In-Situ Observations in the Heliosphere

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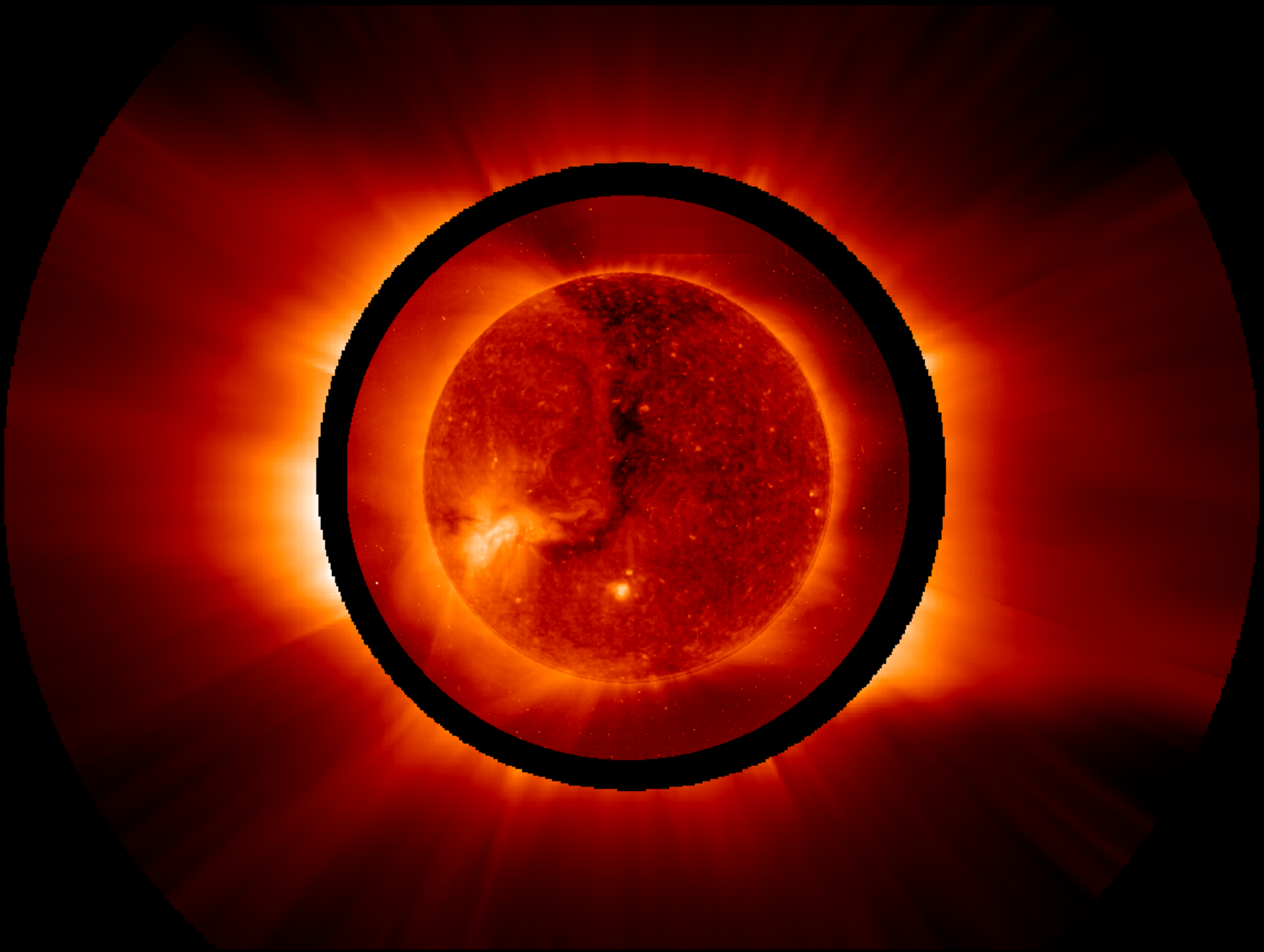
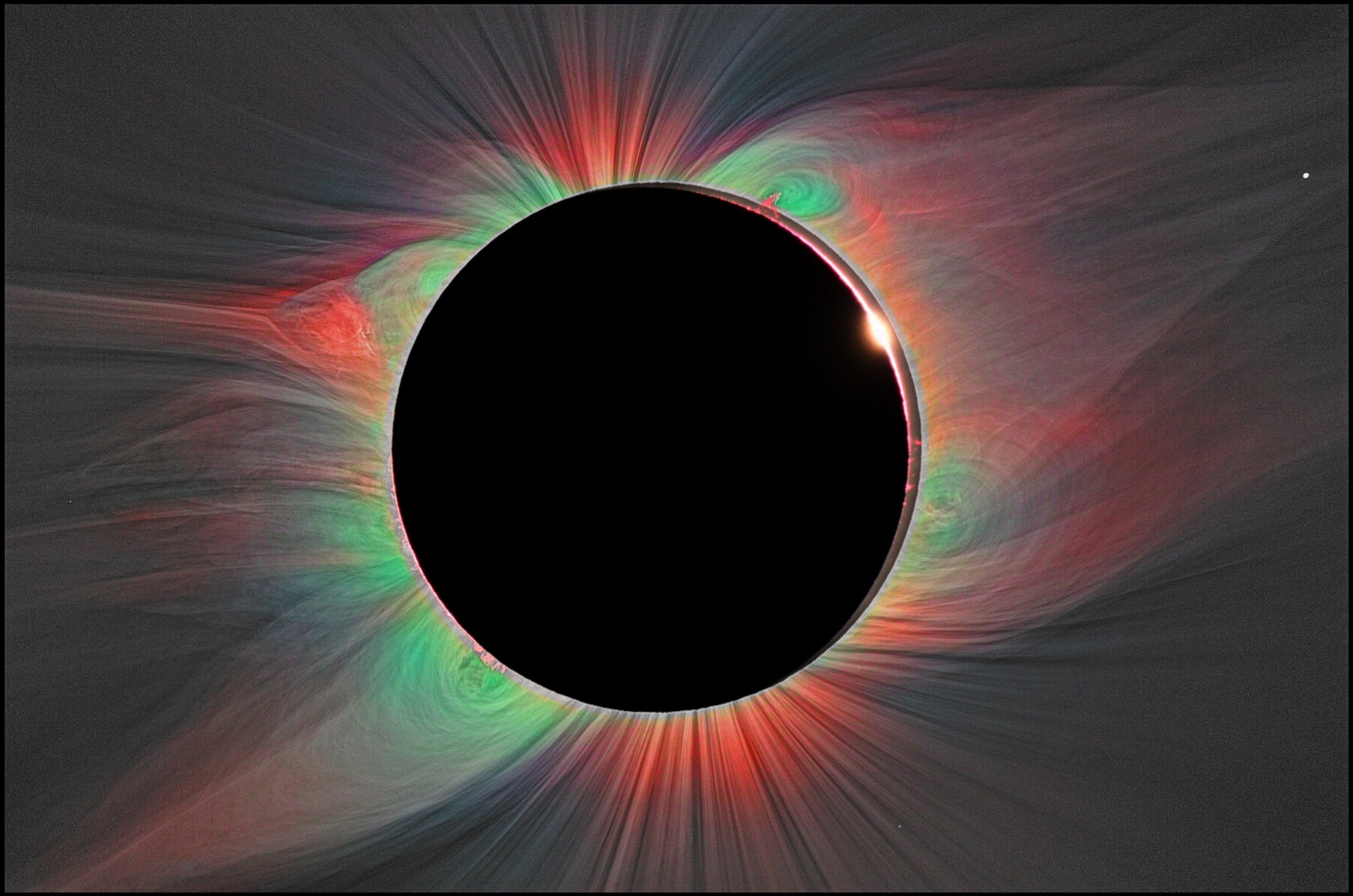
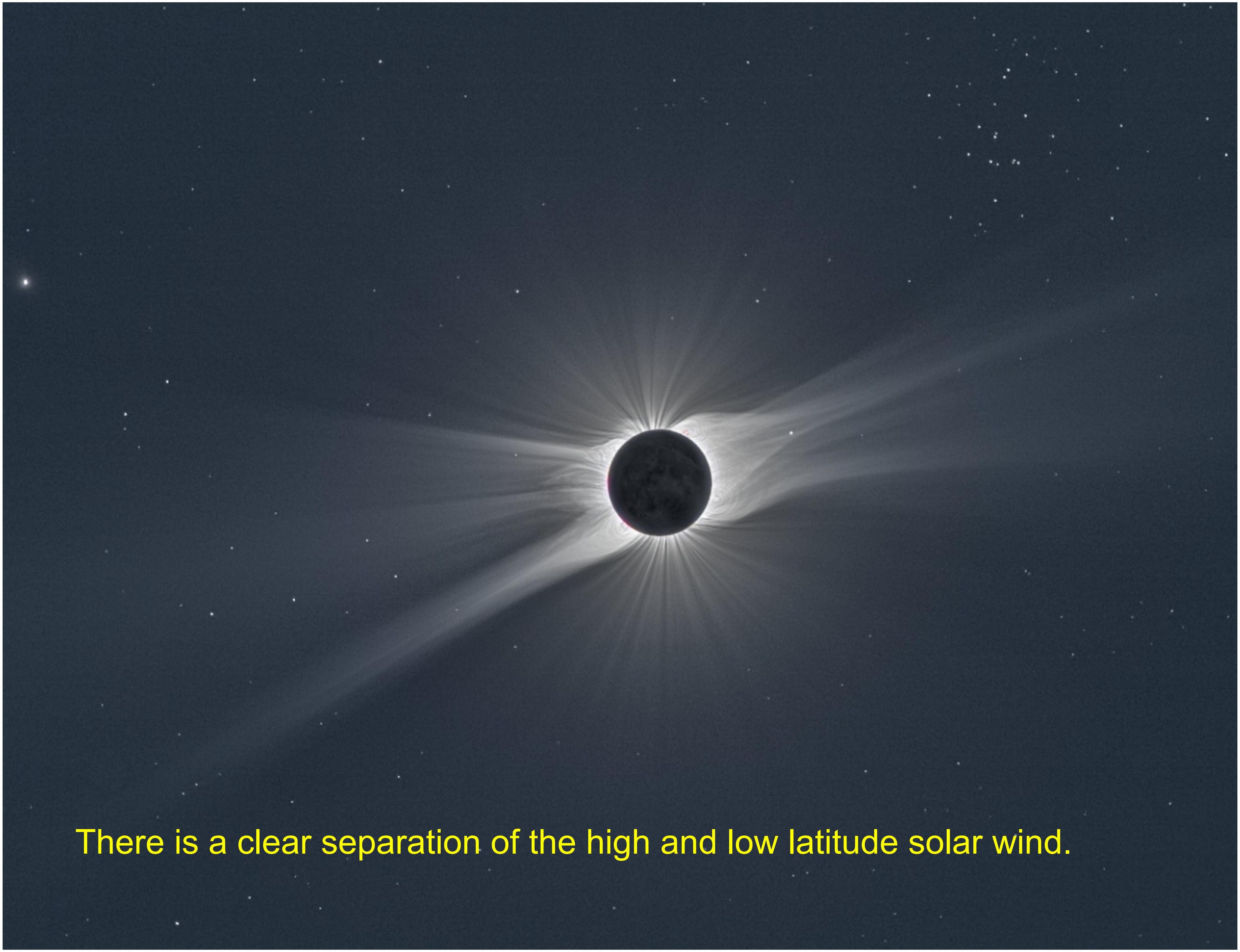
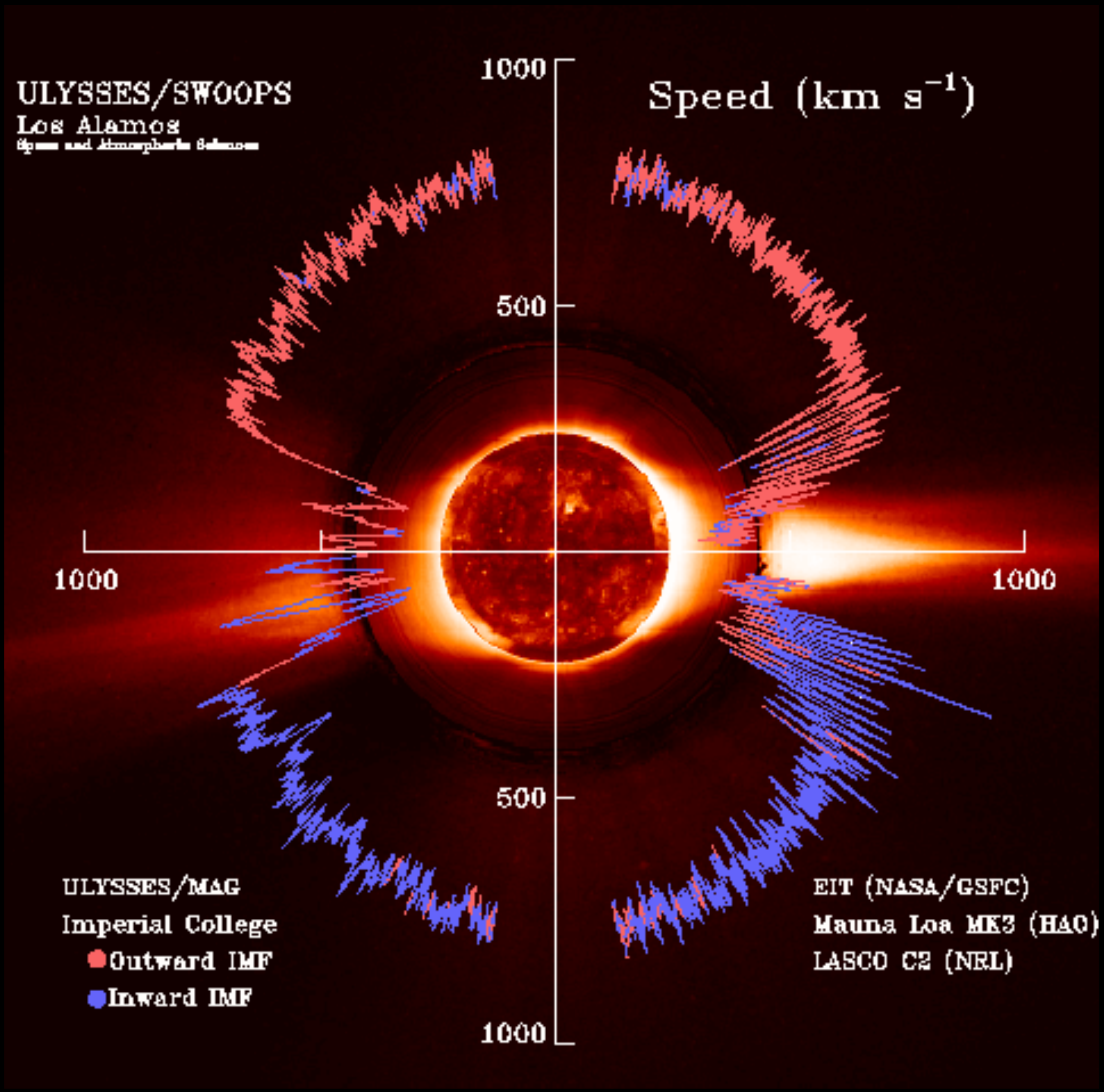


This SOHO extreme ultraviolet (EIT) and scattered visible light (LASCO) composite image shows the outward streaming solar corona forming the supersonic solar wind



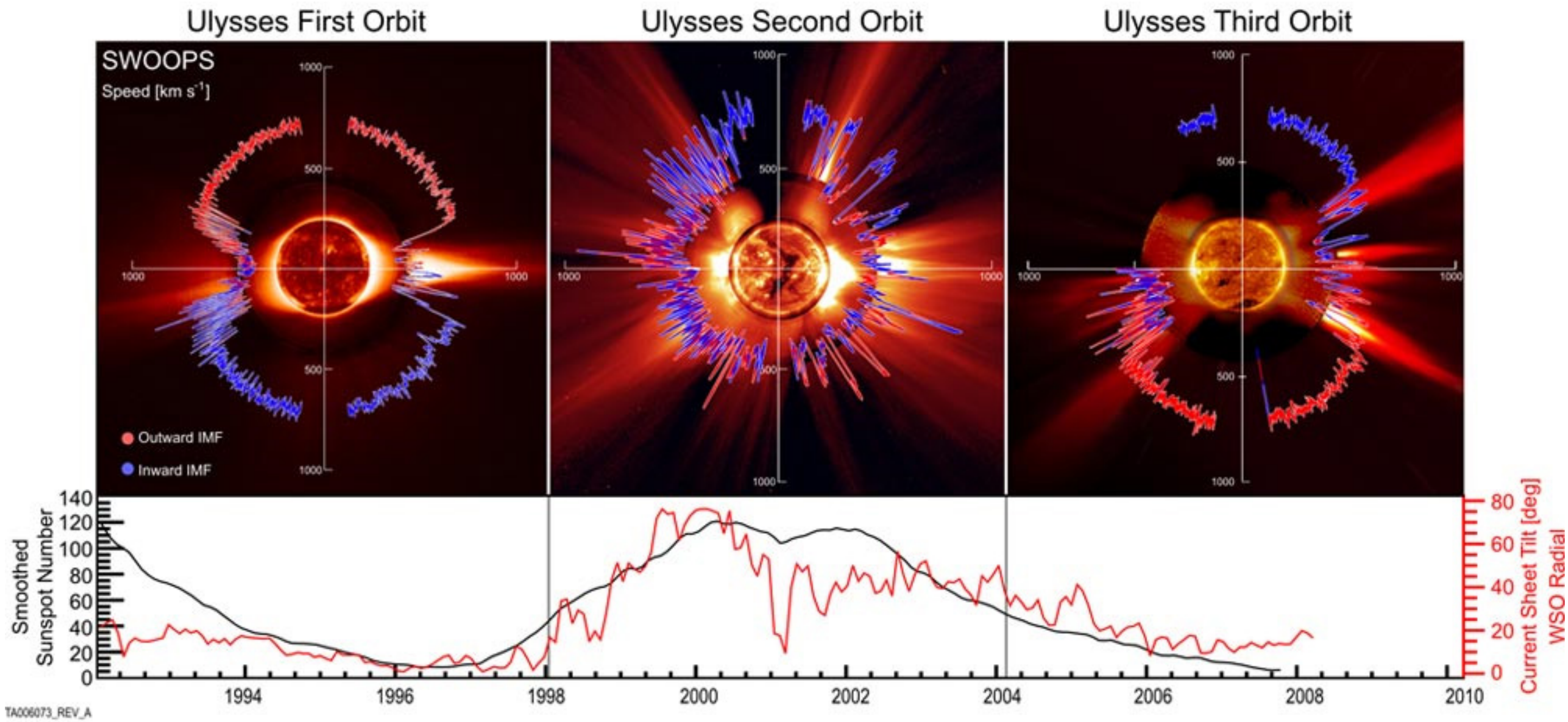
Eclipse: RED 1.1 10^6 K *Iron X-XI (RED)* GREEN 2 10^6 K Iron *XIII-XIV (GREEN)*
This eclipse image shows the magnetic topology of the corona.


There is a clear separation of the high and low latitude solar wind.



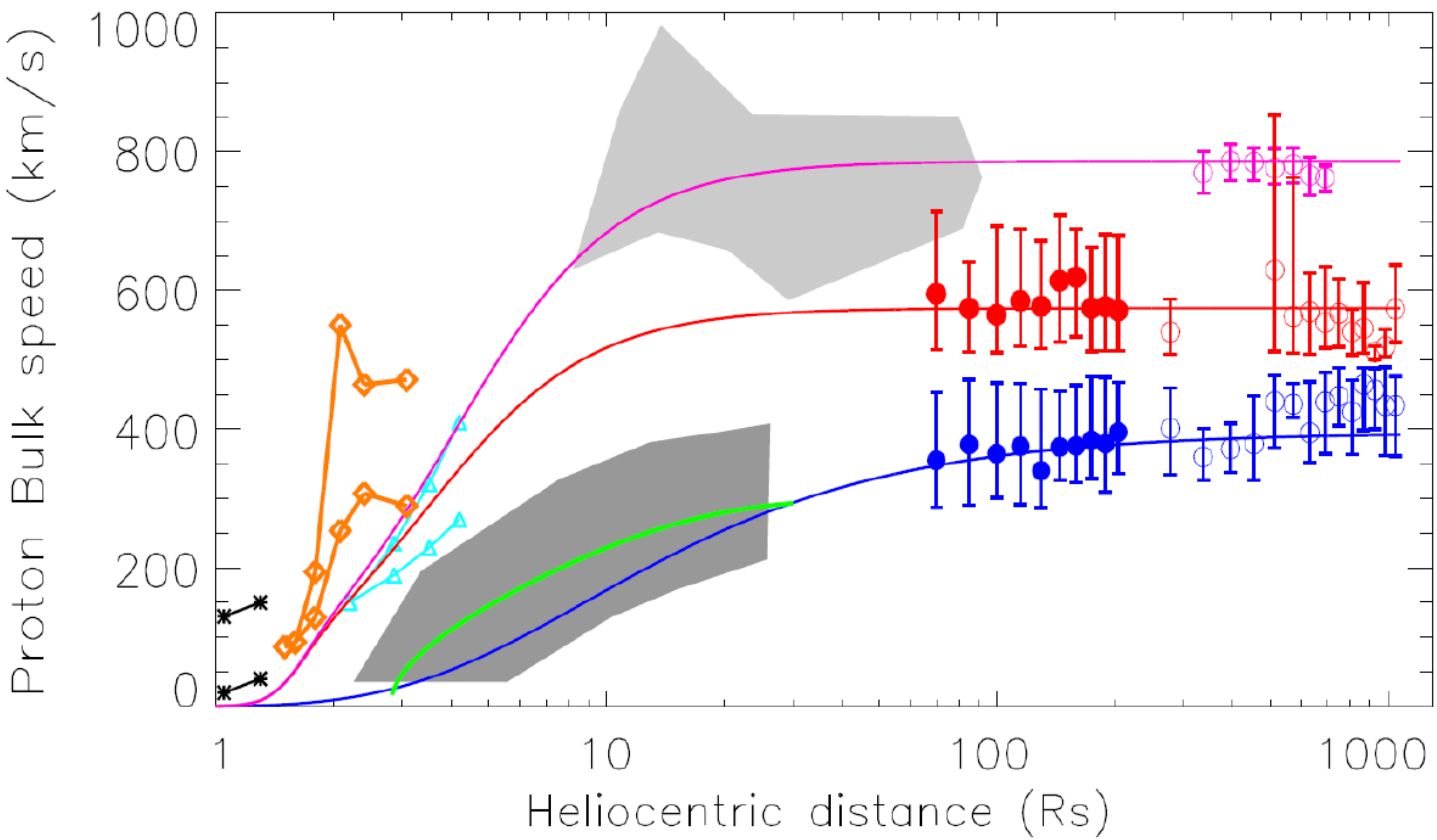
The Ulysses mission, orbiting the Sun in a plane nearly perpendicular to the ecliptic,has verified that the quiet solar wind is indeed structured into a high speed polar flow and a slower and more turbulent equatorial region.

Fast and Slow Solar Wind



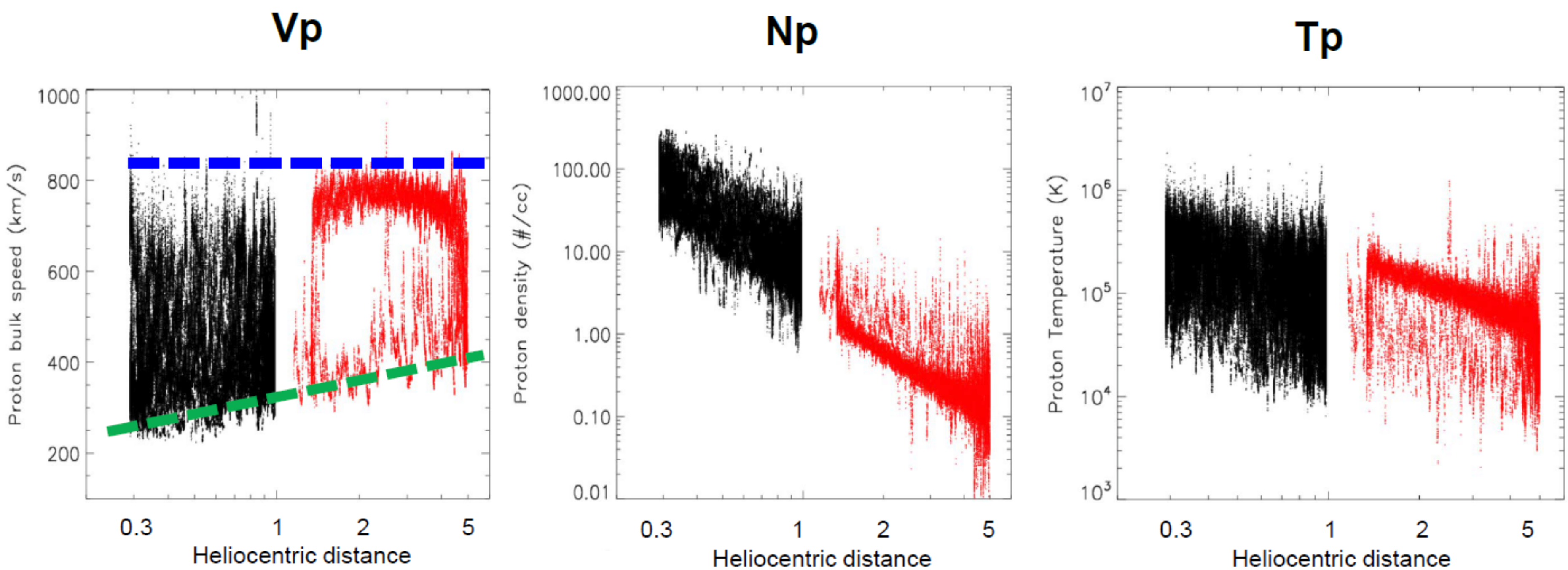
During solar maximum, this order almost completely disappears

Empirical solar wind speed profiles

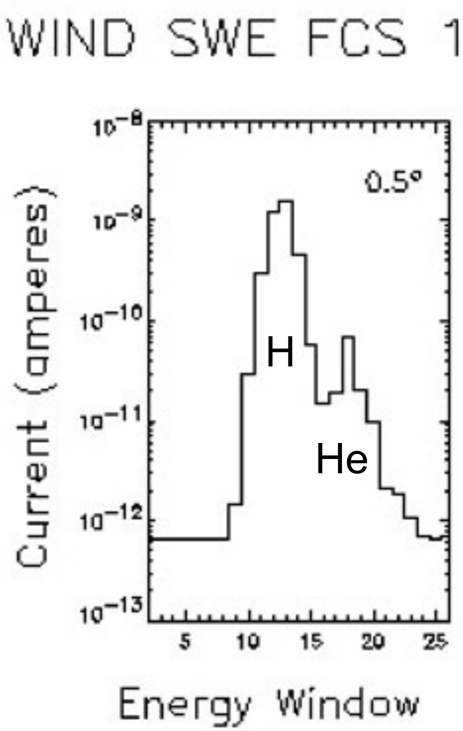


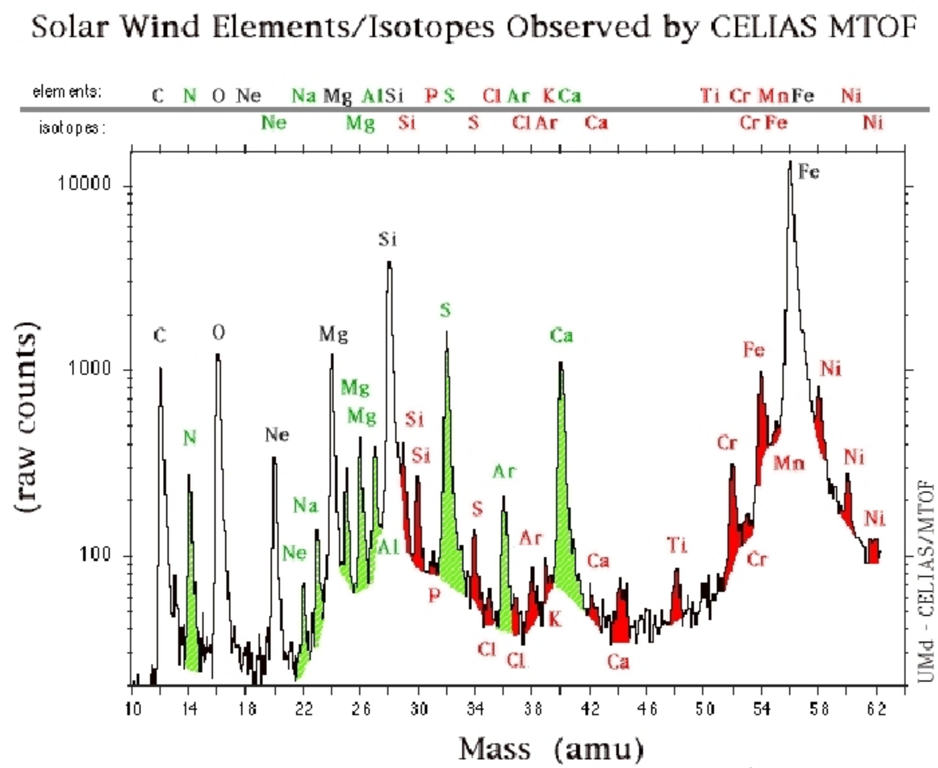
Radial Dependence of Solar Wind Properties

Helios & Ulysses proton data

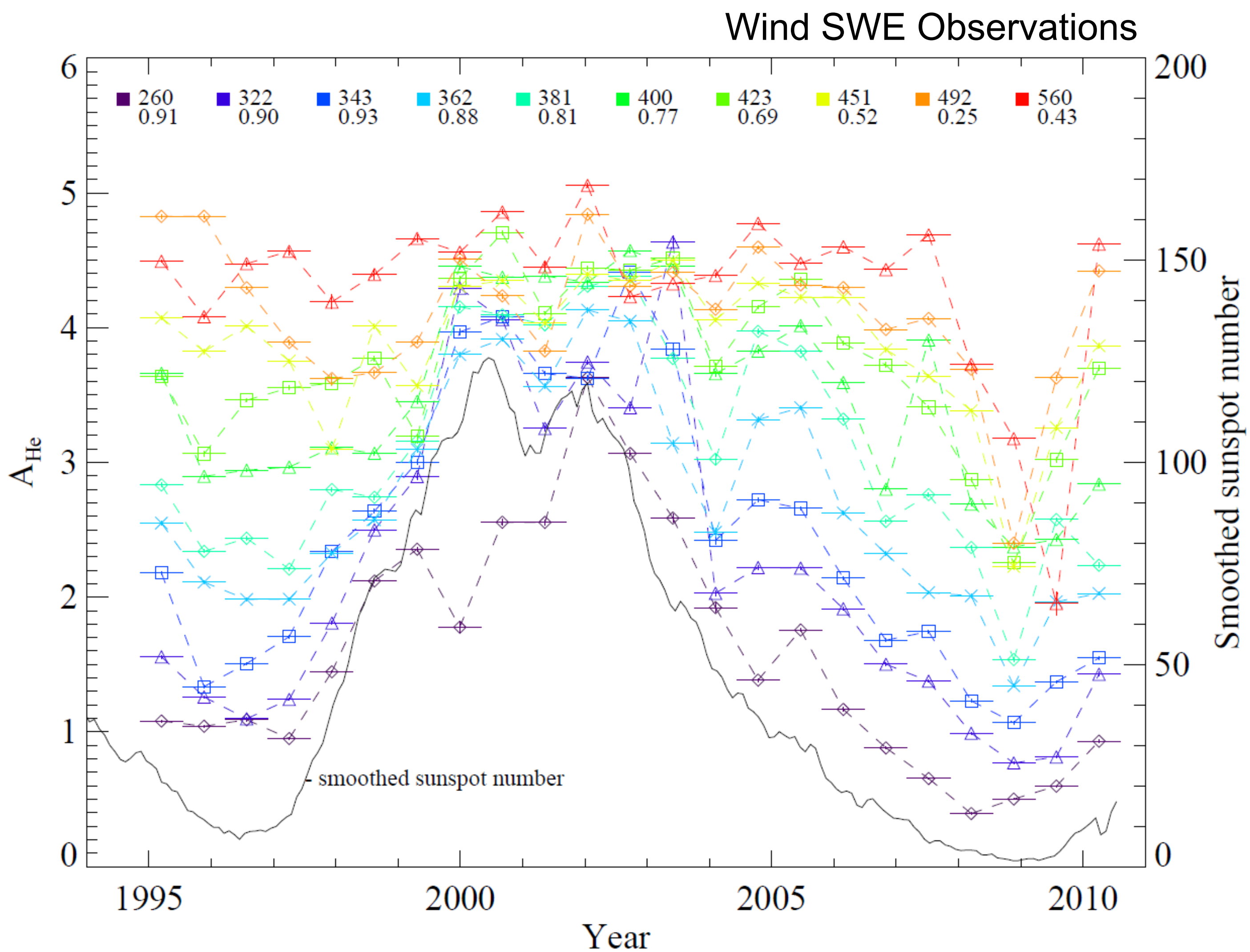


Composition of the solar wind



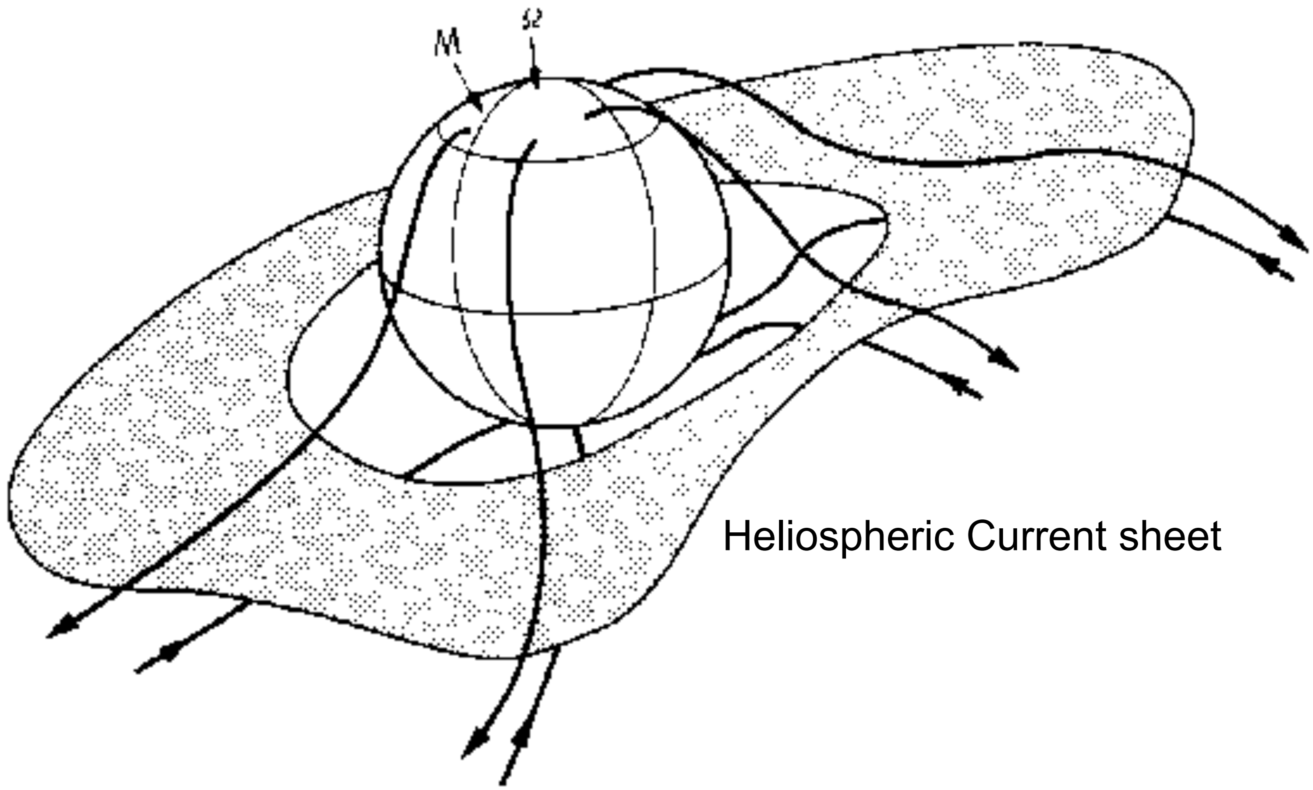


Time Variation of Composition



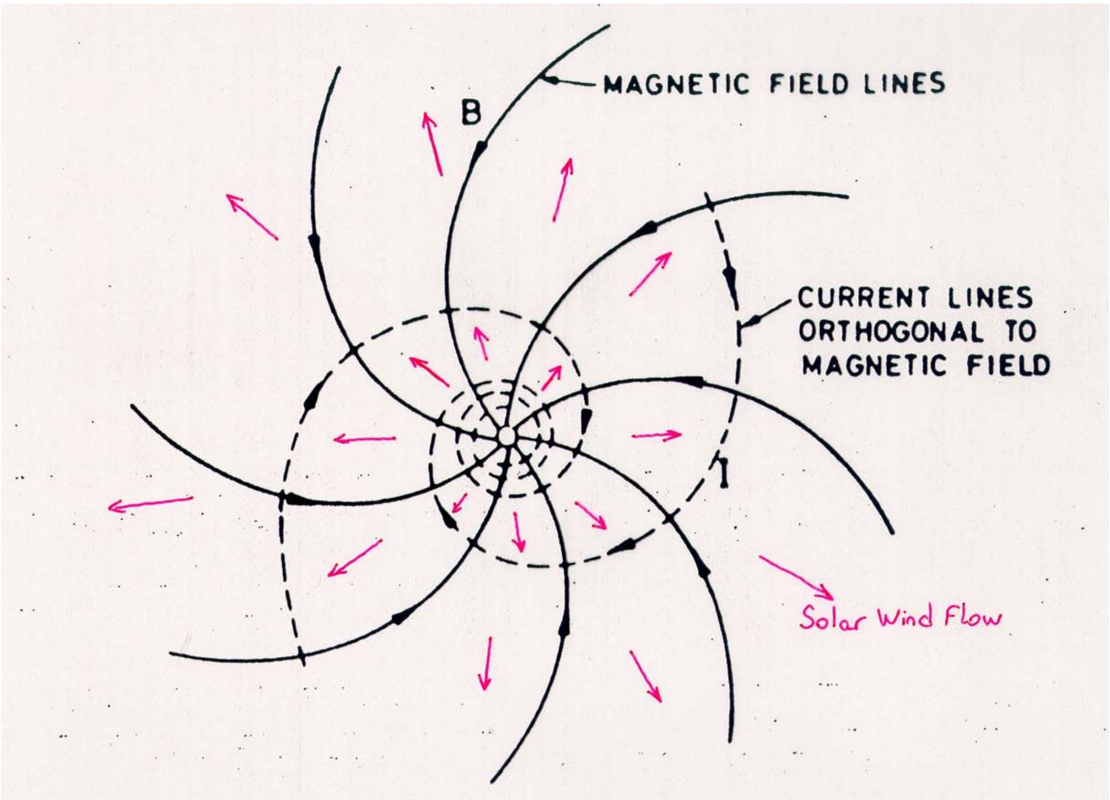
Kasper et al., ApJ, 2011

Interplanetary Magnetic Fields



The radially expanding solar wind carries the solar magnetic fields outward forming a very large current sheet, the heliospheric current sheet, a layer through which the interplanetary magnetic field suddenly reverses direction. The field lines above and below the current sheet are still connected at large distances, but they are stretched out extensively by the solar wind.

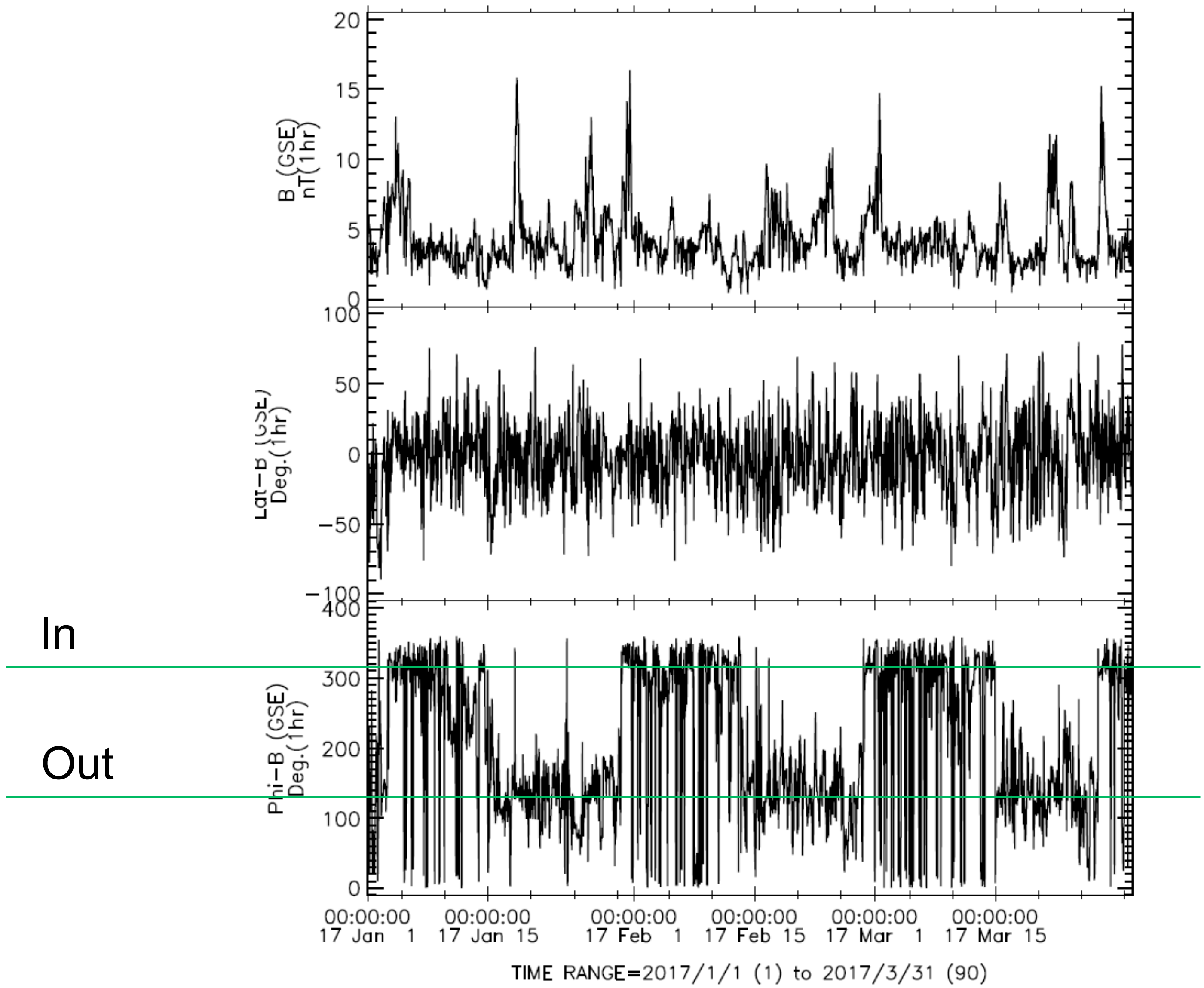
Parker Spiral

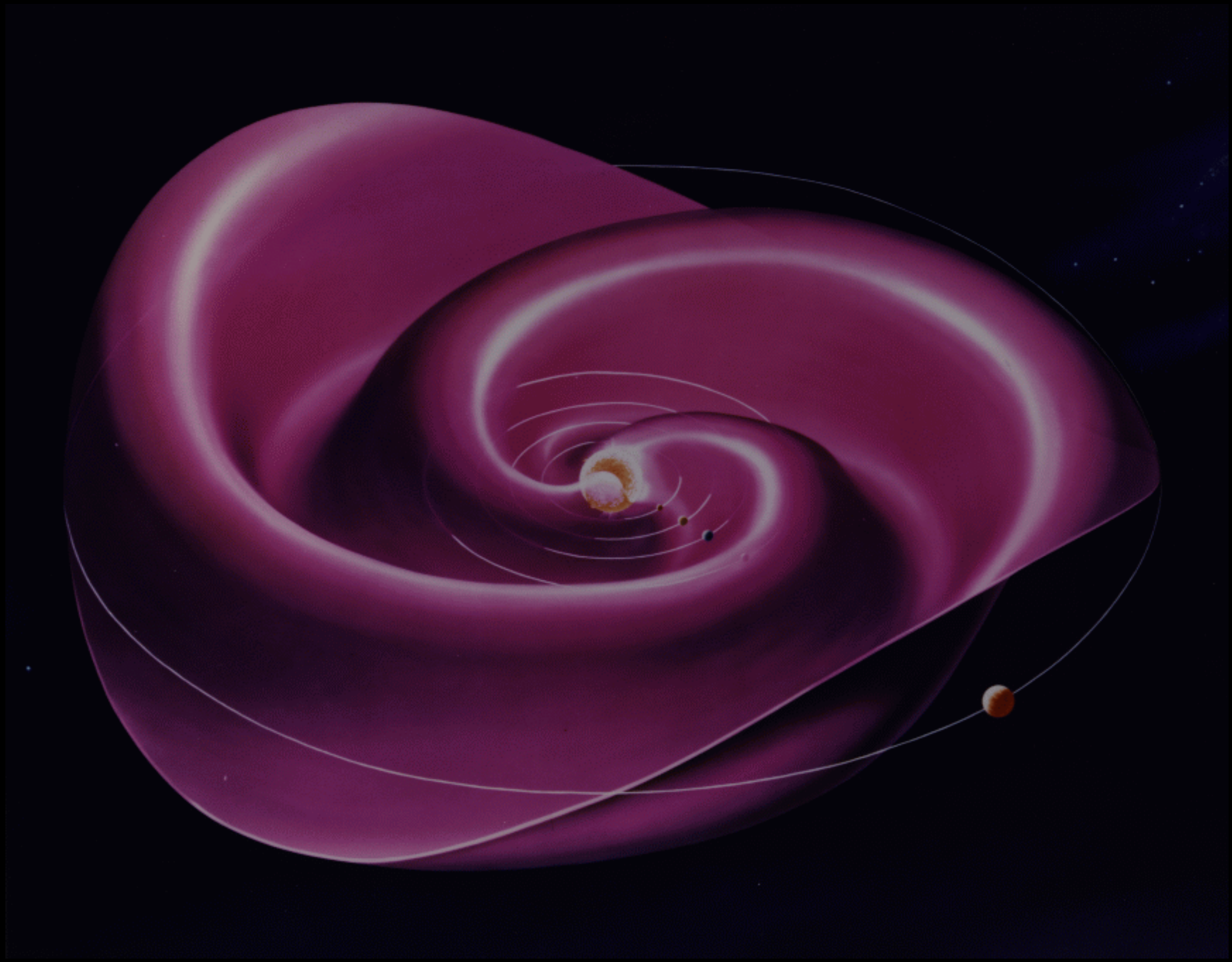


At 1 AU, the Parker Spiral is in the 135/315 deg direction in GSE coordinates

Looking down from the top of the Sun, the solar magnetic field lines are stretched out into a Archimedean spiral known as the Parker spiral. Even though the solar wind that carries the “frozen in” field lines flows radially outward, due to the Sun’s rotation, parcels lifting up from the same point on the surface of the Sun will form a spiral just as is the case for an ordinary garden sprinkler.

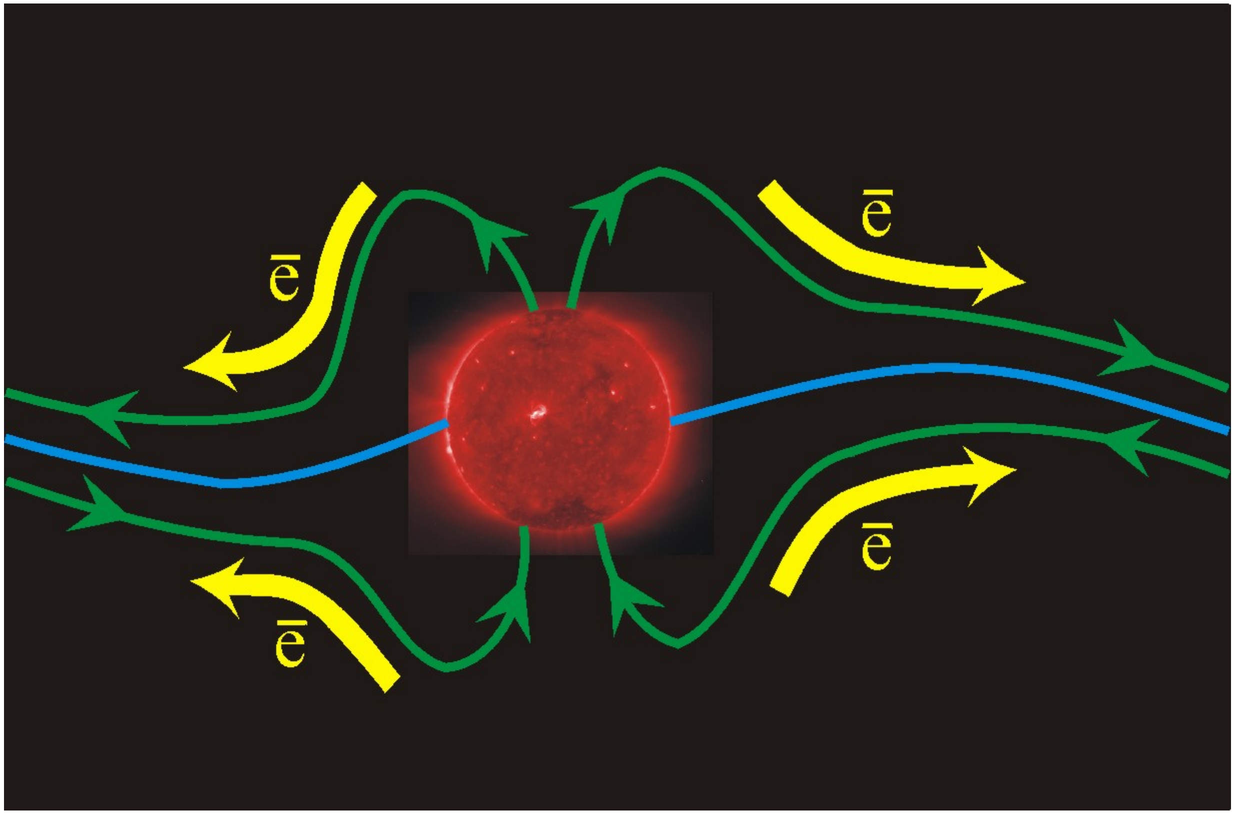
IMF Sector Structure





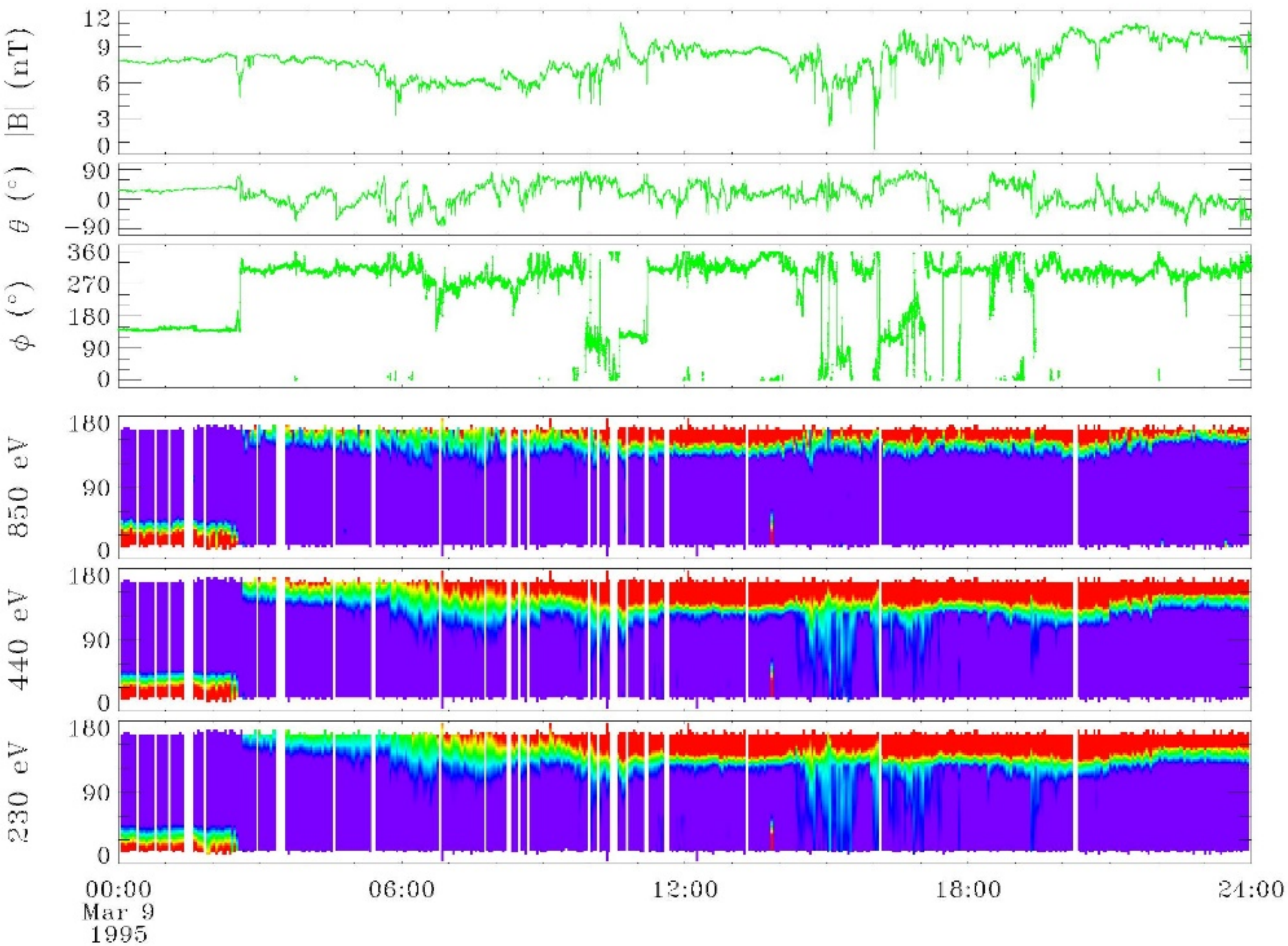
The heliospheric current sheet, the largest coherent structure in the solar system, is a wavy sheet, resembling a ballerina skirt, due to the fact that the Sun's magnetic dipole is tilted by different amounts, depending on the phase of the solar cycle, from its rotation axis.

Heat Flux Electrons

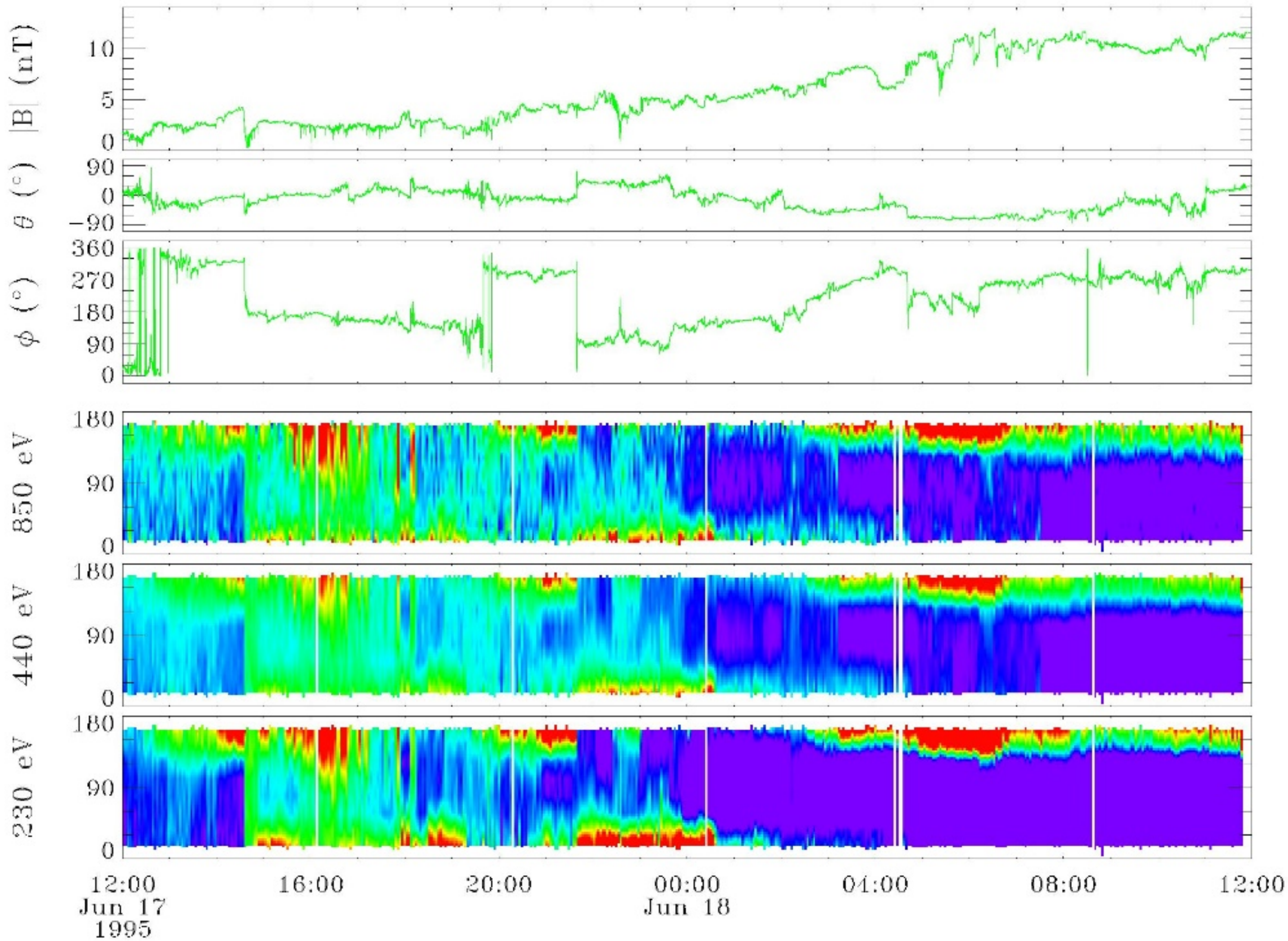


Suprathermal electrons are trying to escape the corona and follow the interplanetary magnetic field lines as they stream away. Unlike thermal electrons, suprathermal electrons have a small range of pitch angles, thus their streaming direction is easy to identify. When the relative direction of the IMF and the electrons changes, we have a sector crossing.

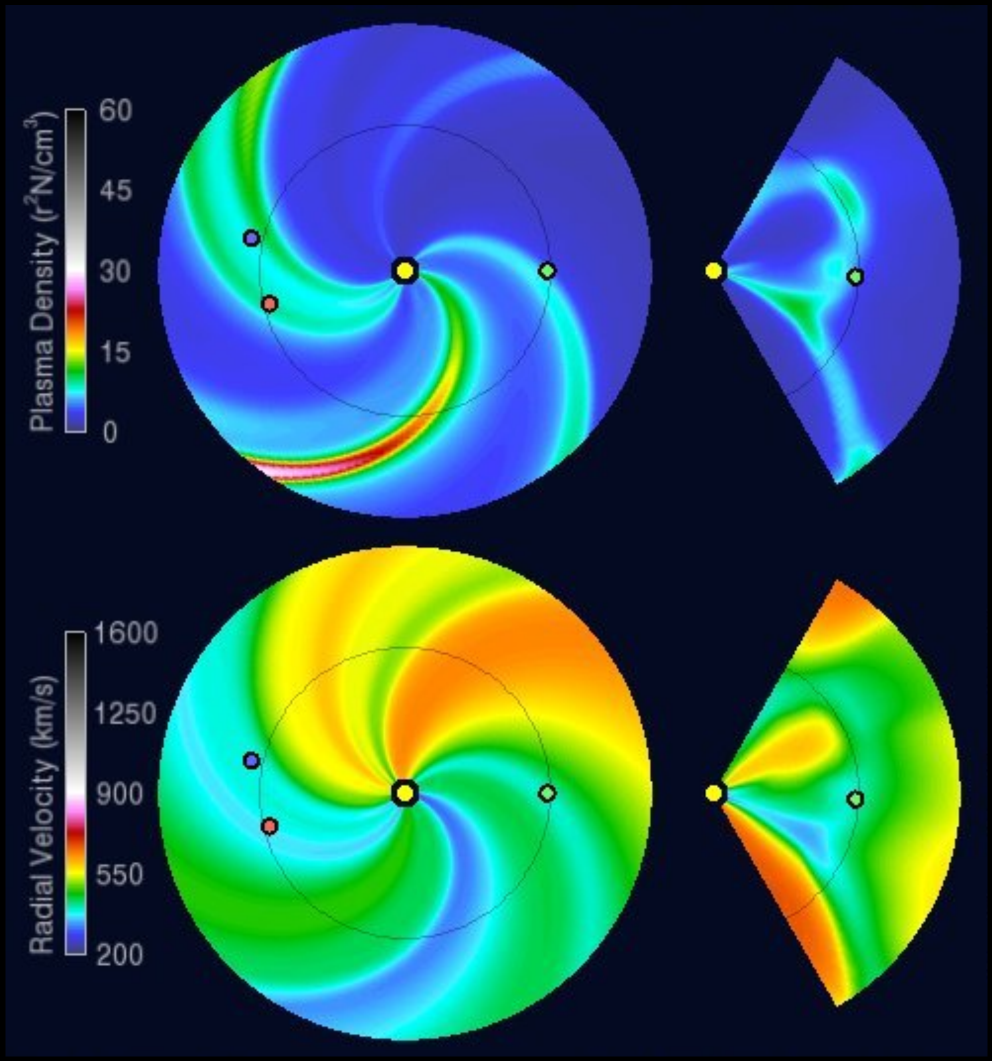
Heliospheric Current Sheet Crossing



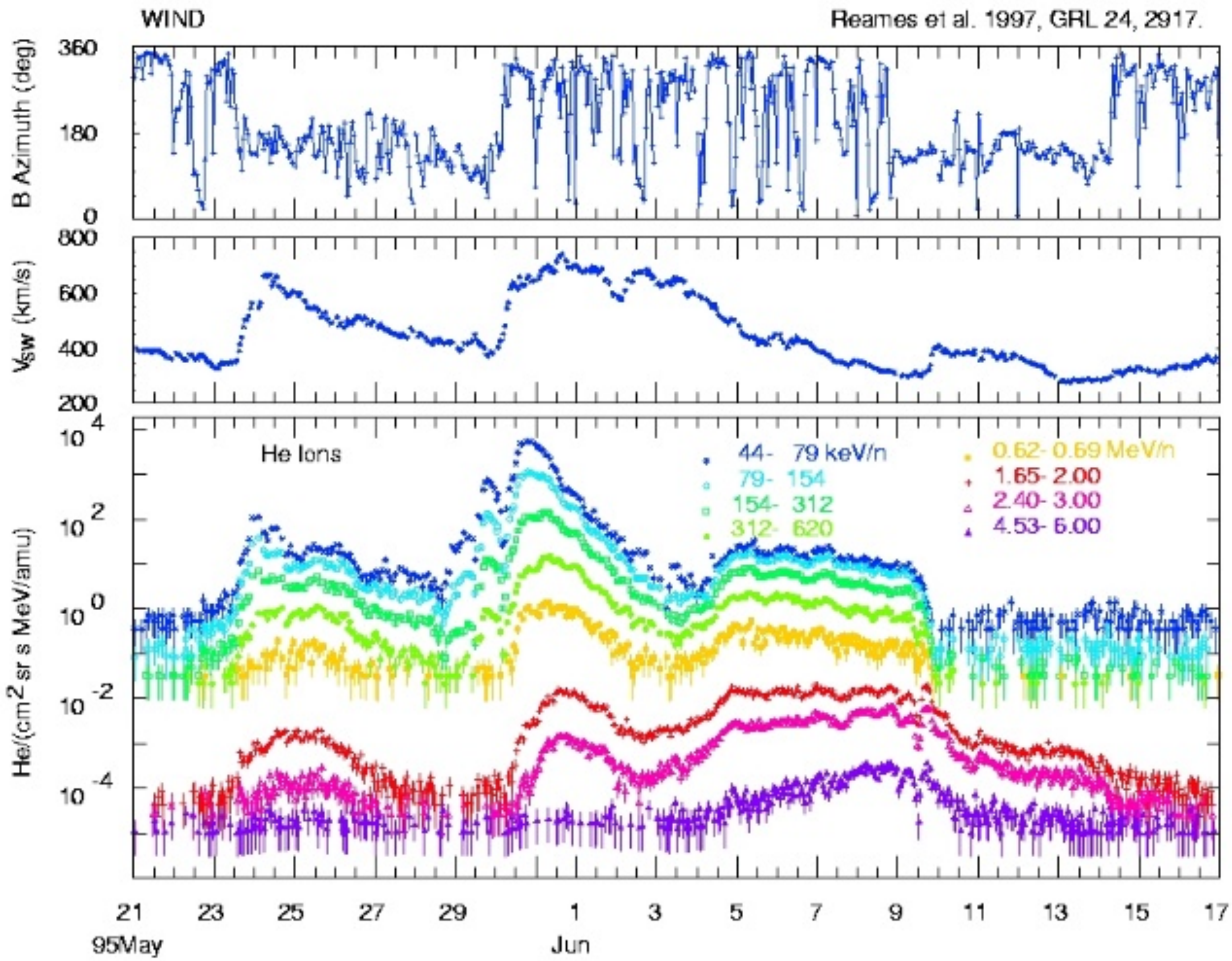
Heliospheric Current Sheet Crossing



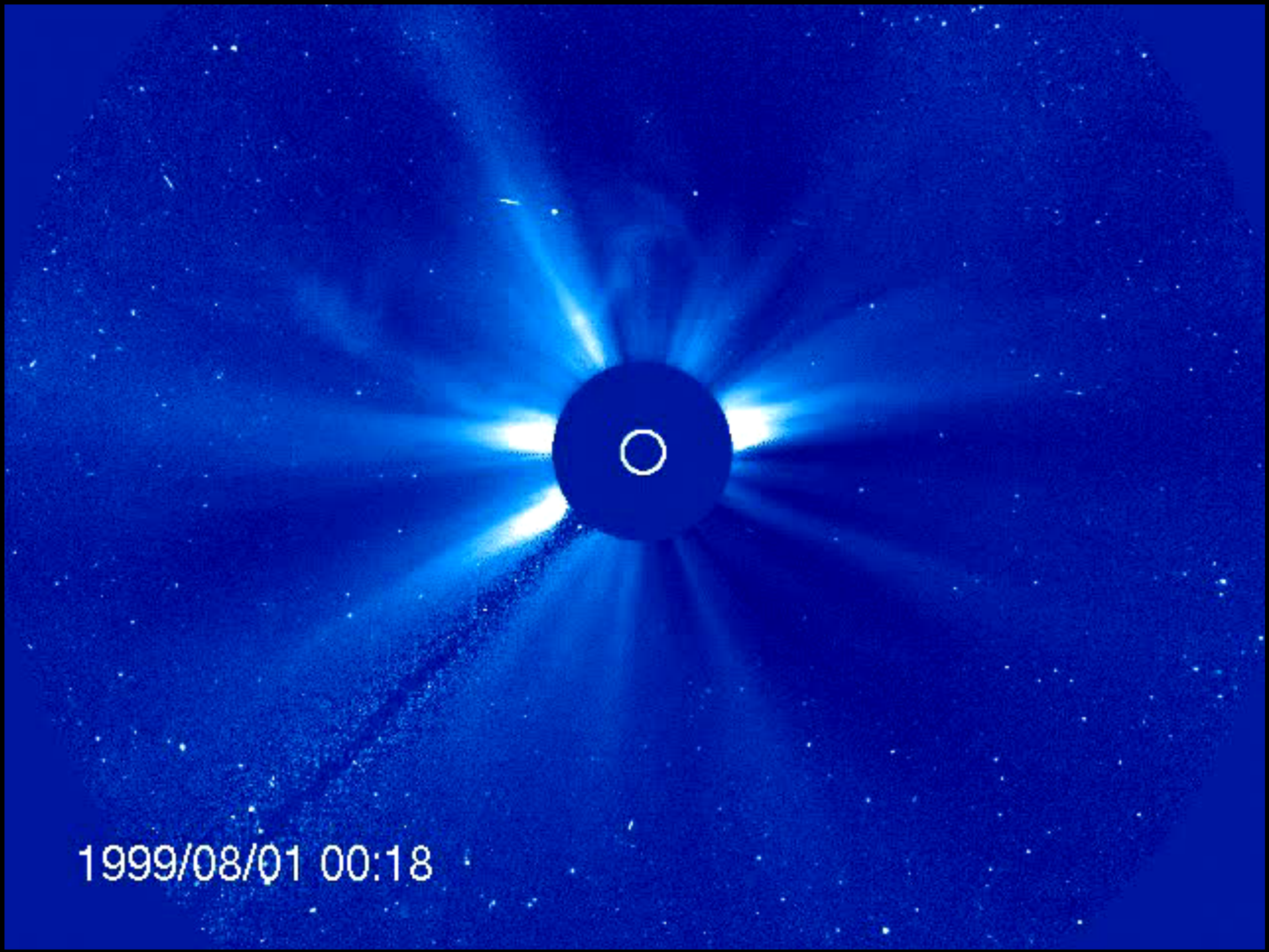
Corotating Interaction Regions



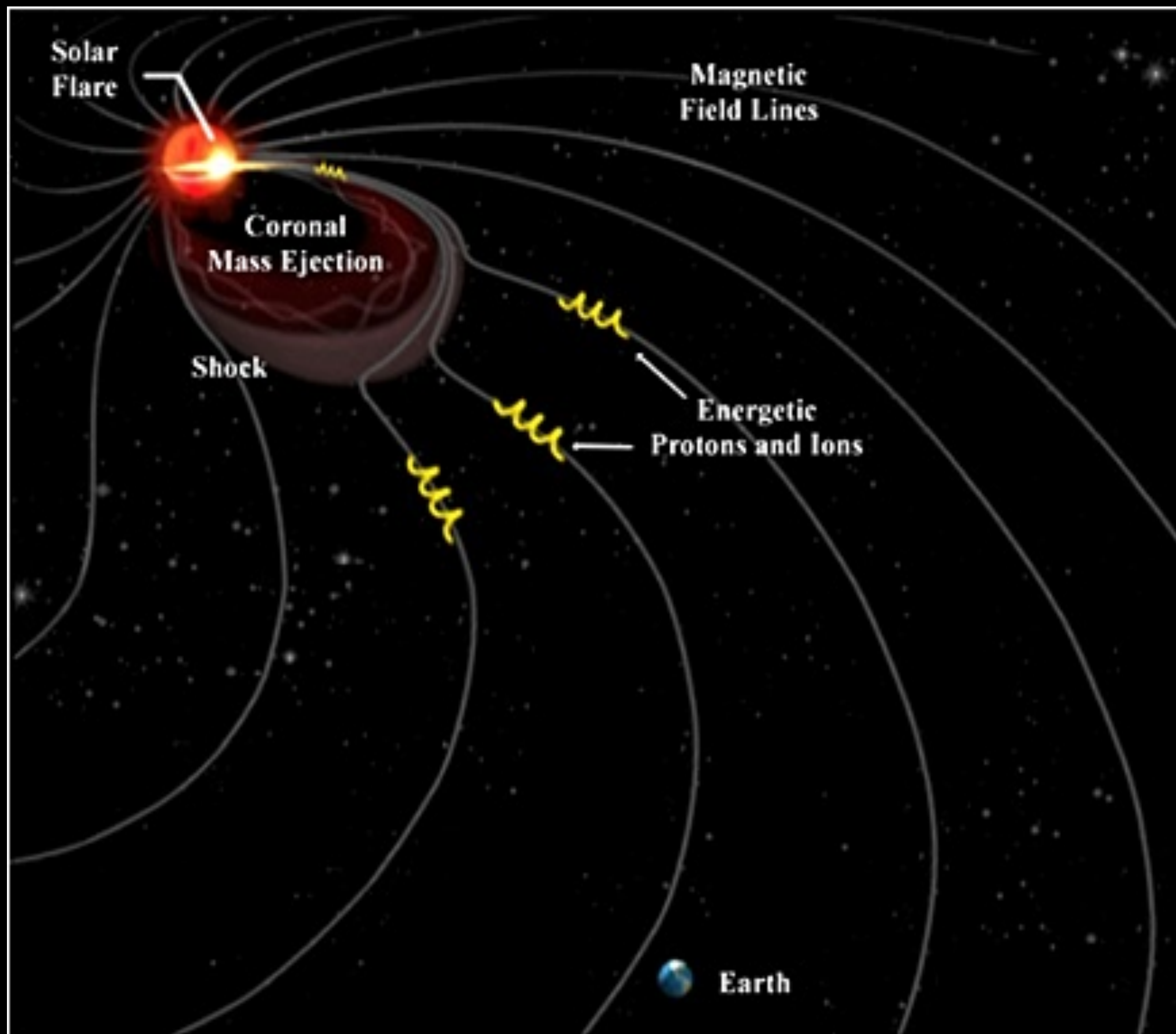
Corotating Interaction Regions



Coronal Mass Ejections (CMEs)



Solar Energetic Particles



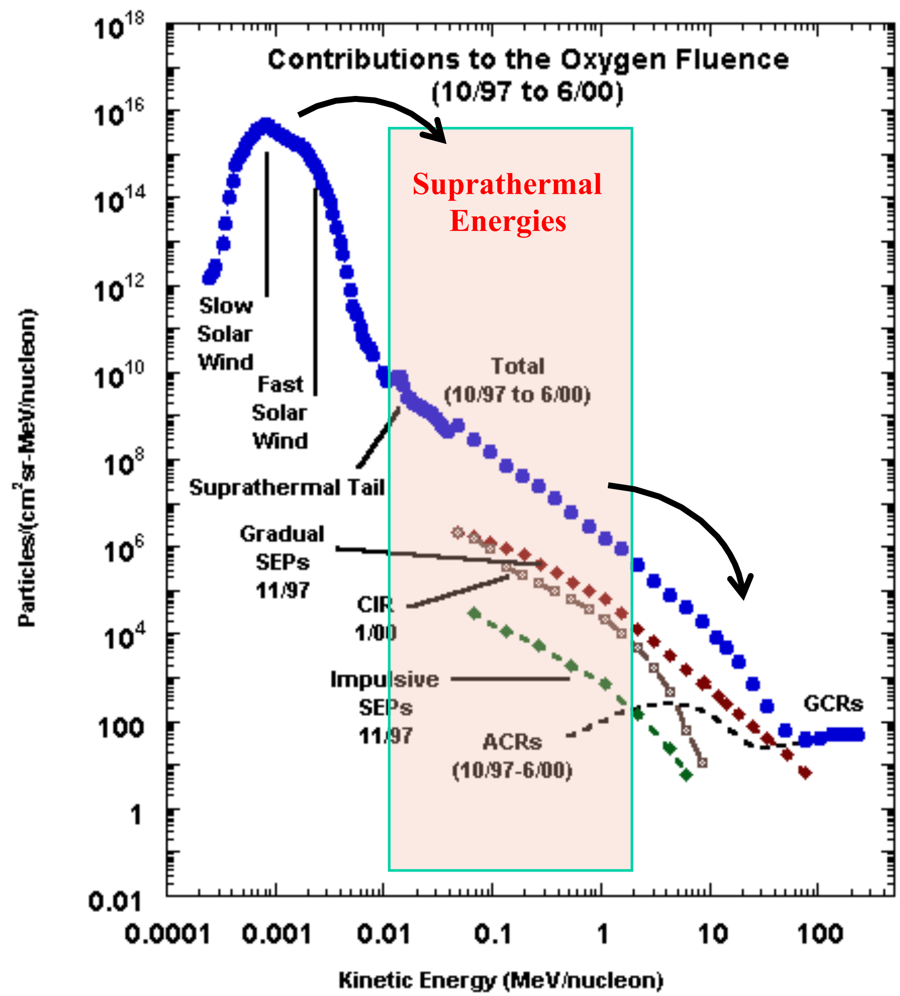
SEP Acceleration is a Two-Step Process

A compelling picture has emerged from a wide range of studies:

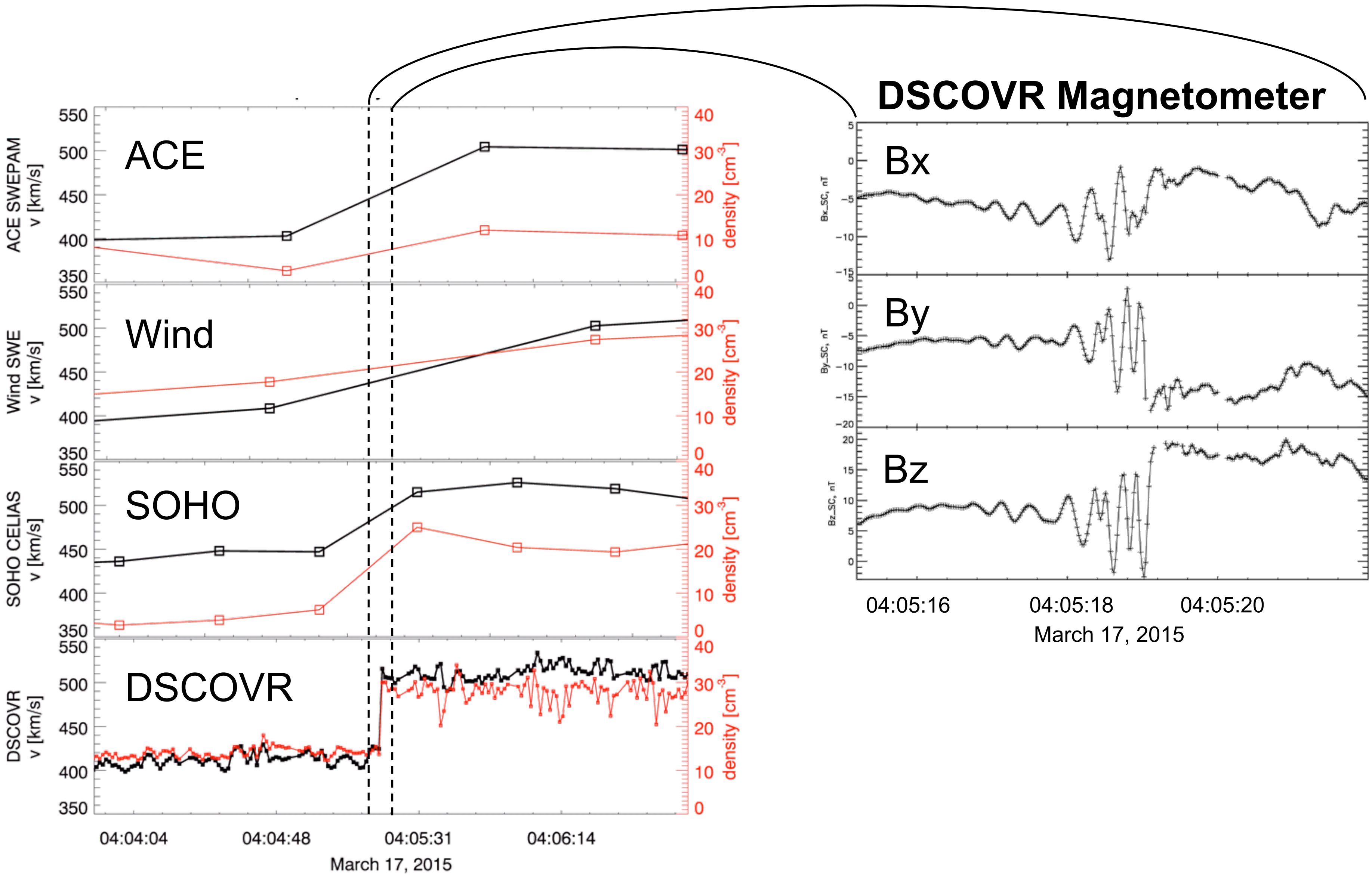
Accelerating particles to 10-100 MeV requires a two-step process

1.Heating the solar wind plasma to suprathermal (~100 keV) energies.

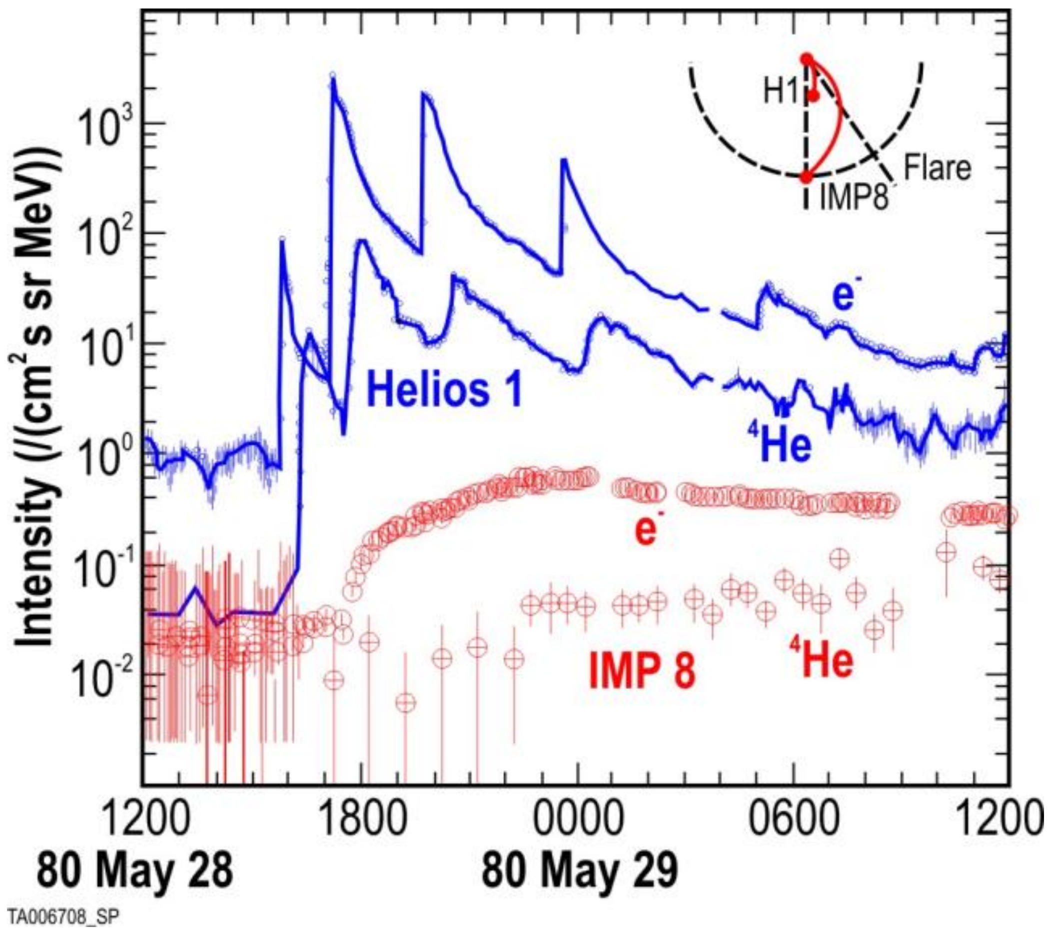
2.Accelerating suprathermal particles to high energies.



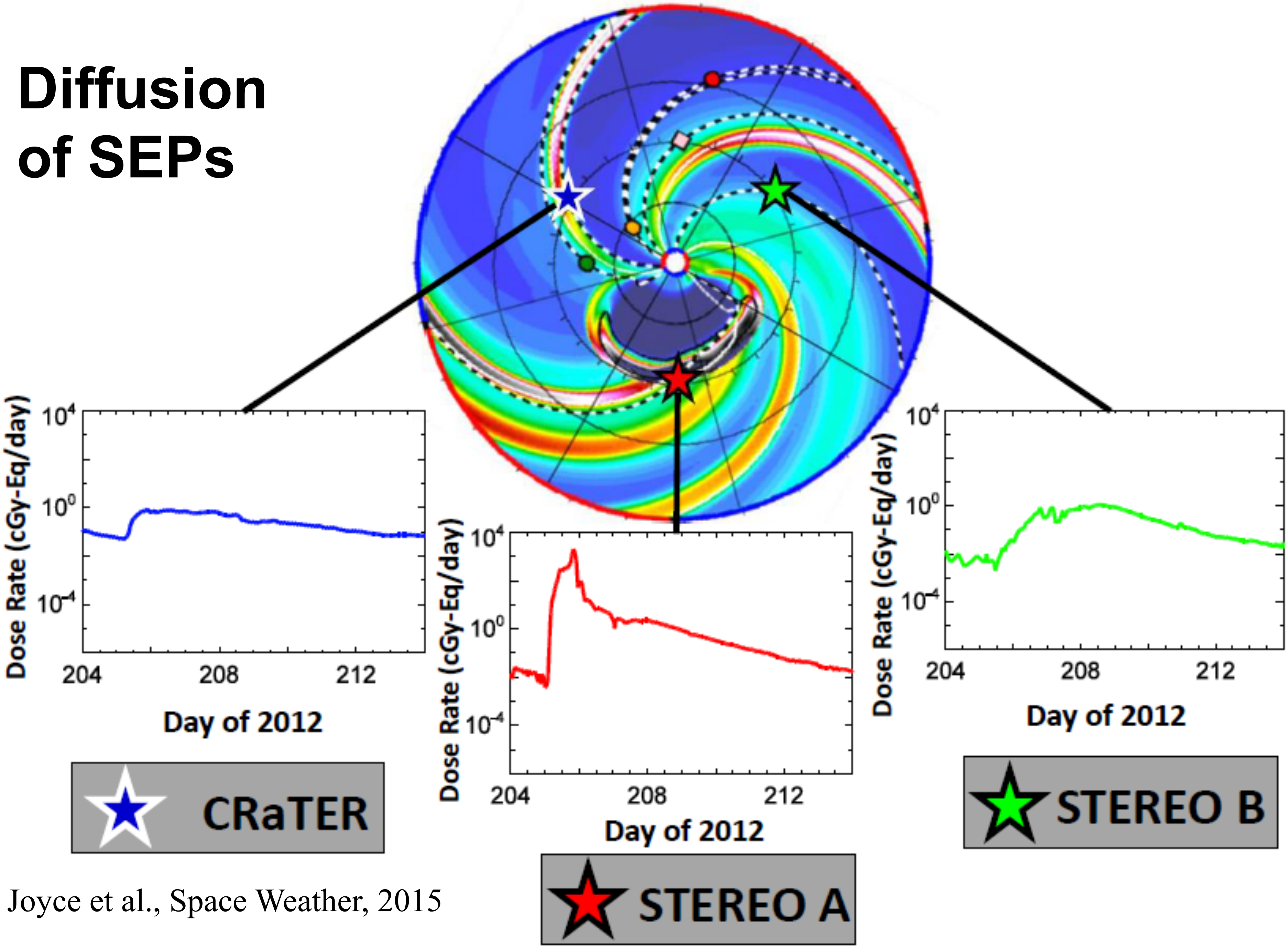
Wave Activity near IP Shocks



Radial Evolution of SEPs

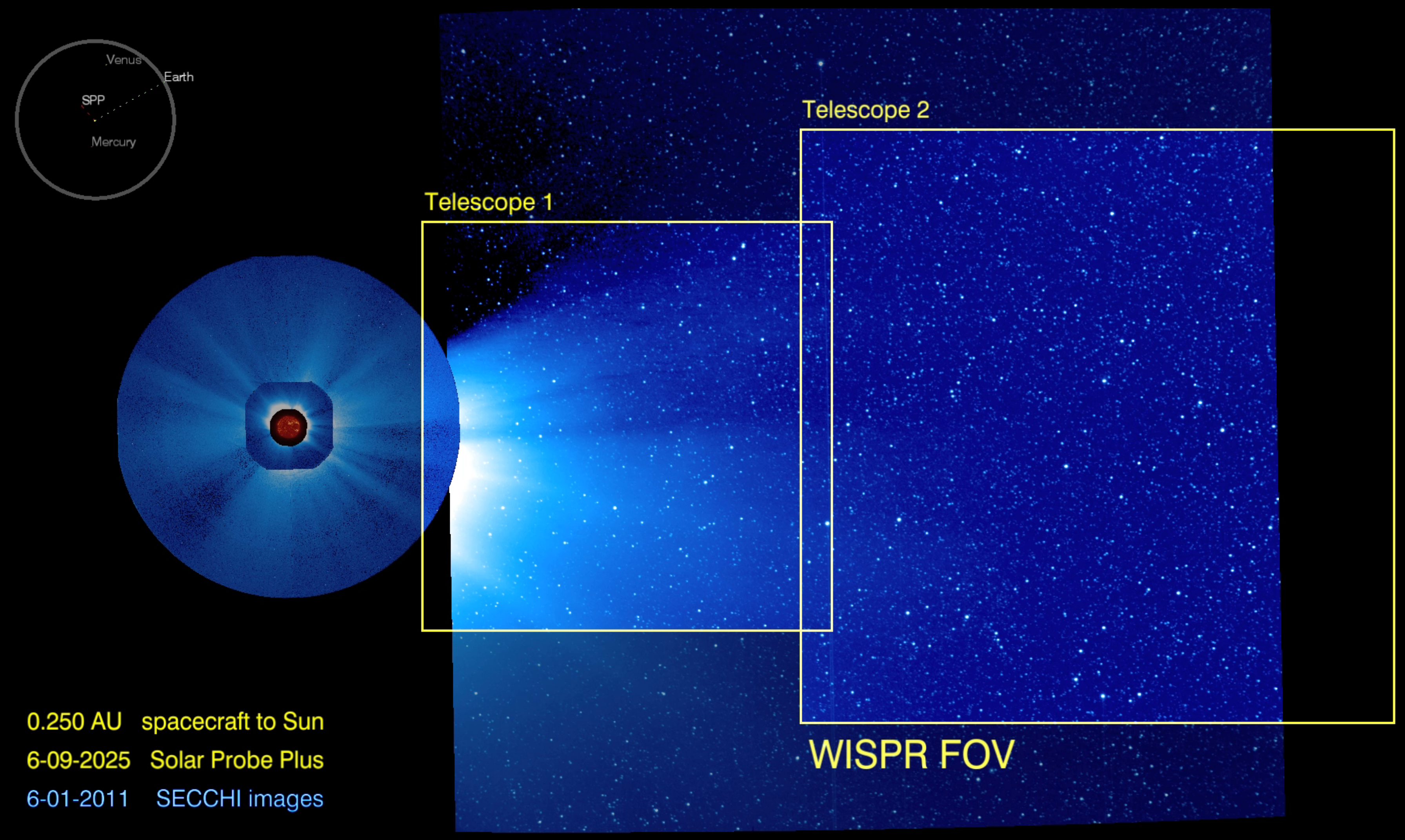


Diffusion of SEPs



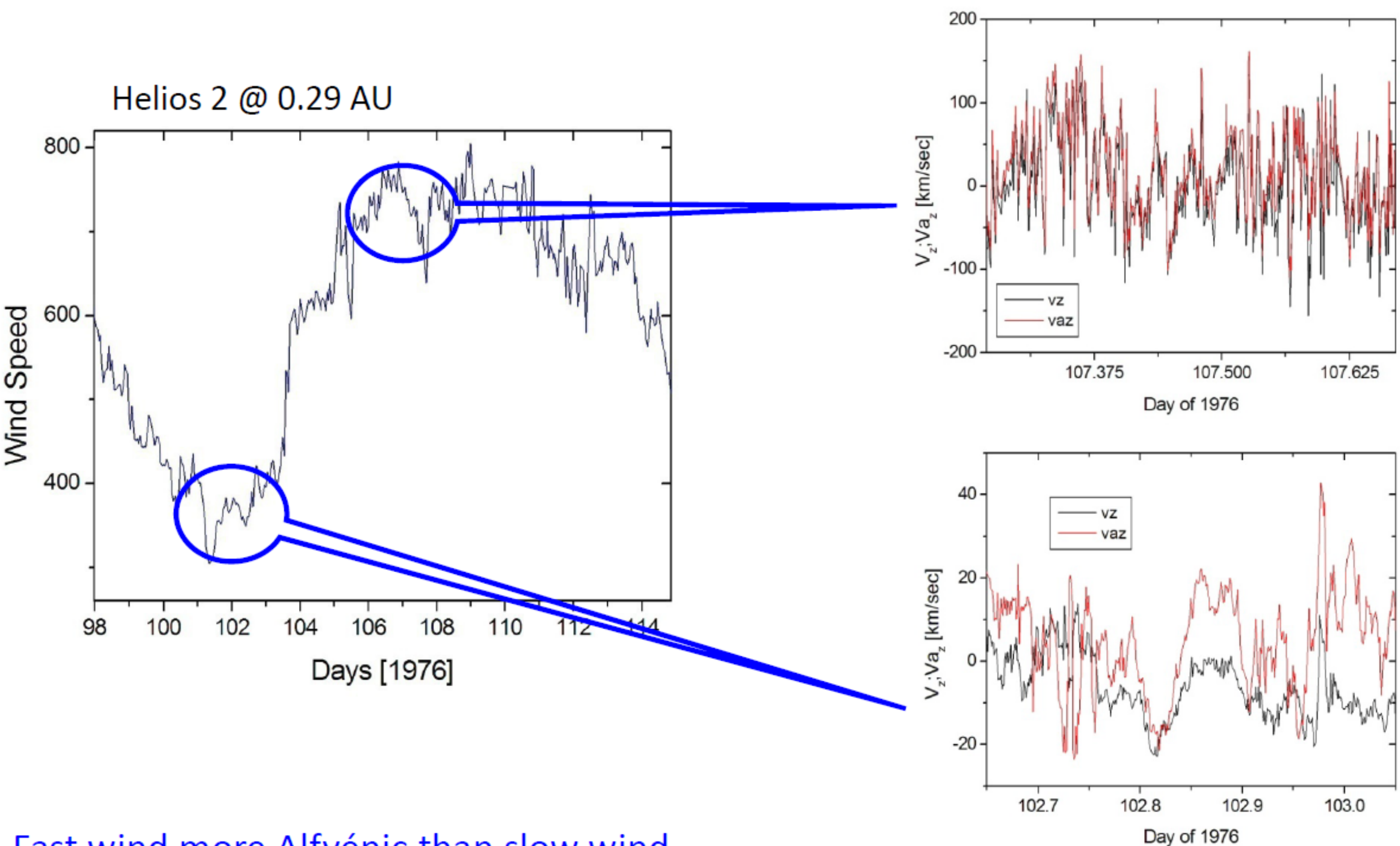
Joyce et al., Space Weather, 2015

Structured Solar Wind



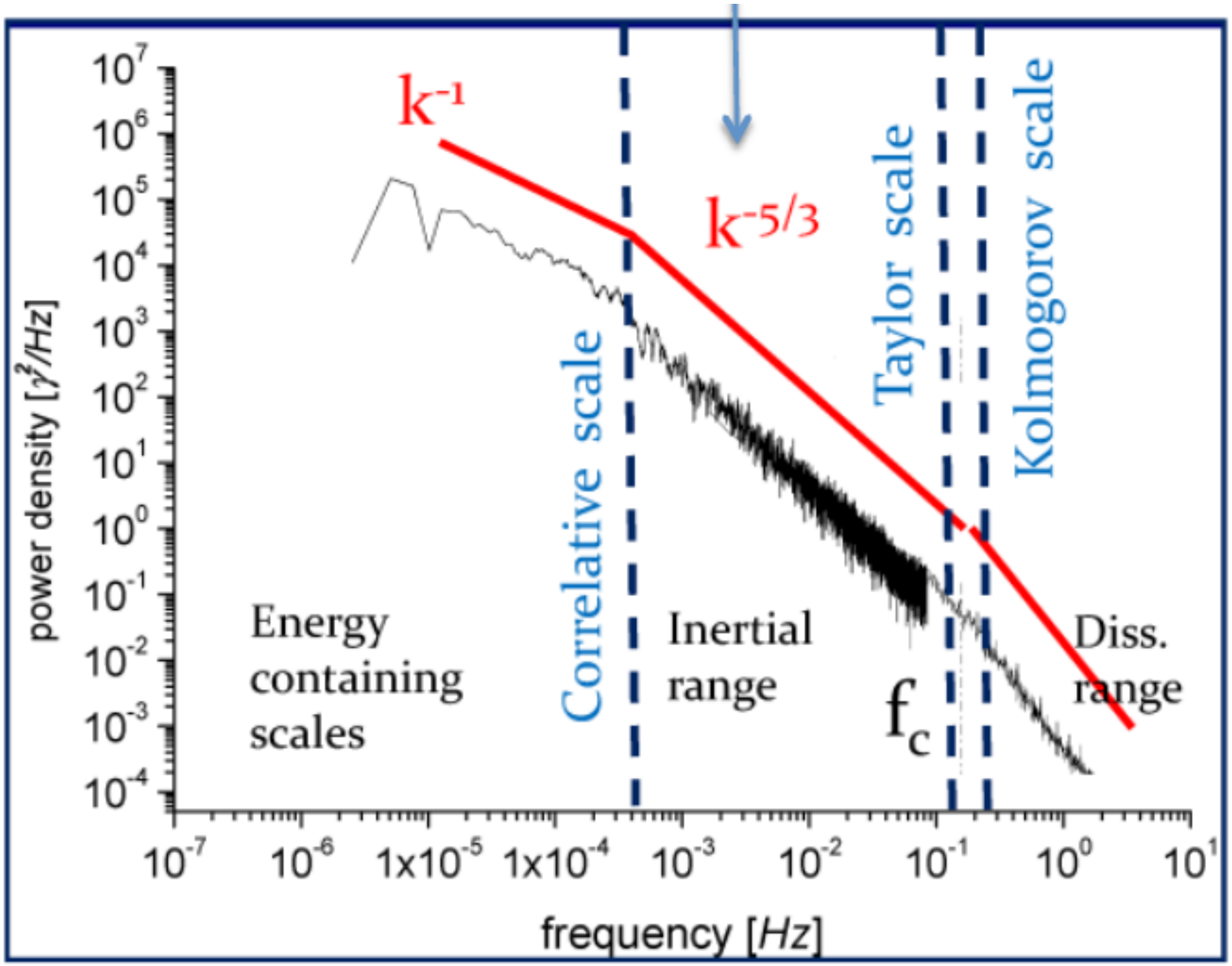
Differences in the Alfvénic character of the fluctuations

$$v_{az} = sign[-\vec{k} \cdot \vec{B}_0] \frac{b_z}{\sqrt{4\pi\rho}}$$



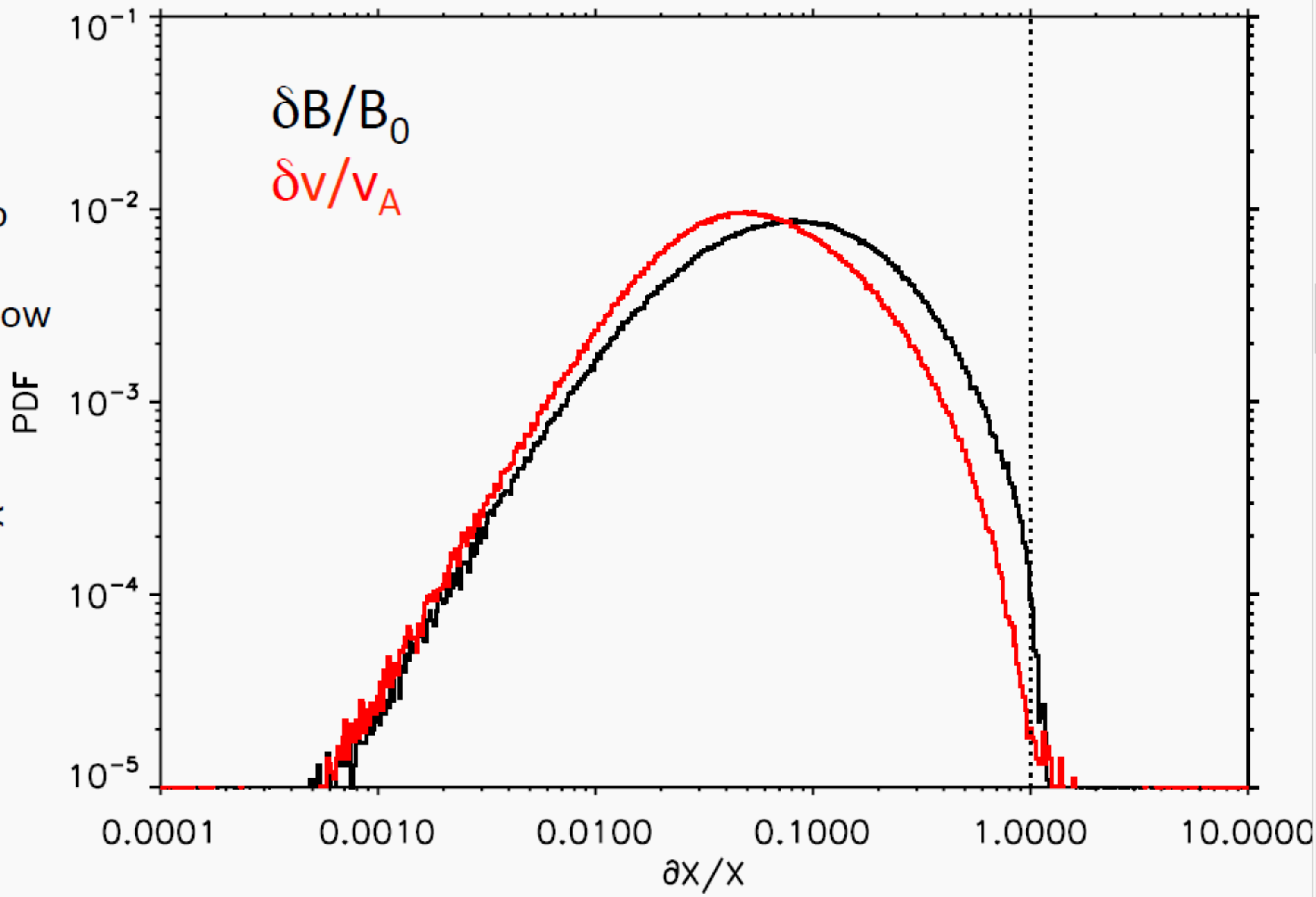
Fast wind more Alfvénic than slow wind

Turbulent Cascade



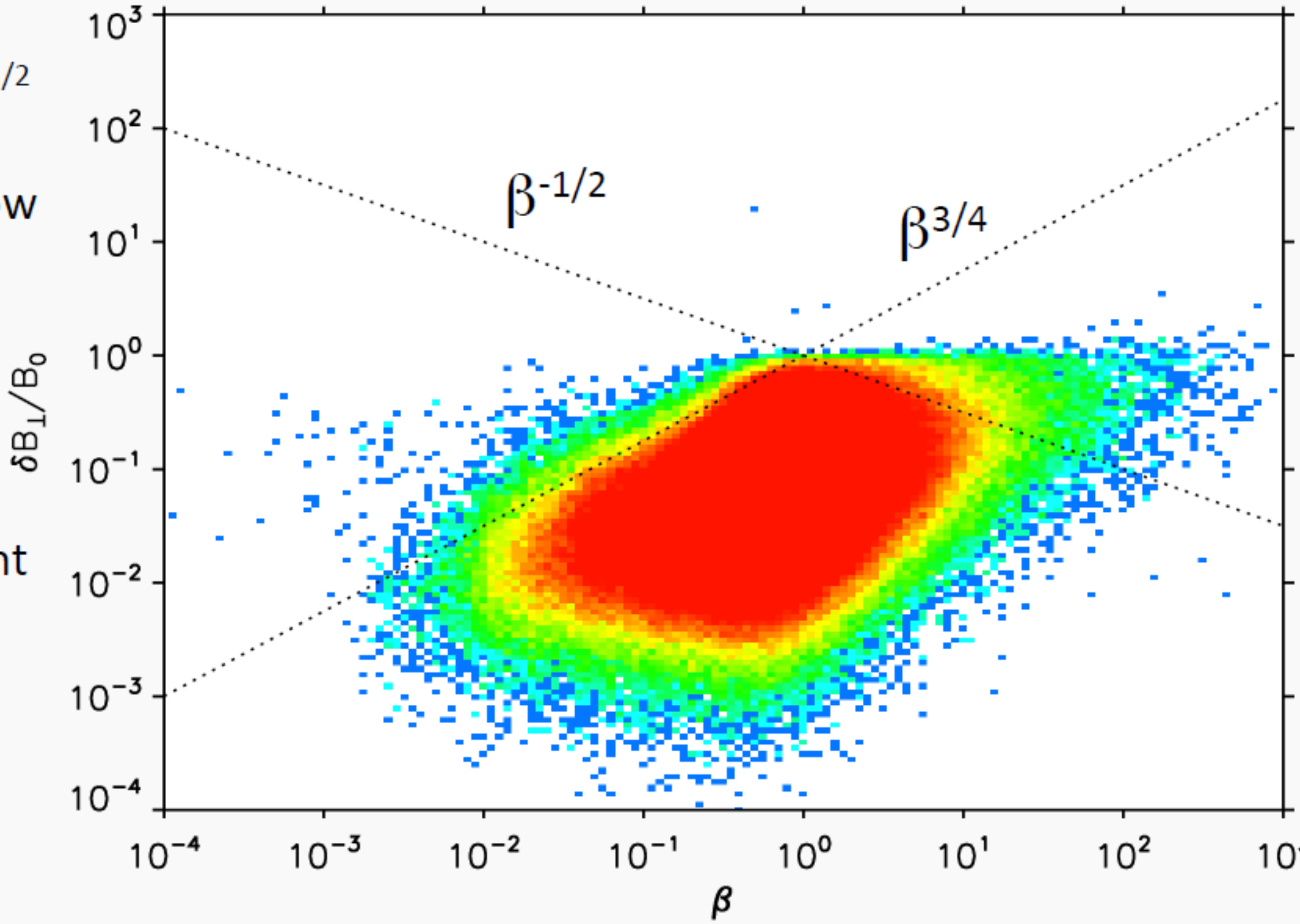
Solar Wind Variations

- Both $\delta v/V_A$ and $\delta B/B_0$ appear to be limited by 1
- Similar pdfs at low values, some departure for large values
- Both peak at =< 0.1



Limits of Solar Wind Variability

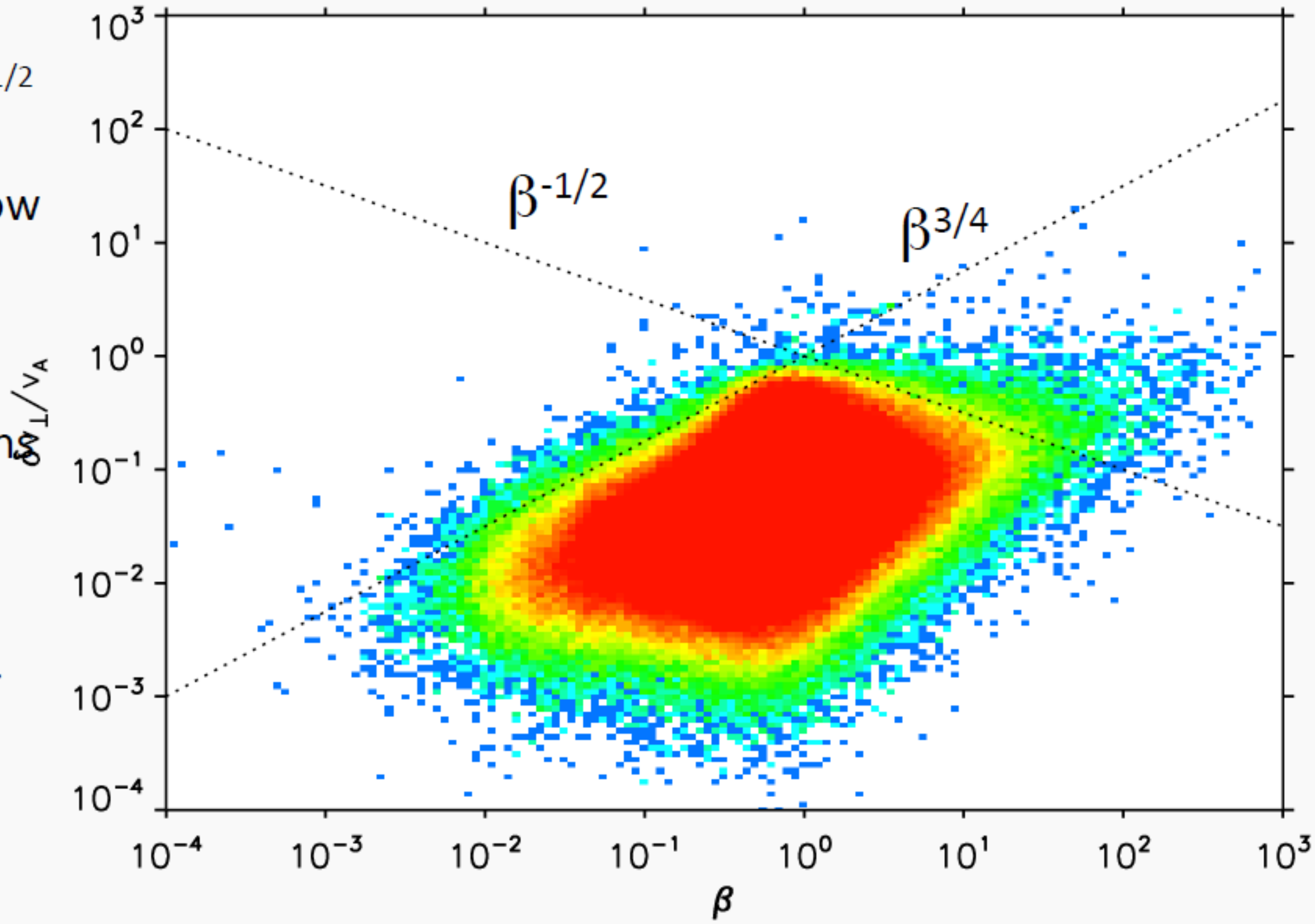
- Clear evidence of $\beta^{-1/2}$ cutoff!
- Also evidence of a low β threshold ~$\beta^{3/4}$… WKB? parametric decay?
- More magnetic field data **past** the threshold. Consistent with Squire et al. prediction



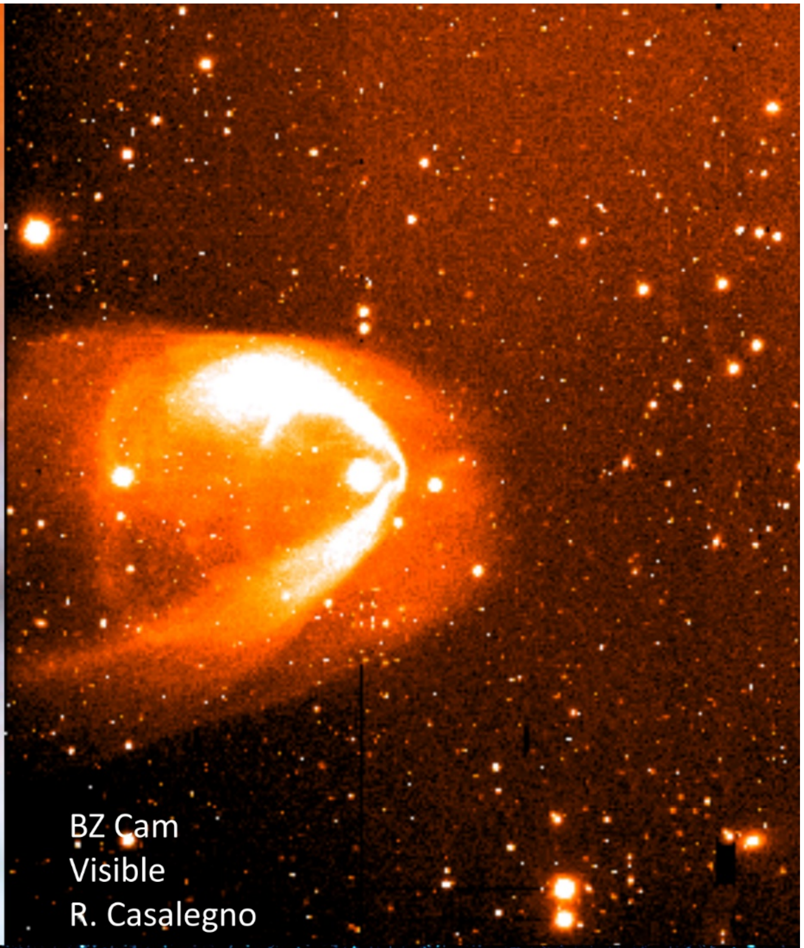
$\beta = 8\pi\, nkT/B^2$ = Thermal / Magnetic Pressure

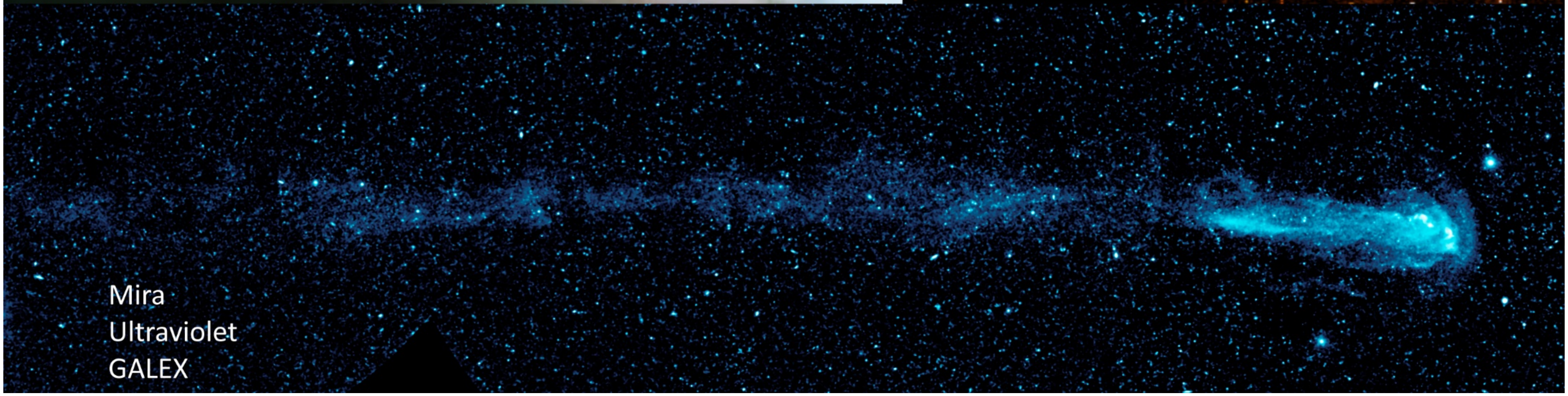
Limits of Solar Wind Variability

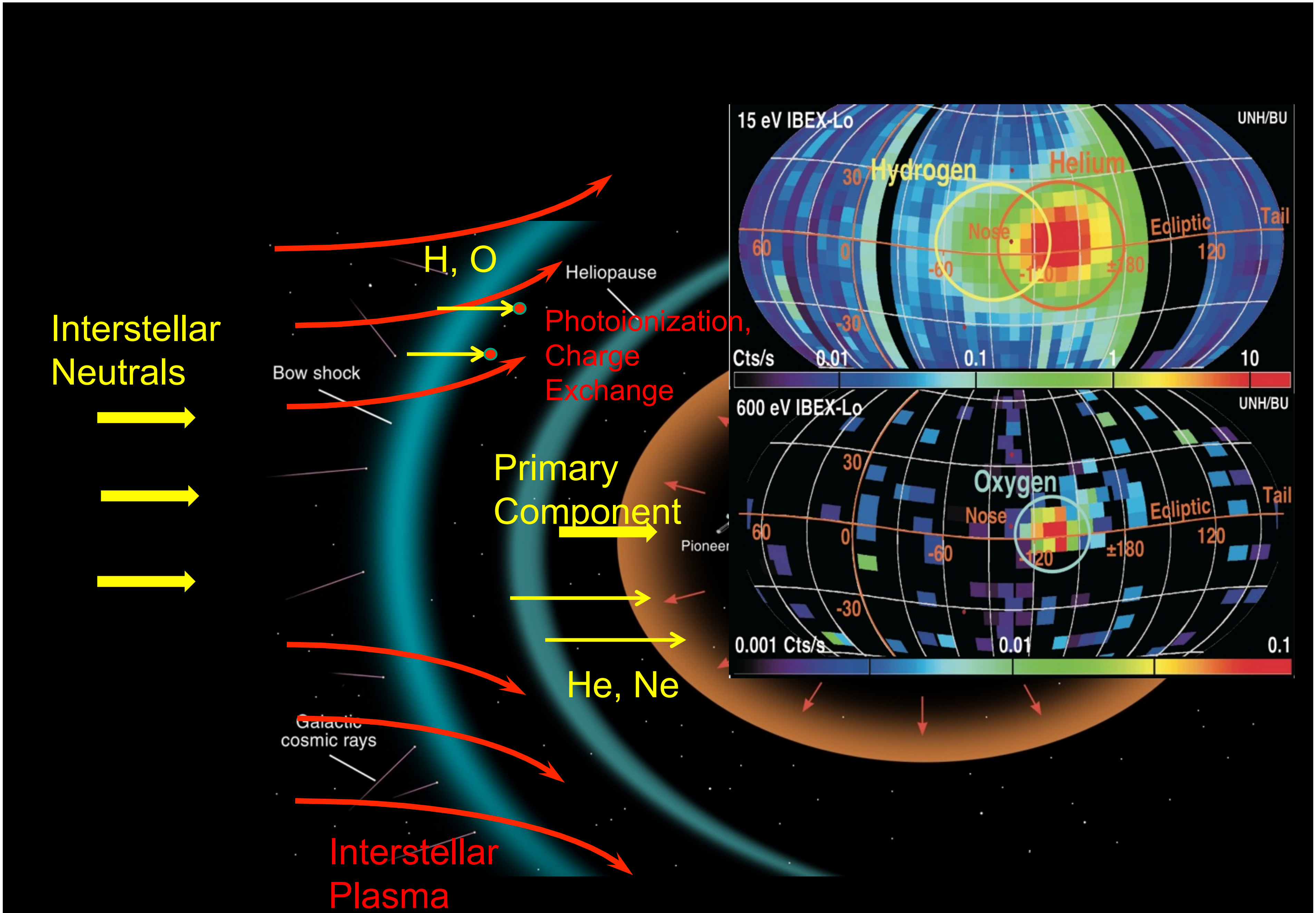
- Clear evidence of $\beta^{-1/2}$ cutoff!
- Also evidence of a low β threshold ~$\beta^{3/4}$… WKB? parametric decay? Most decay instability calculations show β^{α}
- This mimics the marginal stability arguments made for pressure anisotropy instabilities in the solar wind (ie Hellinger)



ASTROSPHERES







Interstellar Neutrals
H, O
Heliopause
Photoionization, Charge Exchange
Bow shock
Primary Component
Pioneer
He, Ne
Galactic cosmic rays
Interstellar Plasma
15 eV IBEX-Lo
UNH/BU
Hydrogen
Helium
Nose
Ecliptic
Tail
Cts/s 0.01 0.1 1 10
600 eV IBEX-Lo
UNH/BU
Oxygen
Nose
Ecliptic
Tail
0.001 Cts/s 0.01 0.1

What is the shape of the Heliosphere?