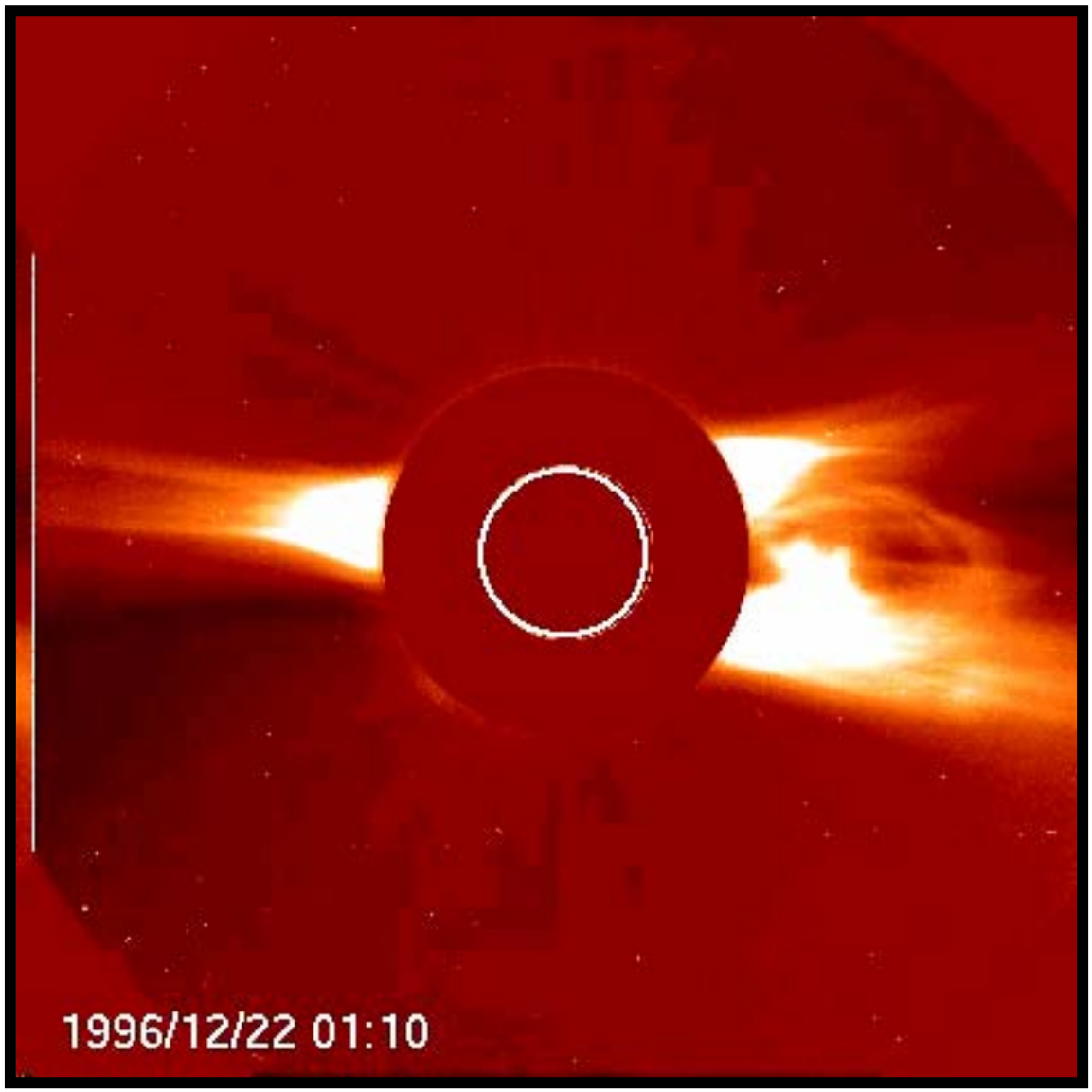
Fast solar wind streams catching up with slower streams cannot mix with the slower stream (frozen-out) Hence the slow stream is compressed and a shock may form (see next section). Slow wind behind the fast wind may cause a rarefaction region of reduced density. These structures may persist for many months and are thus observed every solar rotation (i.e. they corotate with the Sun)

d) Solar cycle effects

- The solar field switches every ~11 years
- The solar wind and IMF properties are particularly variable during the switch
  - Solar Maximum
- More regular in between times
  - Solar Minimum

(c.f. sunspot numbers as a measure of the activity)

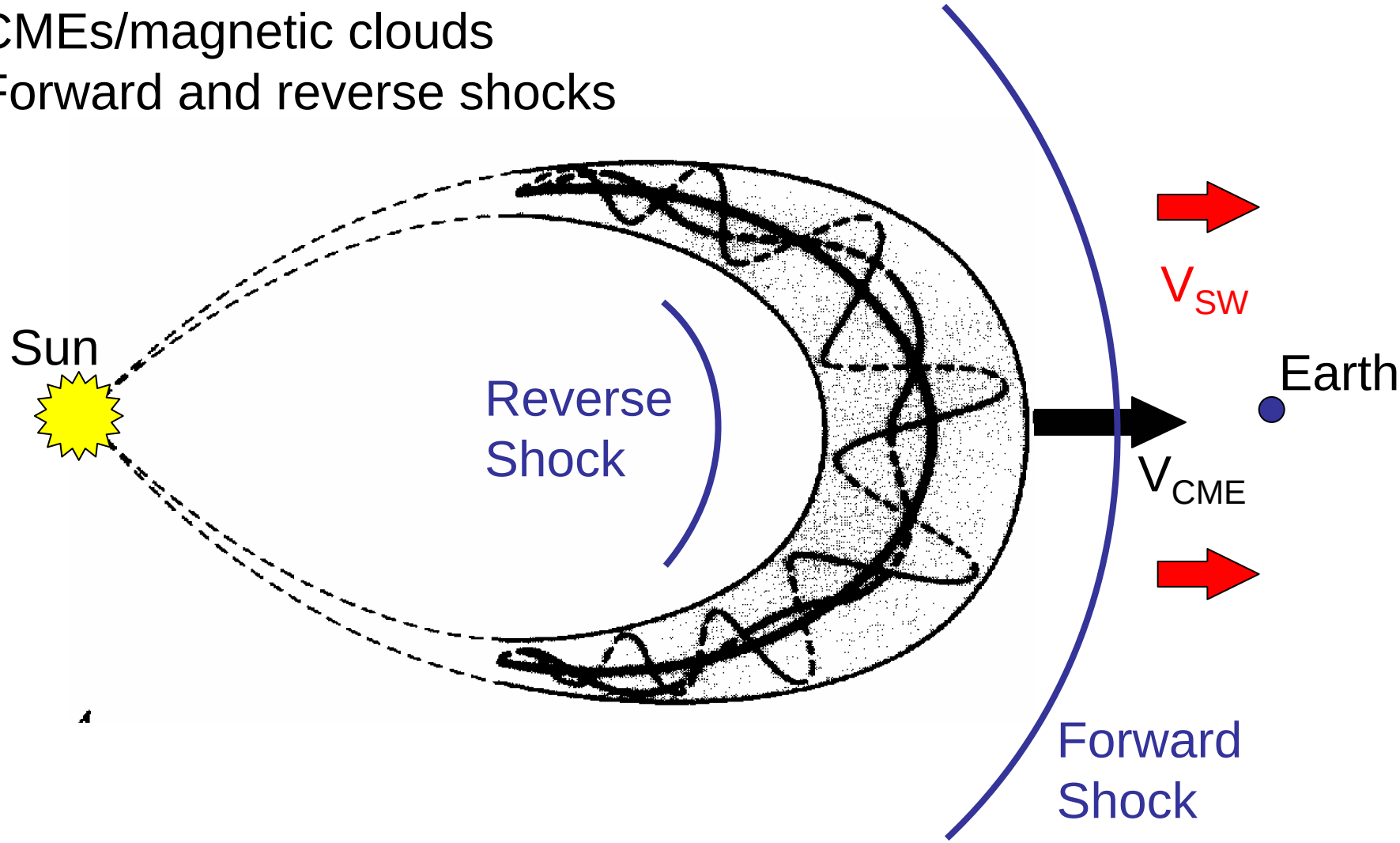
e) Coronal Mass Ejections (CMEs)



- Regions of closed solar magnetic field lines (Helmet streamers are occasionally explosively released as a CME (~10^{12} kg);
- These travel out through interplanetary space and are often associated with ‘Magnetic clouds’ ;
- Those passing Earth may cause magnetic storms (see later).

CMEs/Magnetic Clouds

- CMEs/magnetic clouds
- Forward and reverse shocks

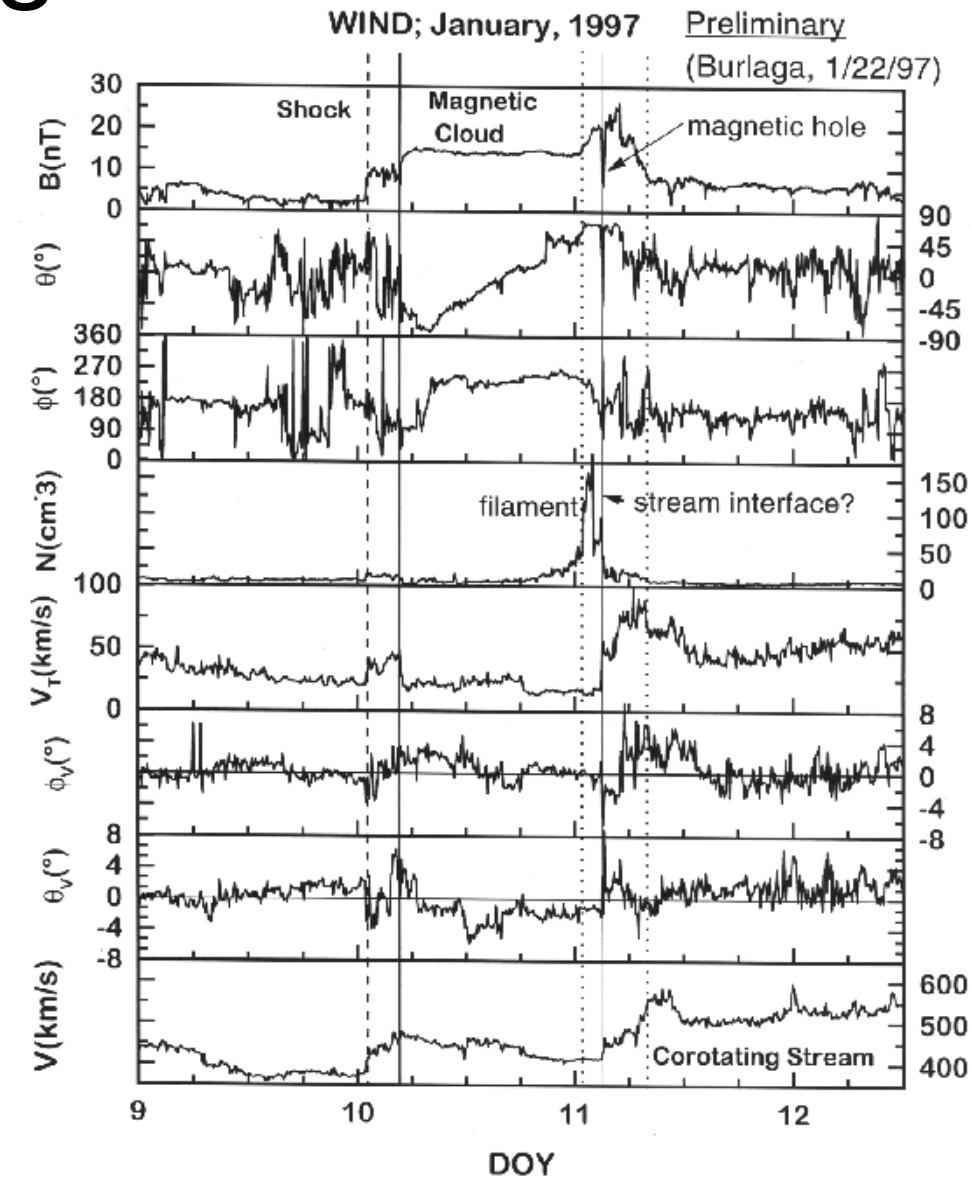


CMEs/Magnetic Clouds

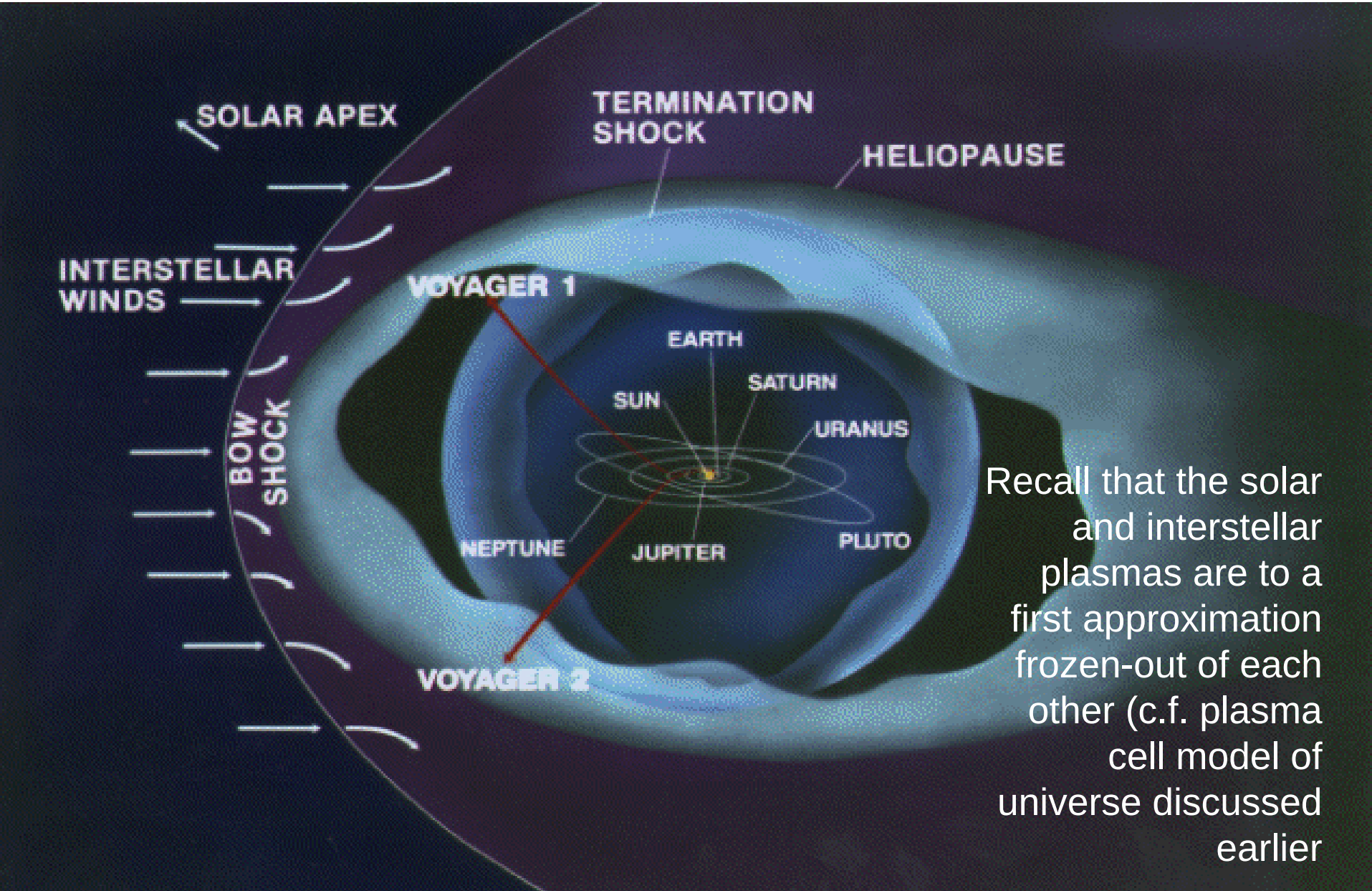
- CMEs/magnetic clouds
- Shocks:

Recall that plasmas of different sources cannot mix (frozen in to their own magnetic fields) – so if one fast (M_S,M_A >> 1) moving plasma runs into a slower moving plasma a shock must form.

(Will cover in more detail in Section 7 shortly)



f) Heliopause and Termination Shock



Recall that the solar and interstellar plasmas are to a first approximation frozen-out of each other (c.f. plasma cell model of universe discussed earlier