Parker Solar Probe

A Mission to Touch the Sun

Exploring the Plasma Physics of the Inner Heliosphere with Parker Solar Probe

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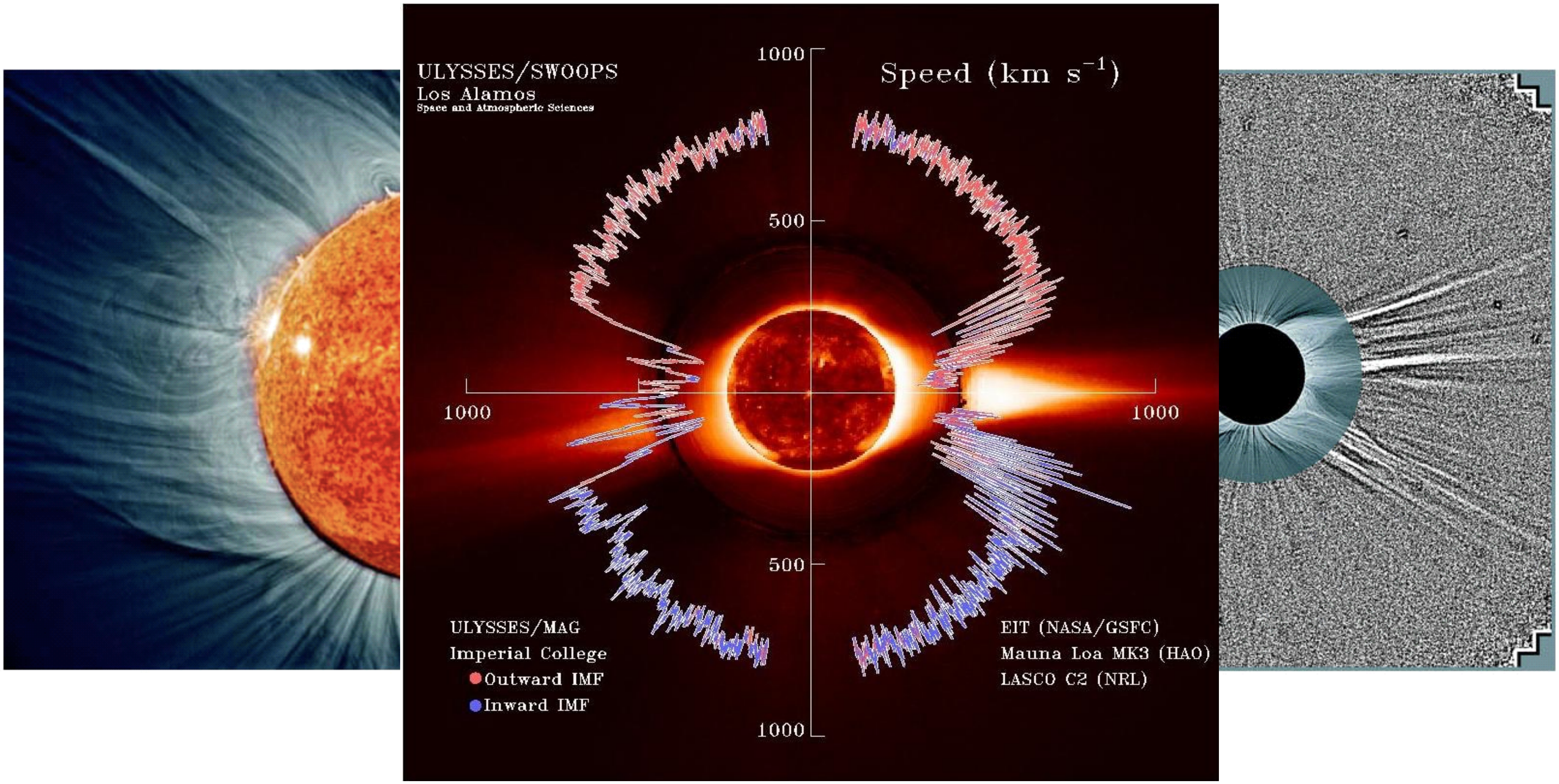
Outline

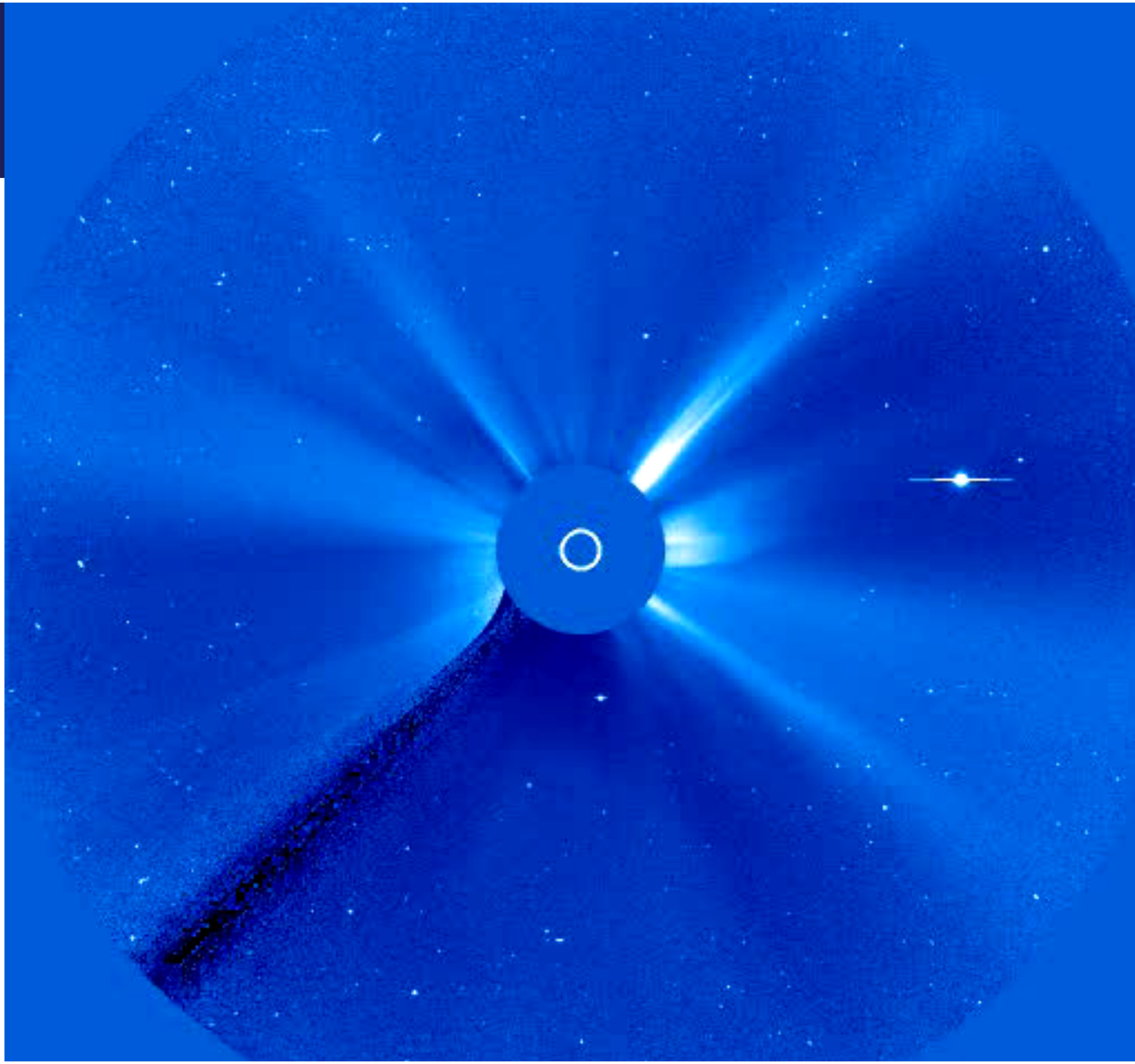
- ***Introduction to the PSP Mission: Mission Objectives and Science Questions, Mission Profile and Payload***

- ***Science Topics in the Physics of Coronal Heating, Solar Wind Acceleration and Solar Wind origins:***

  - ***Where does (Alfvénic) turbulence form and what is its role in coronal heating? MHD turbulence, nanoflares and coronal heating***
  - ***Is the wind source for fast and slow the same, and is there a steady component or is the wind always intermittent in nature?***
  - ***Where does the heliospheric current sheet form and how stable is it close to Sun? Reconnection and its role in coronal and inner heliospheric physics?***

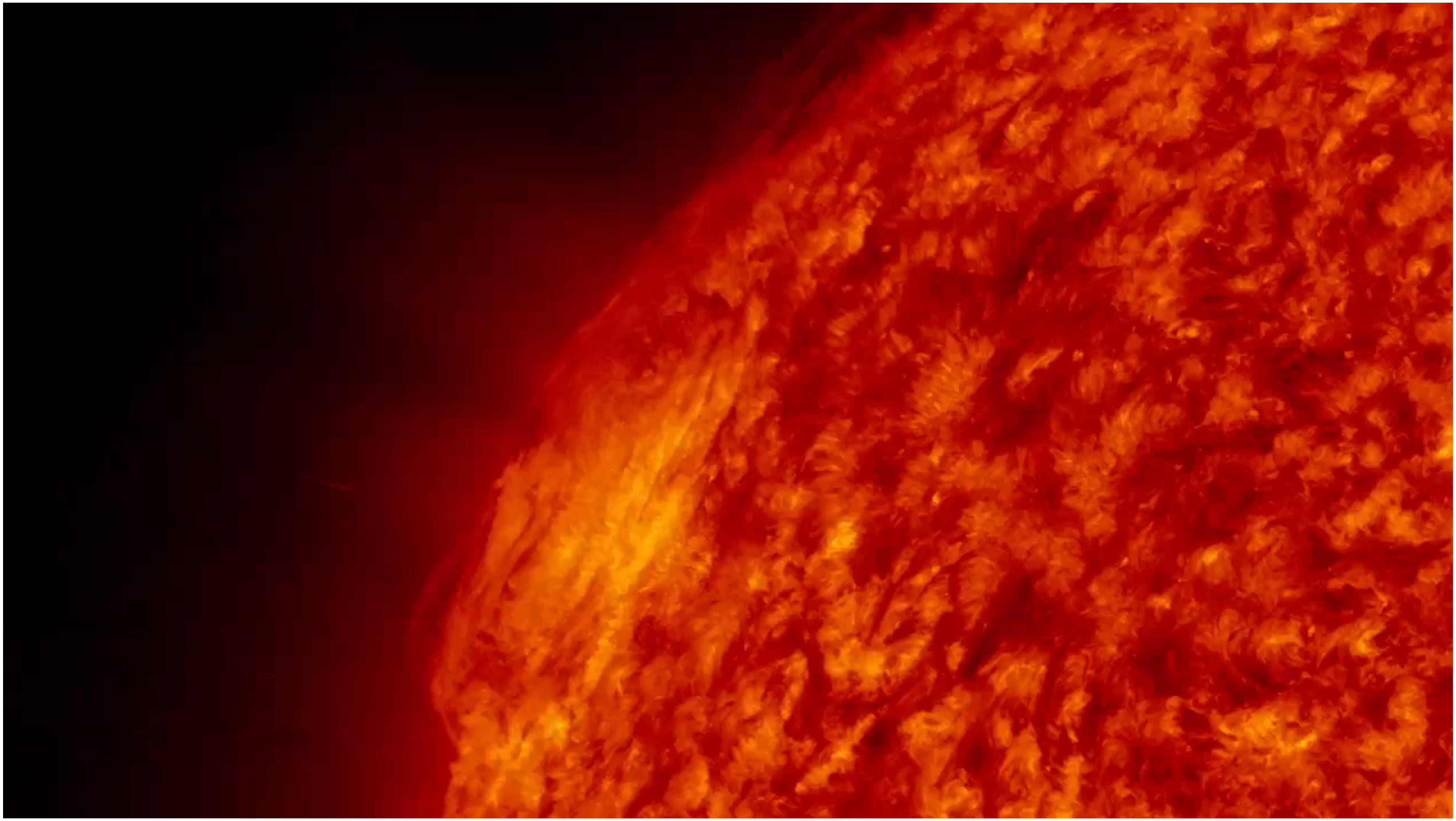
Solar corona, wind and magnetic activity





PARKER SOLAR PROBE

A MISSION TO TOUCH THE SUN

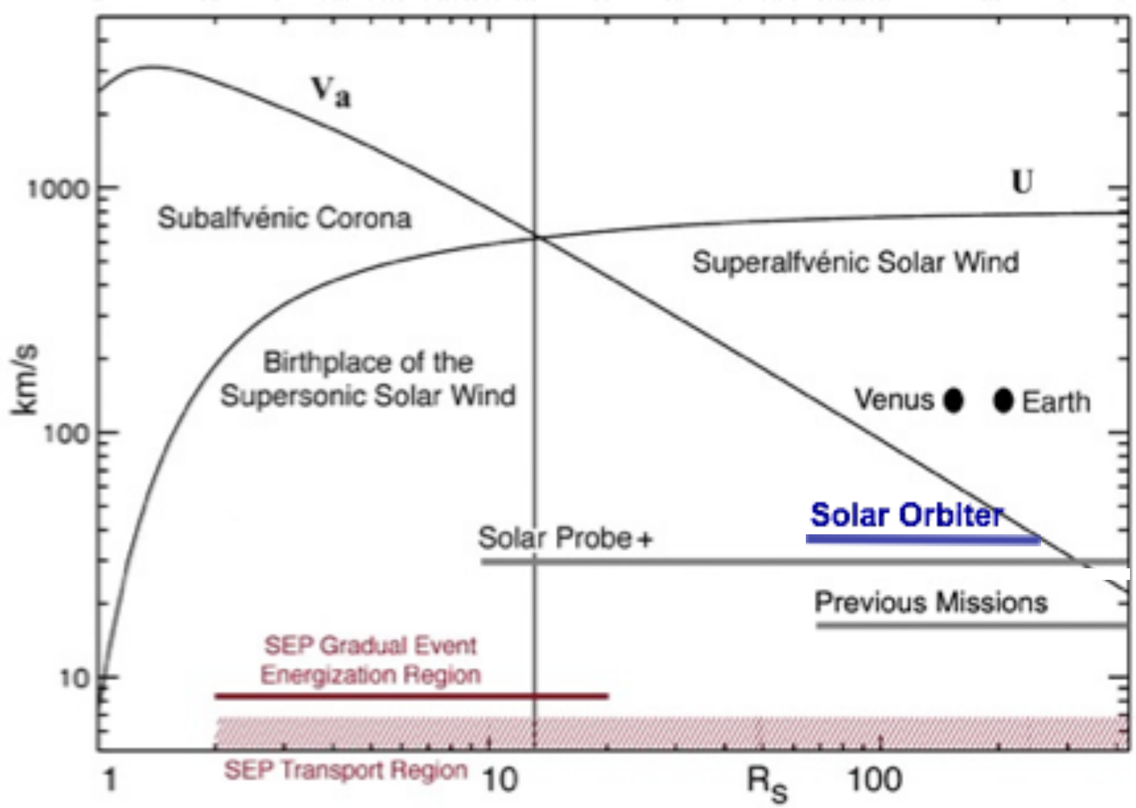


PSP Science Objective

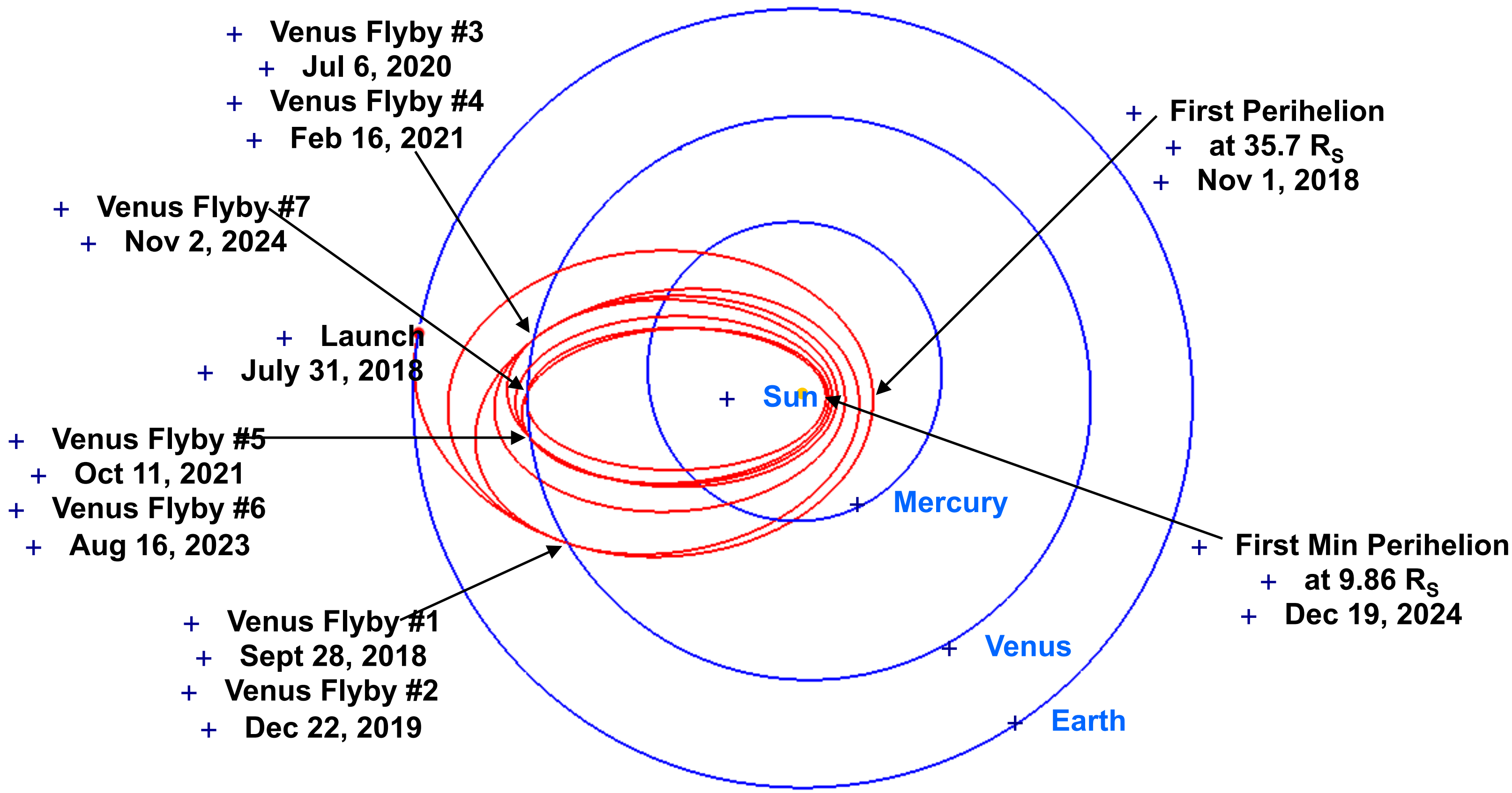
- **To determine the structure and dynamics of the Sun's coronal magnetic field, understand how the solar corona and wind are heated and accelerated, and determine what mechanisms accelerate and transport energetic particles.**

Observations inside 20Rs:

- coronal magnetic structure still channels the flow
- waves, turbulence are strongest
- temperature maximum.
- Collisional - Collisionless transition.



Parker Solar Probe mission profile

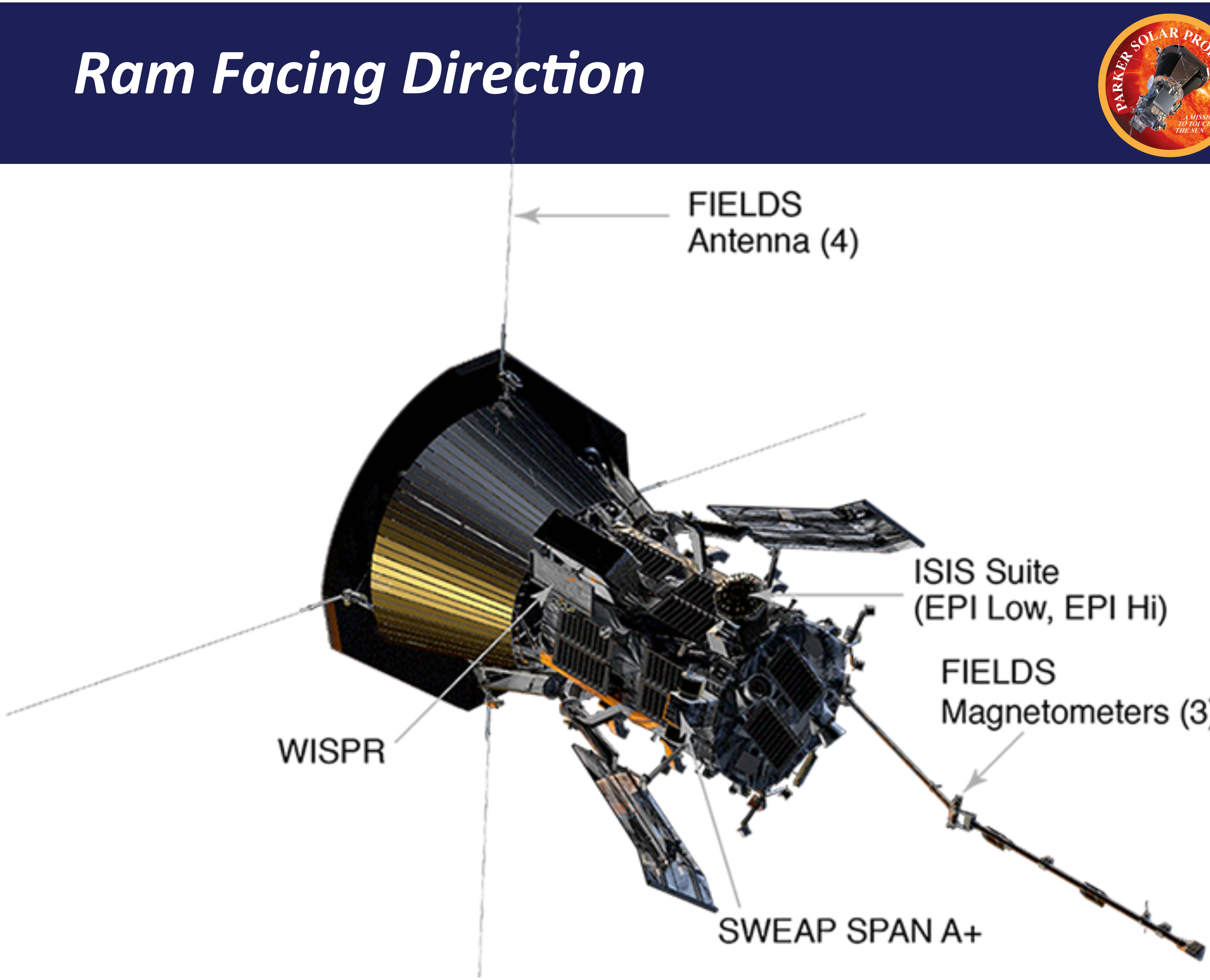


At a speed of 190 km/s: probe crosses the corona taking about: 1 - 3 minutes s-granule

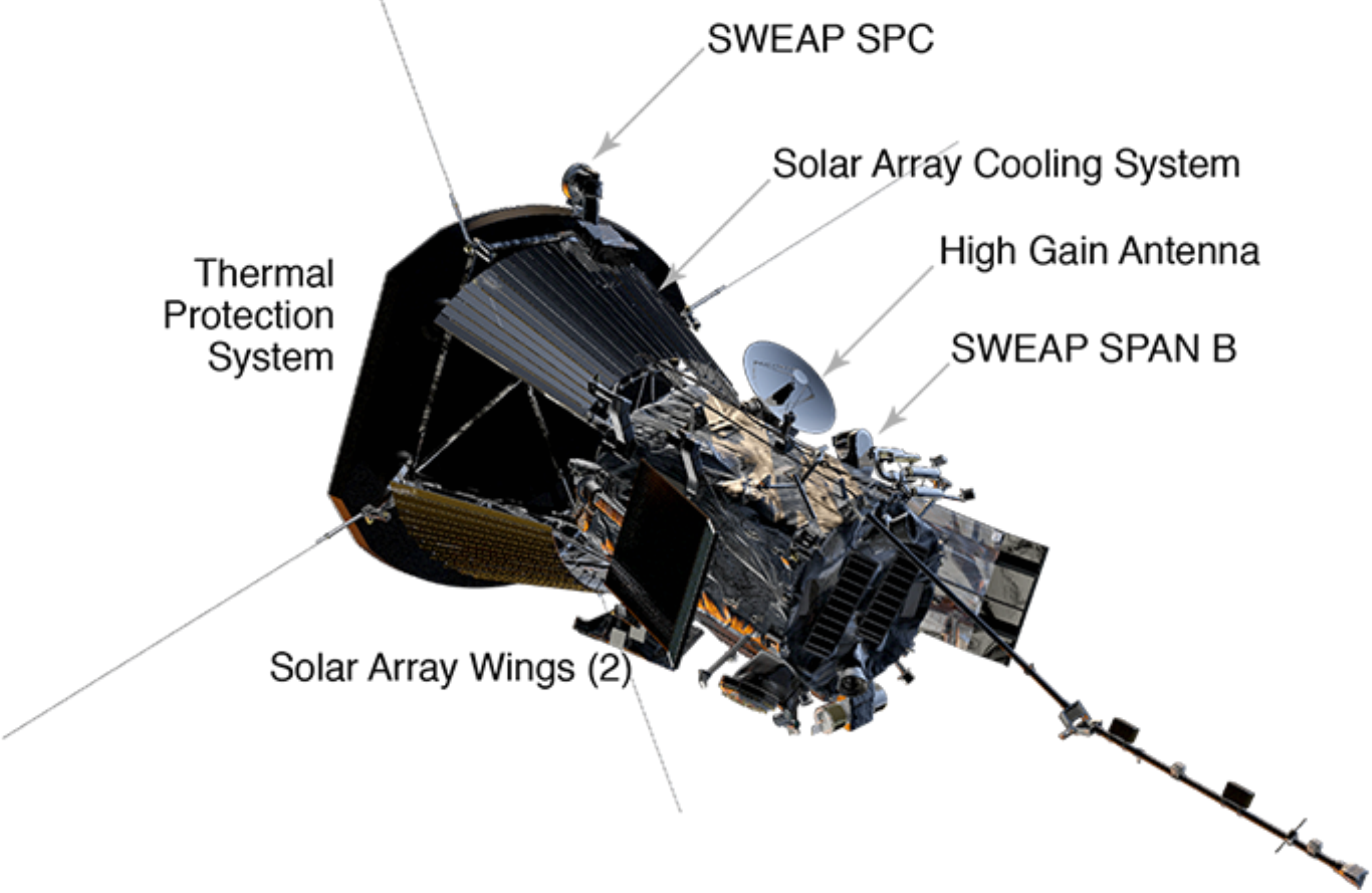
Science Investigations

- *Electromagnetic Fields (FIELDS) Investigation*
  - *PI. Stuart D. Bale, University of California Space Sciences Laboratory, Berkeley, CA*
- *Integrated Science Investigation of the Sun Energetic Particle Instruments (ISIS-EPI),*
  - *PI. David J. McComas South West Research Institution, San Antonio, TX *APL, CalTech*
- *Solar Wind Electrons Alphas and Protons (SWEAP) Investigation*
  - *PI. Justin Kasper, U Michigan *SAO/Berkeley*
- *Wide field Imager for Solar Probe (WISPR)*
  - *PI. Russell A Howard Naval Research Laboratory, Washington, DC*
- *Heliospheric Origins with Solar Probe Plus - Observatory Scientist (HeliOSPP)*
  - *PI. Marco Velli, UCLA and Jet Propulsion Laboratory, Pasadena, CA*
  - *The Observatory Scientist addresses SPP science objectives via multi-instrument data analysis and provides independent advice to optimize the scientific productivity of the mission.*

Ram Facing Direction

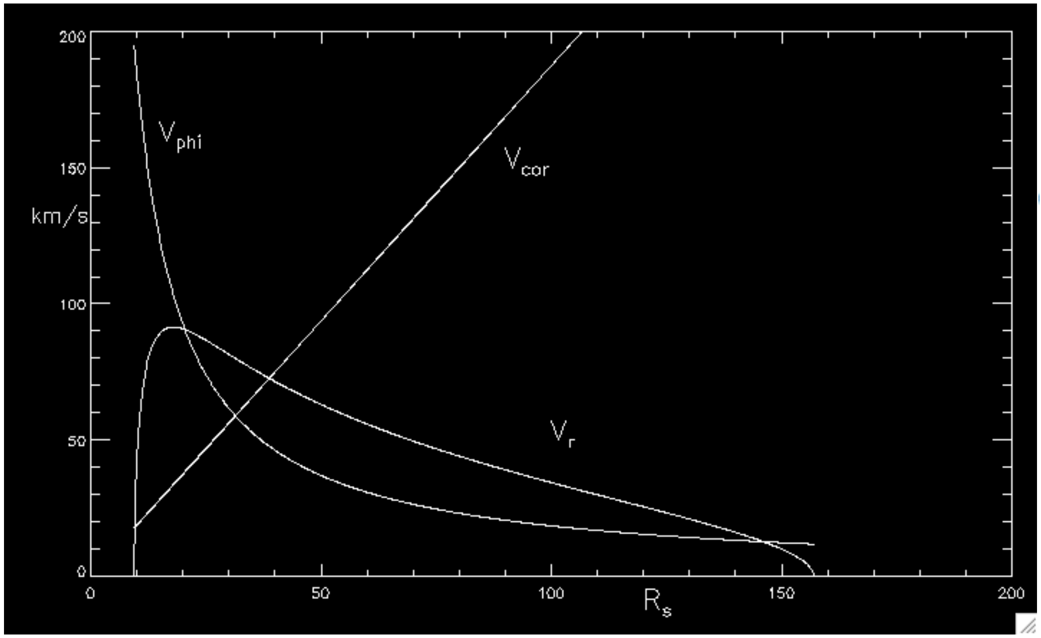


Anti-Ram Facing Direction



Solar Probe Plus mission profile

Radial Scan (SR) (between 23 and 37 R_S; 2 days), to sample the same solar wind stream for an extended interval while the spacecraft is in quasi-corotation with the Sun.



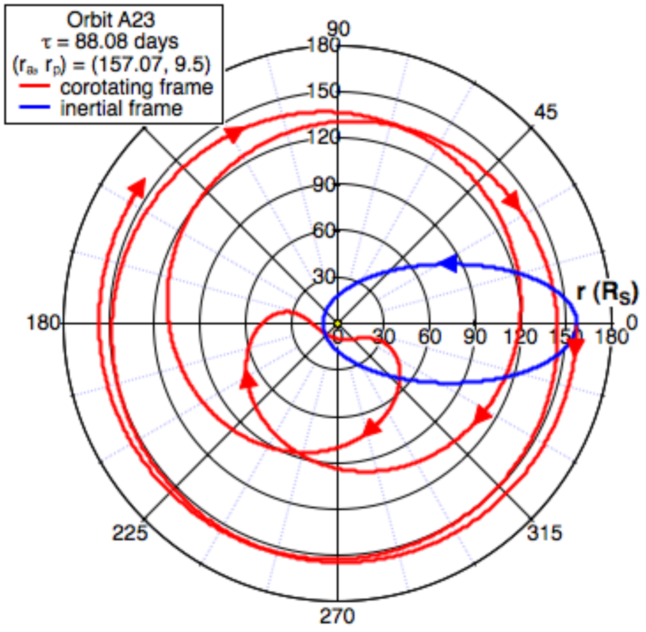


Figure: Decker and Lario 2011

Science Implementation

- ***Statistical survey of outer corona***

  ~920 Hrs inside 20 R_s 12 inside 10 R_s

  Excellent sampling of all types of Solar Wind

  More time within Alfvén critical point than 2005 study

- ***In-Situ measurements***

  Plasma, suprathermals, energetic particles, magnetic fields, waves (indirect dust: field)

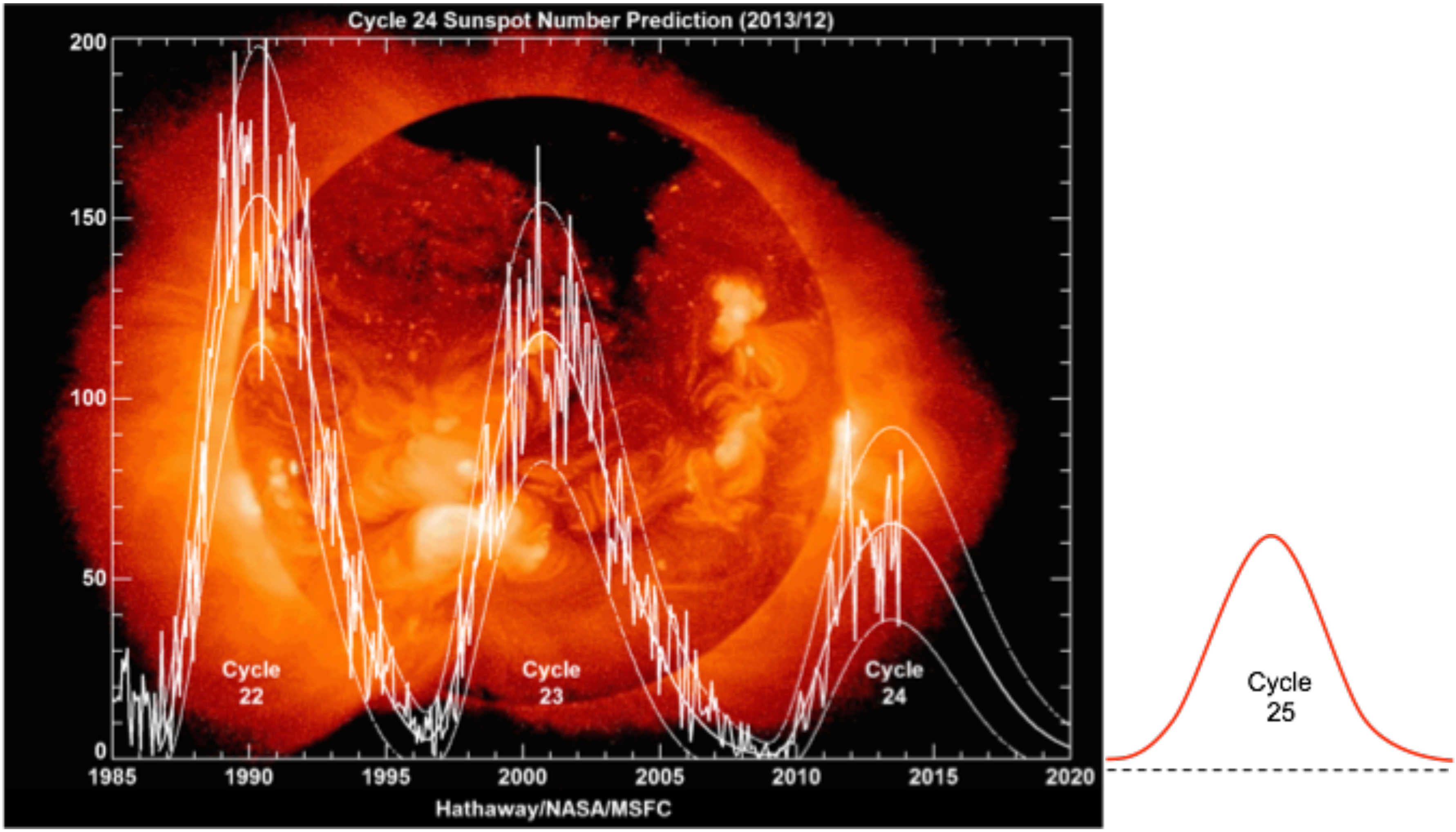
- ***On-board remote-sensing observations***

  White light imaging provide both context and quasi in-situ measurements of density and dust

- ***Coordinate extensive remote-sensing from other assets which can view solar source regions***

  ~450 Hrs while PSP is inside 20 R_s and the footprint is visible from Earth

Solar Cycle: SPP will be going from minimum to ascending phase?



Heating and acceleration: Some General Considerations

- Steady state conservation equations (in rotating frame of reference and neglecting centrifugal force, important only at large distances from the sun)

$$\nabla \cdot (\rho \vec{U}) = 0$$

$$\nabla \cdot (\rho \vec{U}\vec{U}) = -\nabla \left(p + \frac{B^2}{8\pi} + \frac{< \delta B \delta B >}{8\pi} \right) + \frac{\vec{B}}{4\pi} \cdot \nabla \vec{B} + \rho \mathbf{g} - \nabla \cdot (\rho < \delta U \delta U > - < \delta B \delta B > /4\pi)$$

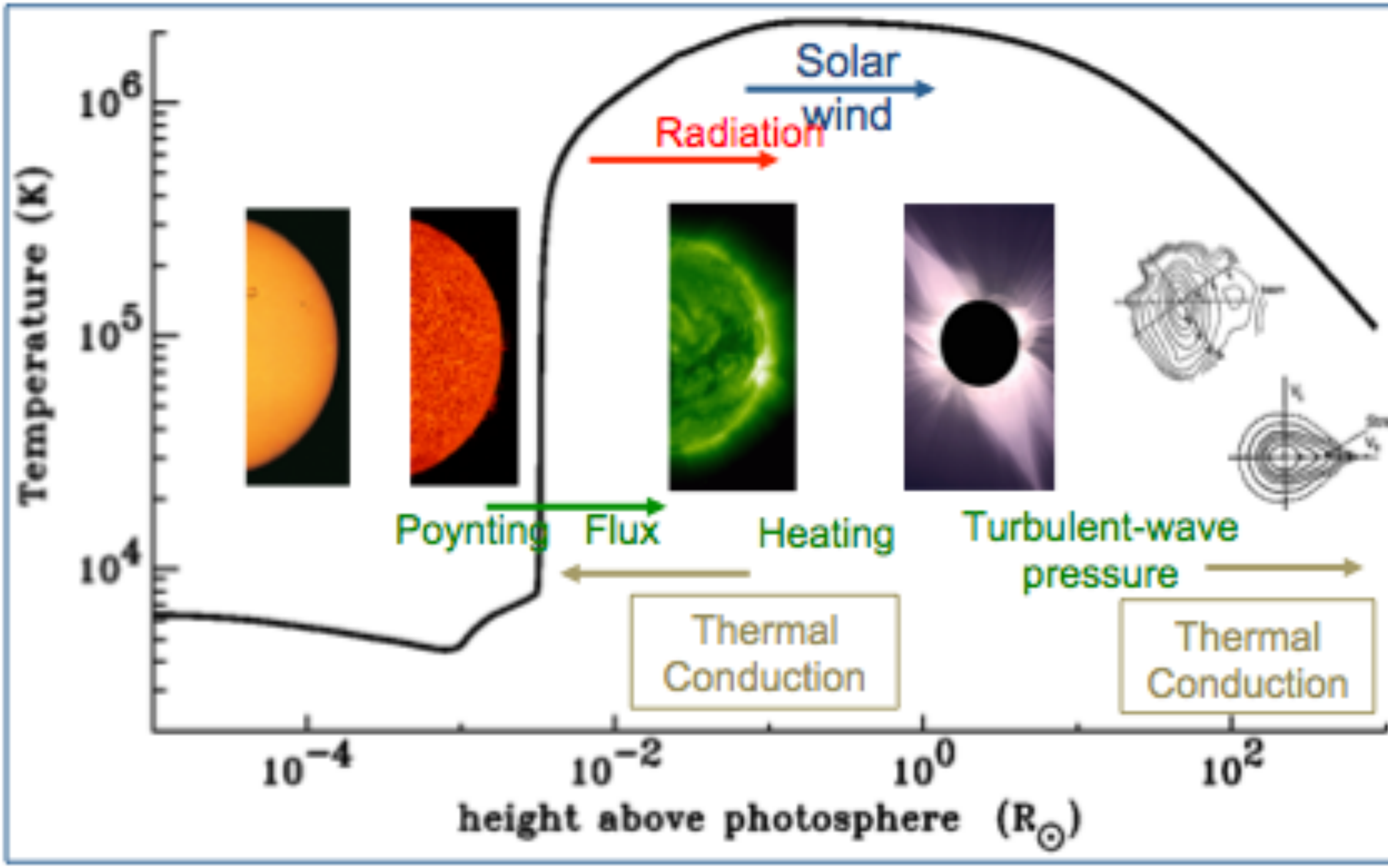
- "critical points" appear as singularities in the steady state equations, and the equations can change character in the 2D transfield direction (hyperbolic/elliptic et.c.)

$$(U - \frac{V_T^2}{U})\frac{dU}{dr} = \frac{V_T^2}{A}\frac{dA}{dr} - \frac{V_g^2}{2}\frac{1}{r^2}$$

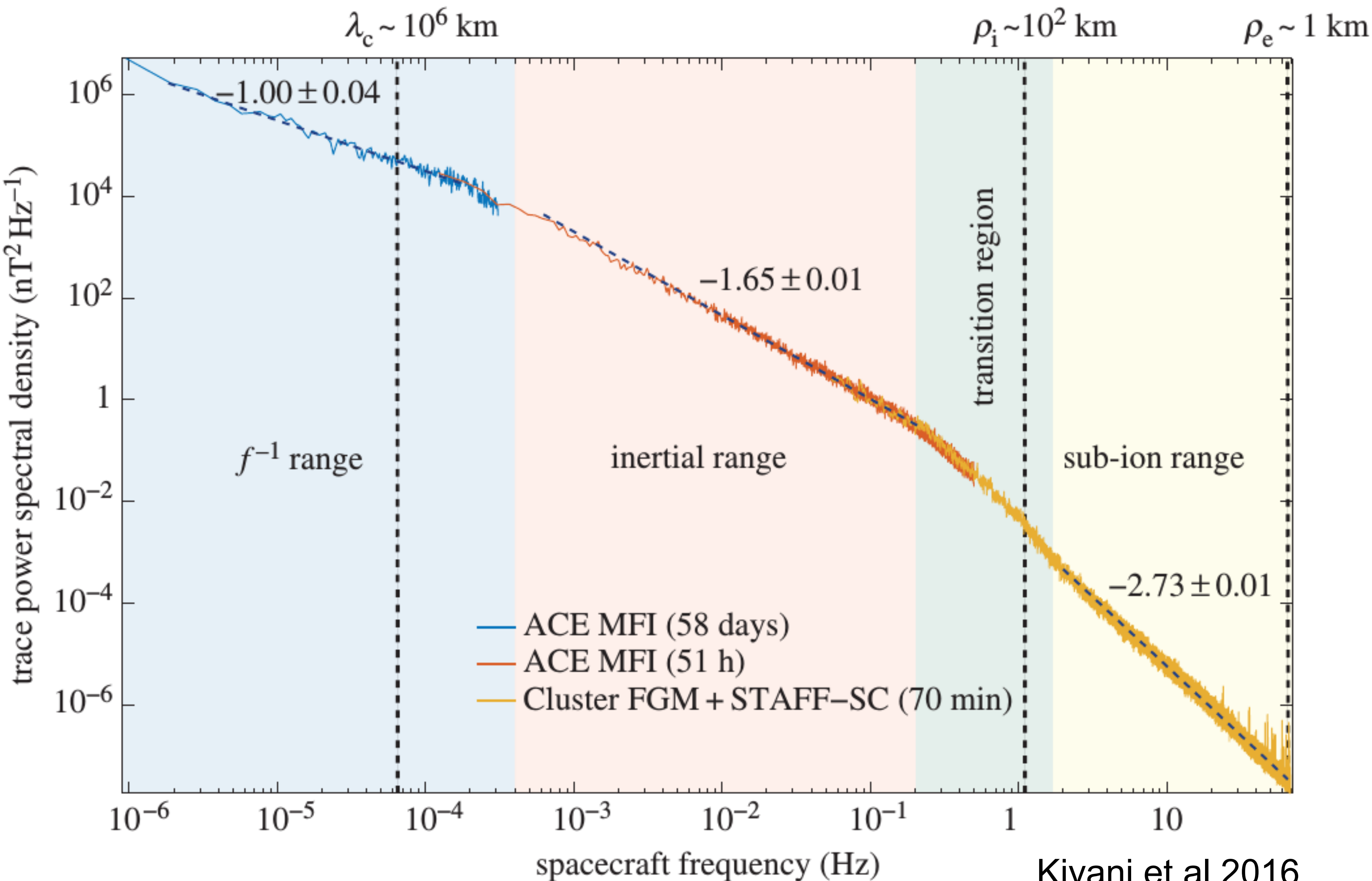
$$\frac{\partial z^\pm}{\partial t} + (V \pm V_a) \bullet \nabla z^\pm + z^\mp \bullet \nabla (V \mp V_a) + \frac{1}{2}(z^- - z^+)\nabla \bullet (V_a \mp \frac{1}{2}V) =$$
$$-\frac{1}{\rho}\nabla (p^T - \langle p^T \rangle - \left[z^\mp \bullet \nabla z^\pm - \langle z^\mp \bullet \nabla z^\pm \rangle \right]$$

How is energy from the lower solar atmosphere transferred to, and dissipated in, the corona and solar wind?

Solar Probe Plus
A NASA Mission to Touch the Sun

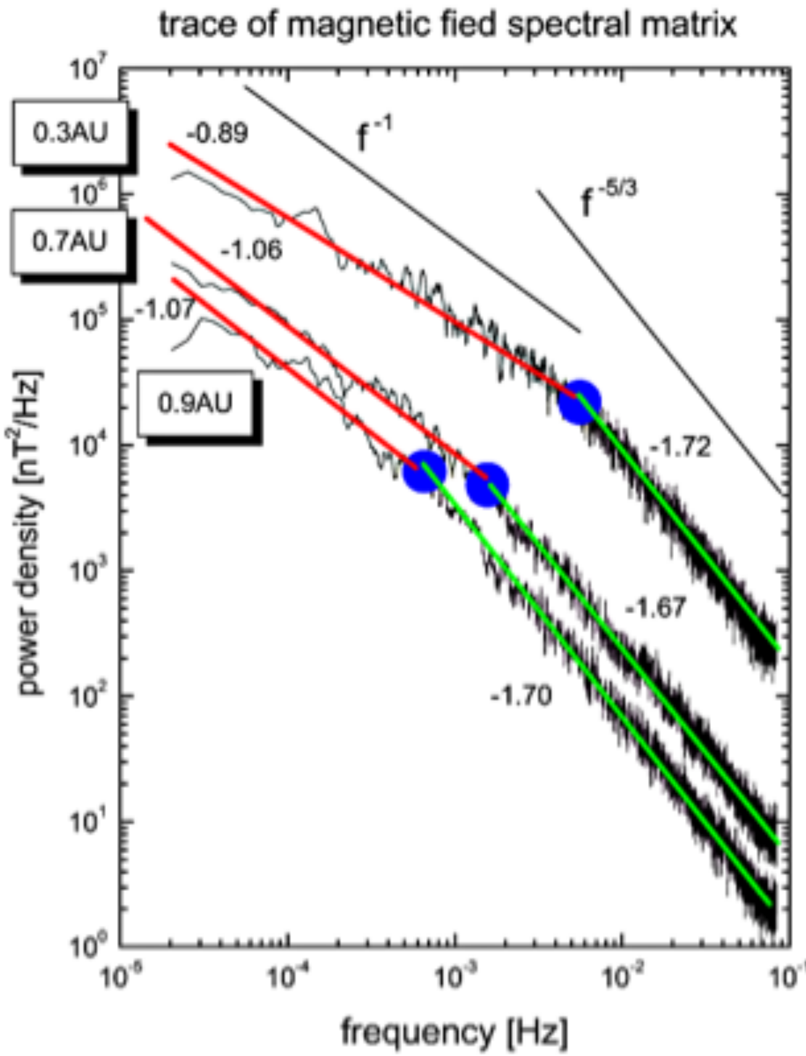


Magnetic field energy spectrum at 1 AU



Kiyani et al 2016

MHD Turbulence in the Evolving Corona and Solar Wind



With well developed spectra, which evolve from a shape with P(ω) ~ ω^{-1} at low frequencies, to P(ω) ~ $\omega^{-1.67}$ at high frequencies.

Energy in the fluctuations
$E = \rho u^2/2 + b^2/8\pi = E^+ + E^-$ also evolves with distance $E(R) \sim R^{-a}$ with a >3
- $E^+ \sim R^{-3.48}$, $E^- \sim R^{-2.42}$

$E^- / E^+ \sim 0.5$ for R>2.5 AU
Bavassano et al. 2000)

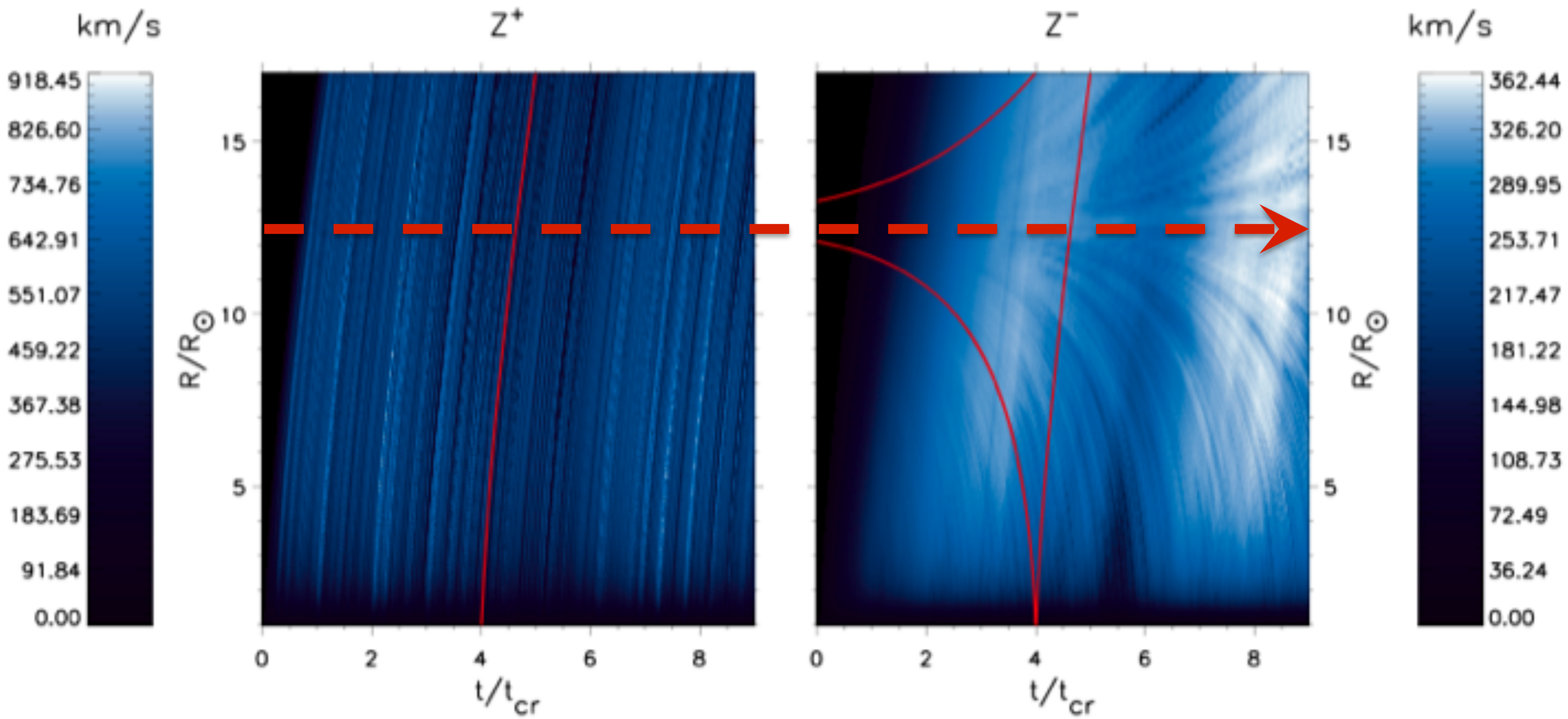
MHD Turbulence in the Evolving Corona and Solar Wind

Models for the evolution of turbulence in the solar wind: starting point are the MHD wave equations in a radially expanding flow

$$\frac{\partial z^{\pm}}{\partial t} + (V \pm V_a) \bullet \nabla z^{\pm} + z^{\mp} \bullet \nabla (V \mp V_a) + \frac{1}{2}(z^{-} - z^{+}) \nabla \bullet (V_a \mp \frac{1}{2} V) =$$
$$-\frac{1}{\rho} \nabla p - \left[z^{\mp} \bullet \nabla z^{\pm} - \left\langle z^{\mp} \bullet \nabla z^{\pm} \right\rangle \right]$$

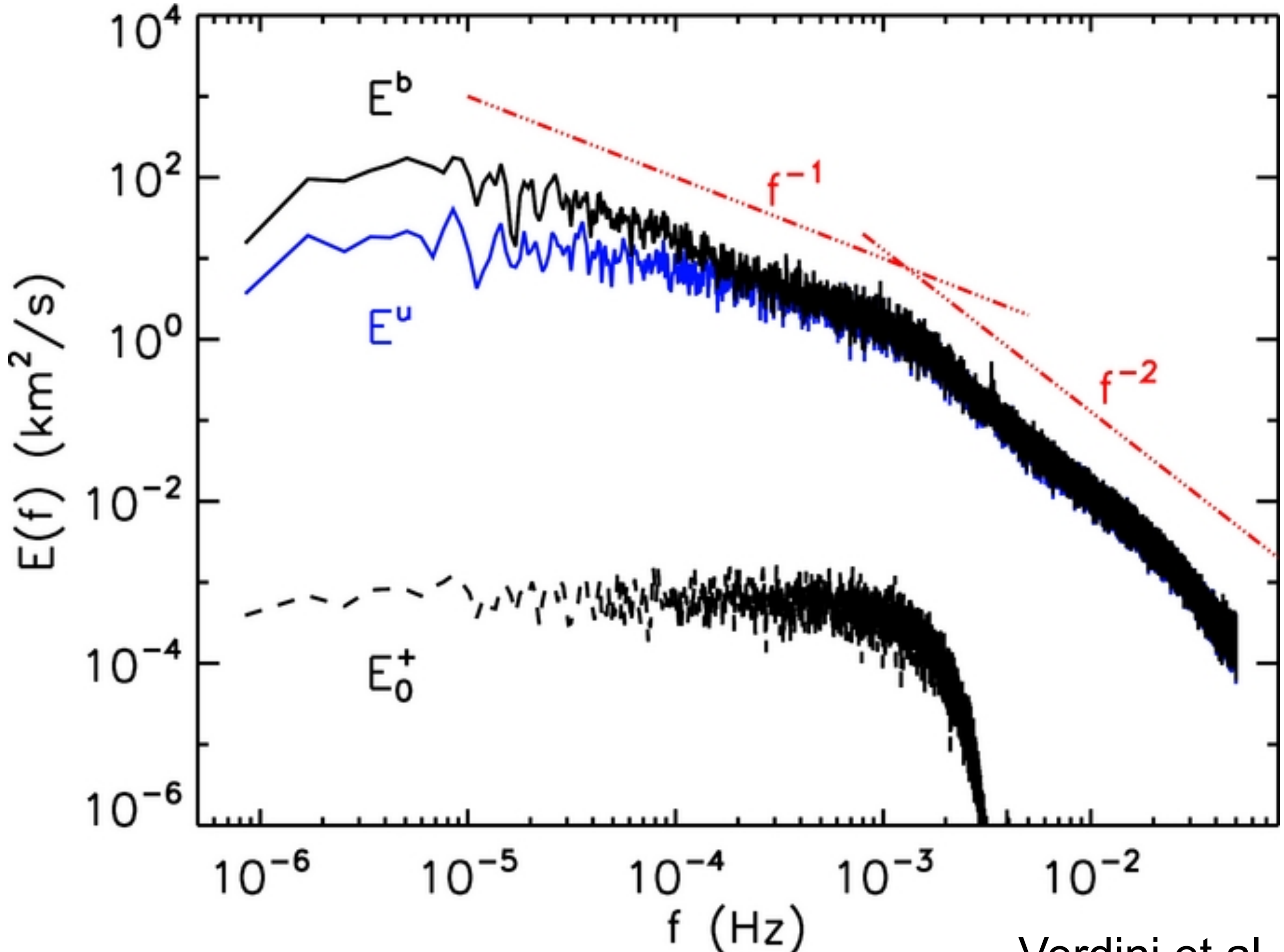
Main drivers of evolution Spherical Expansion; Velocity and Alfvén speed gradients; Nonlinearity

Alfvén point provides distinct coronal turbulence regions



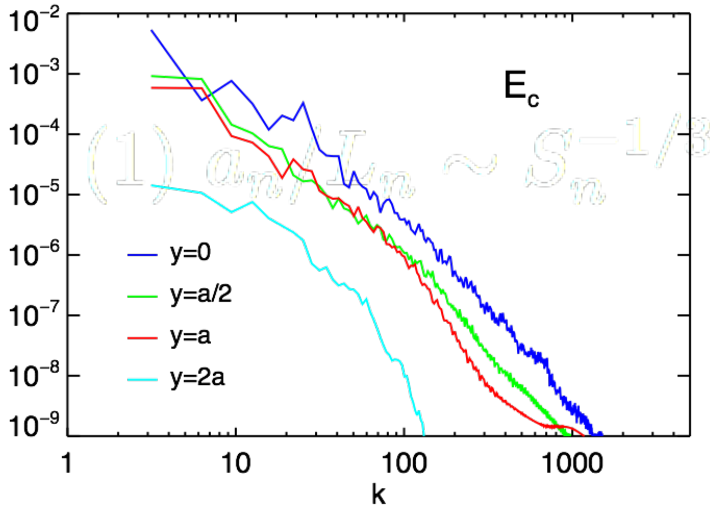
Outward Alfven waves "Inward" Alfven waves

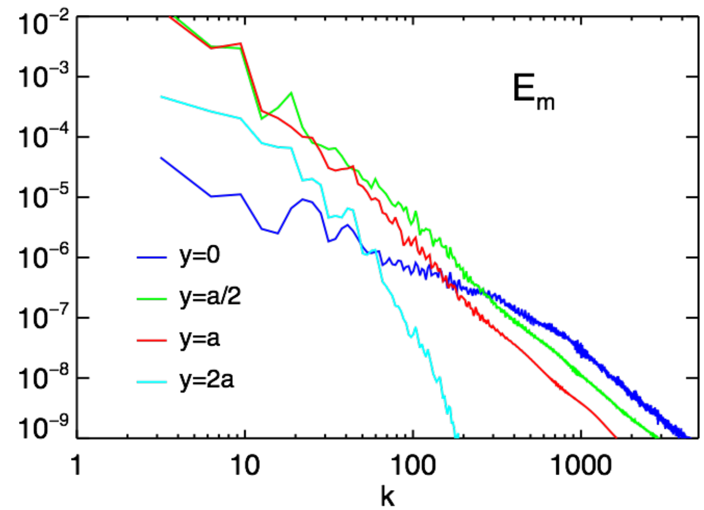
f^{-1} originating from coronal turbulence

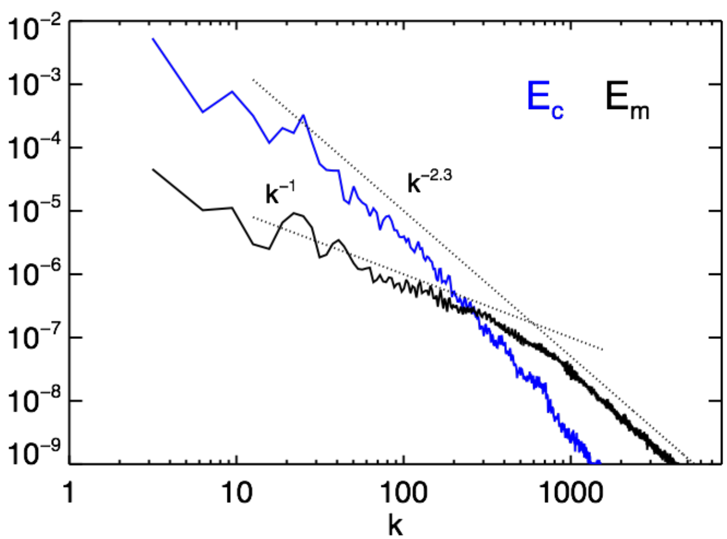


Verdini et al. 2013

Or a spectral signature of “recursive tearing”?



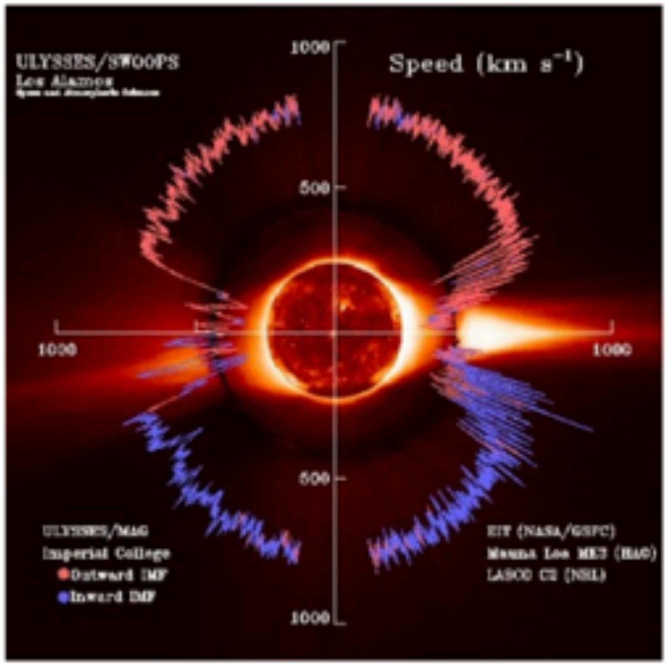




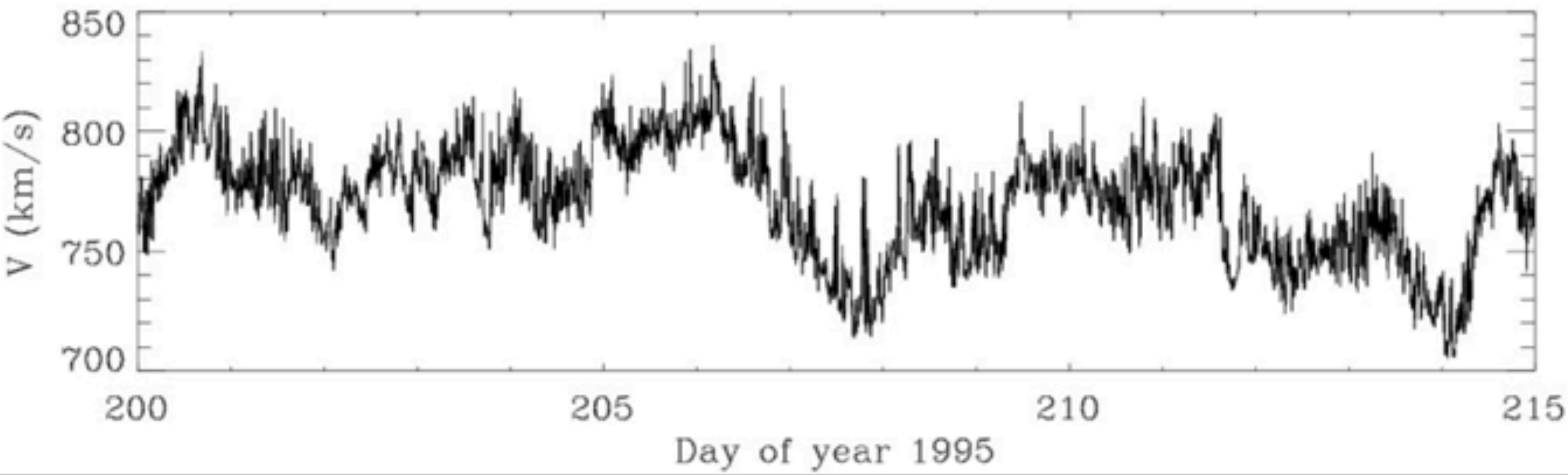
A possible avenue to form the low-frequency spectrum in the solar wind.
Plasmoid / density spectrum?

Tenerani et al2017

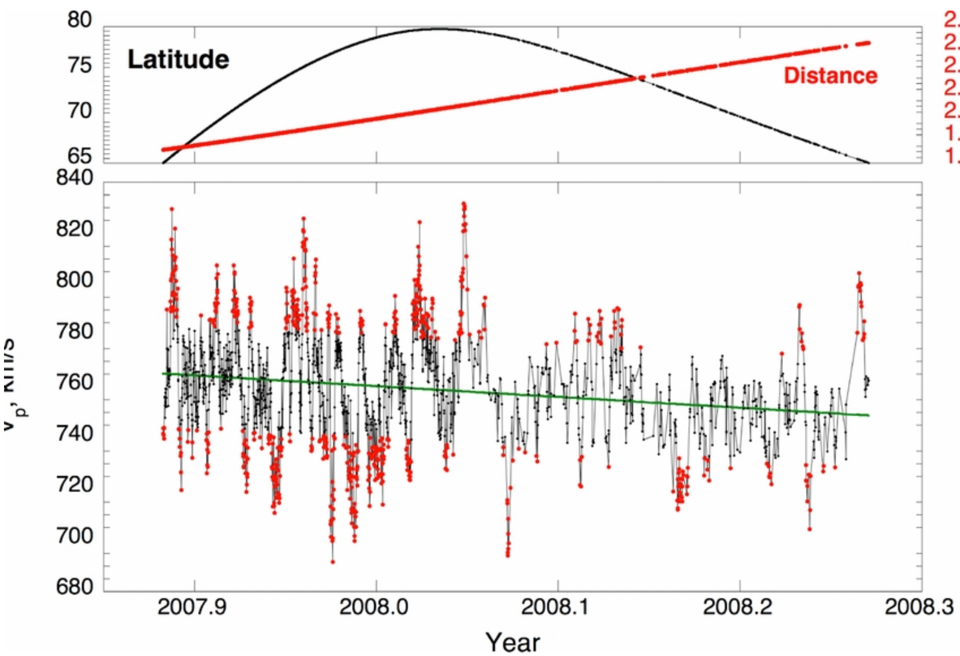
Solar wind velocity profile

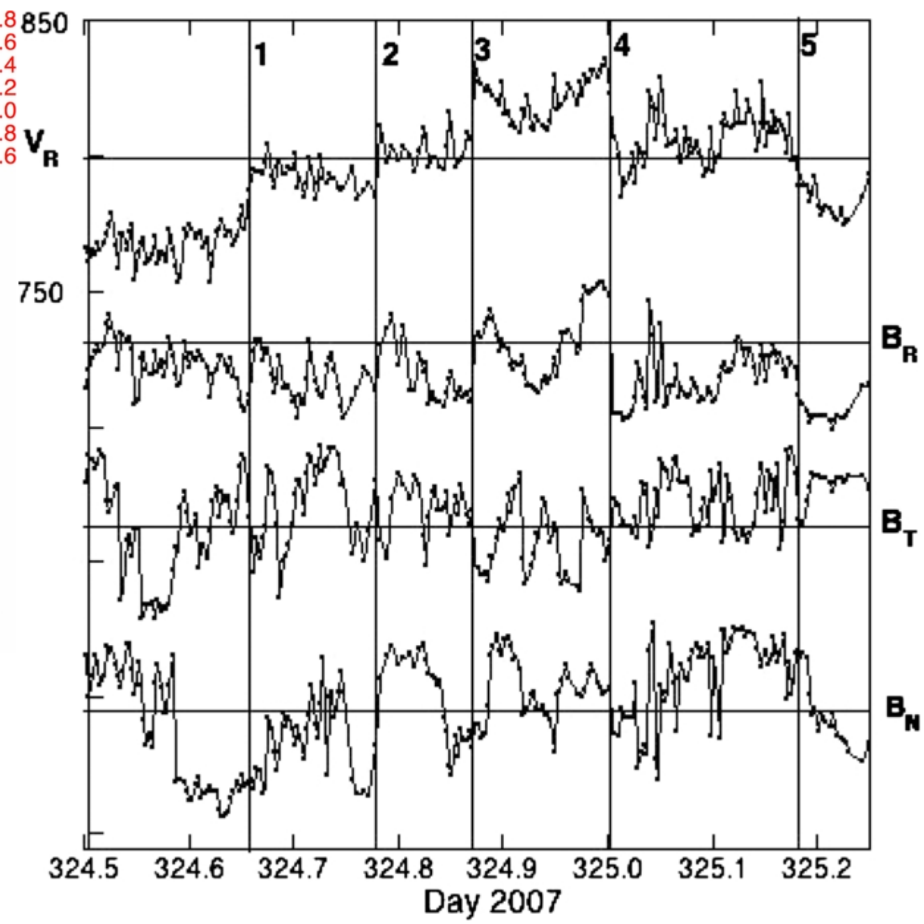


- Fast wind from Solar poles
- Dipole magnetic field
- Speed variations:
  - structures (~day)
  - Alfvénic fluctuations (~hour)



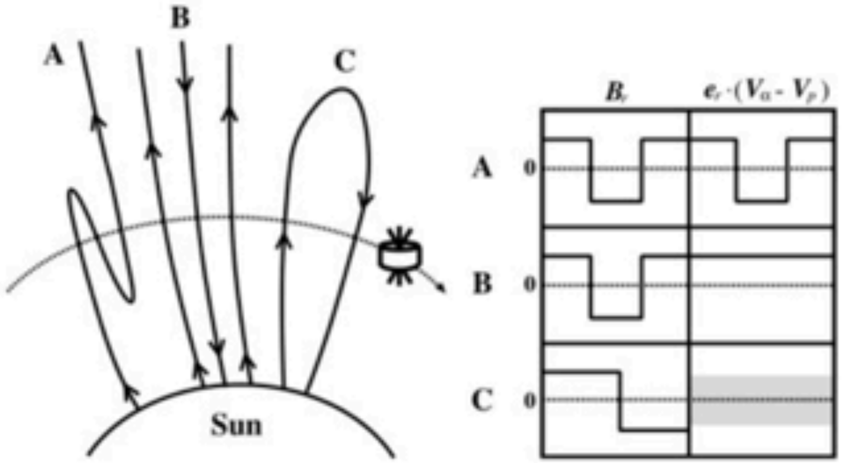
High speed streams microstreams/ Alfvenic Jets





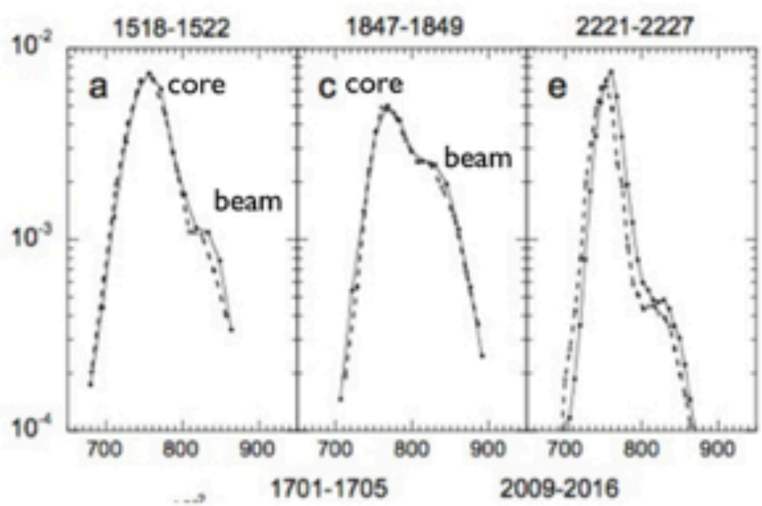
Neugebauer 2012
Matteini et al. 2013-2016

switchbacks
(magnetic field reversals)



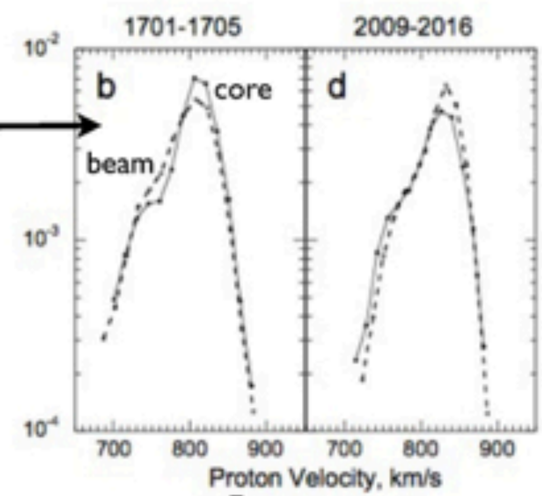
Reversal during switchbacks:
- Electron heat flux
- Alpha-proton drift
- Propagation of Alfvén waves

Yamauchi et al. 2004



before and after switchbacks

Proton core and beam also inverted when B_R changes sign

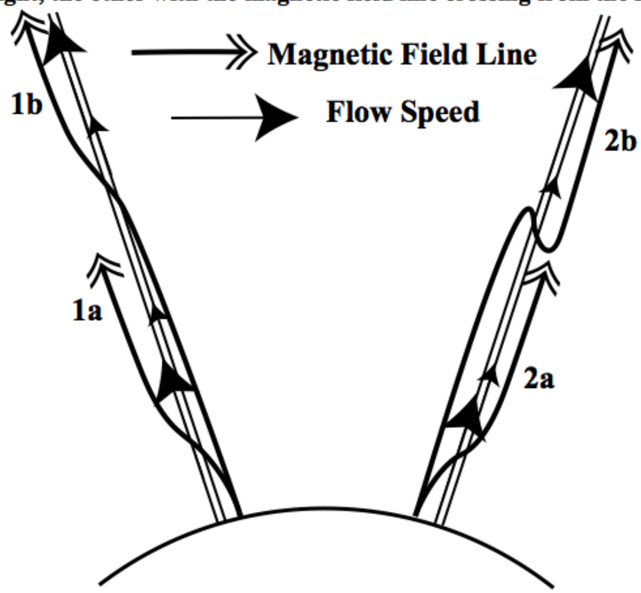


Neugebauer & Goldstein 2012

switchbacks

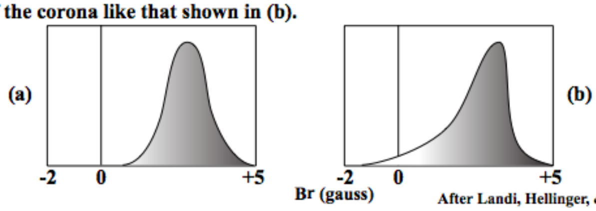
Formation of tails in the radial magnetic field

Two similar shear layers, one with a magnetic field line crossing from the right, the other with the magnetic field line crossing from the left.

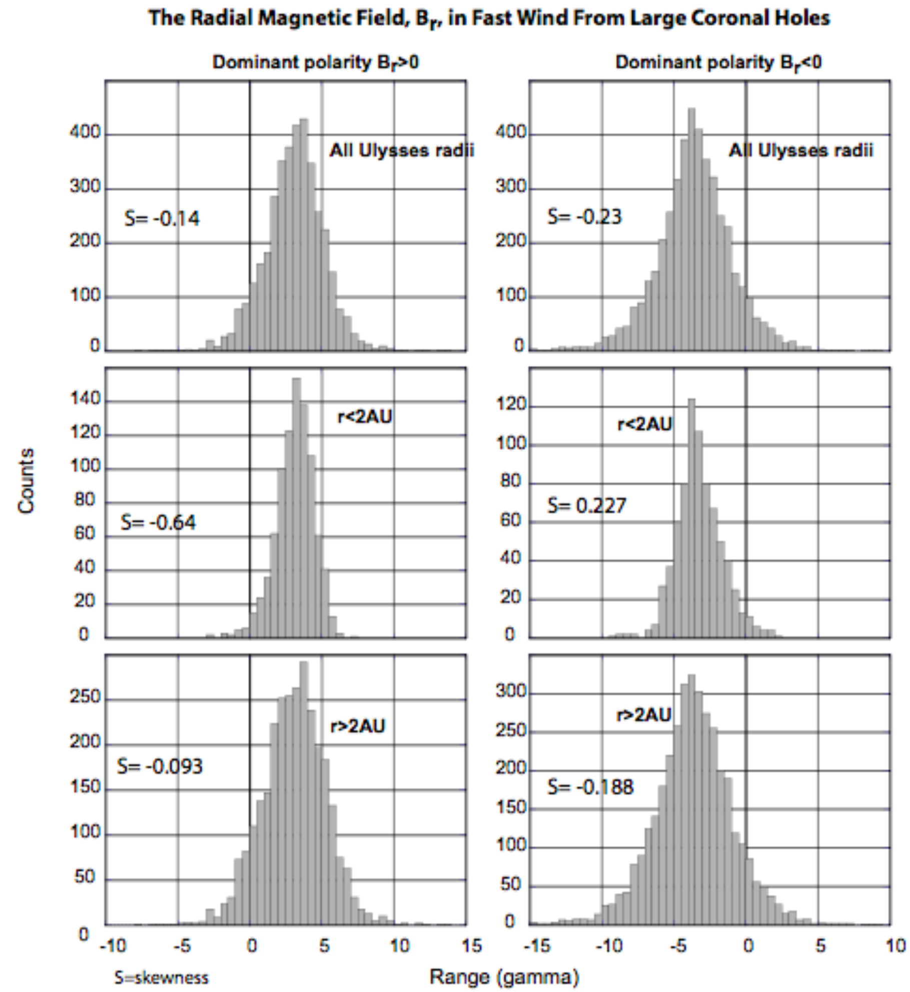


The field line on the left is stretched and slightly amplified (1a -> 1b).
The field line on the right is folded (2a-> 2b).

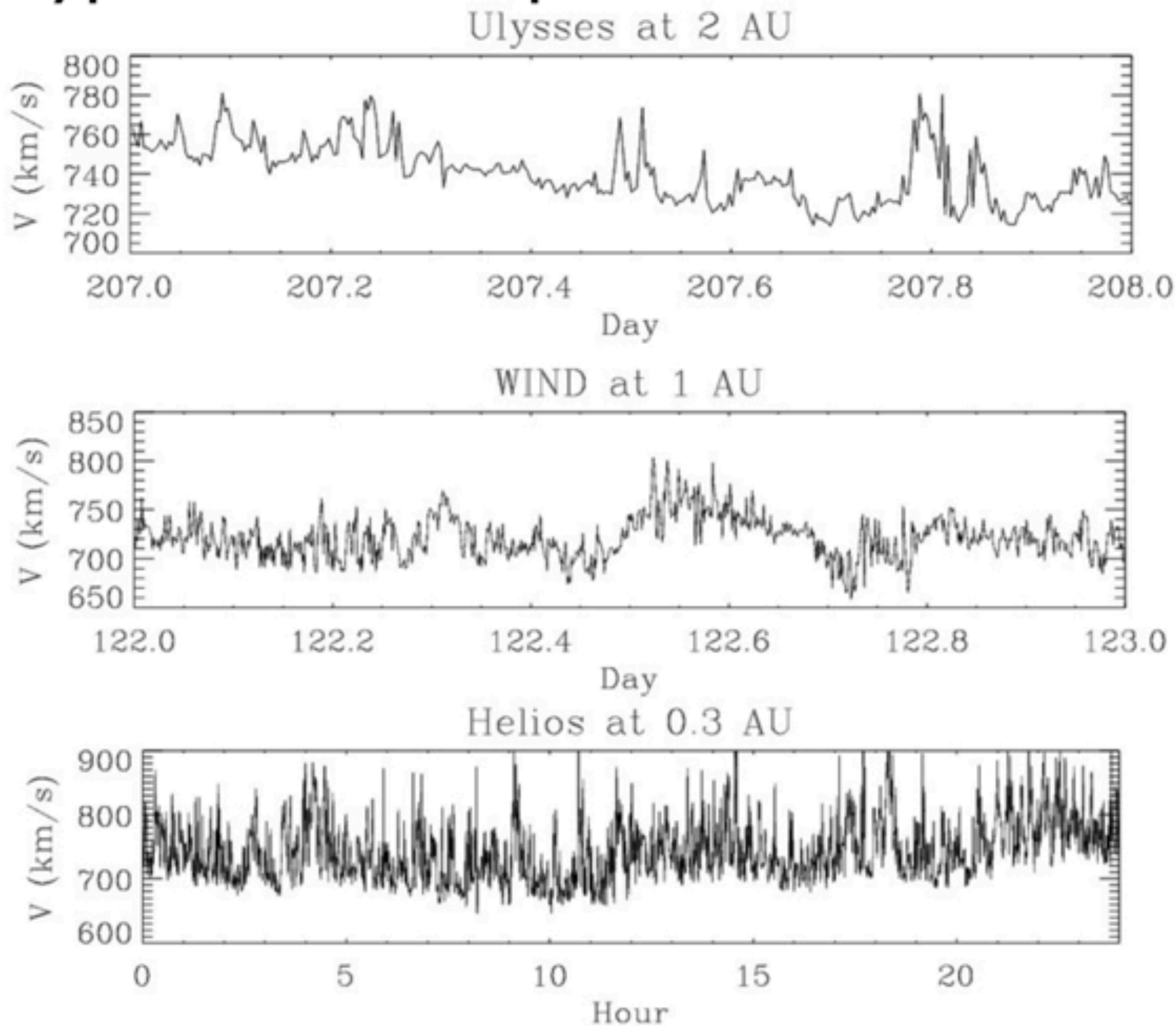
If the initial distribution of (positive) B_r at the photosphere is as shown below in (a), then an interaction with shear layers will produce a distribution at the top of the corona like that shown in (b).



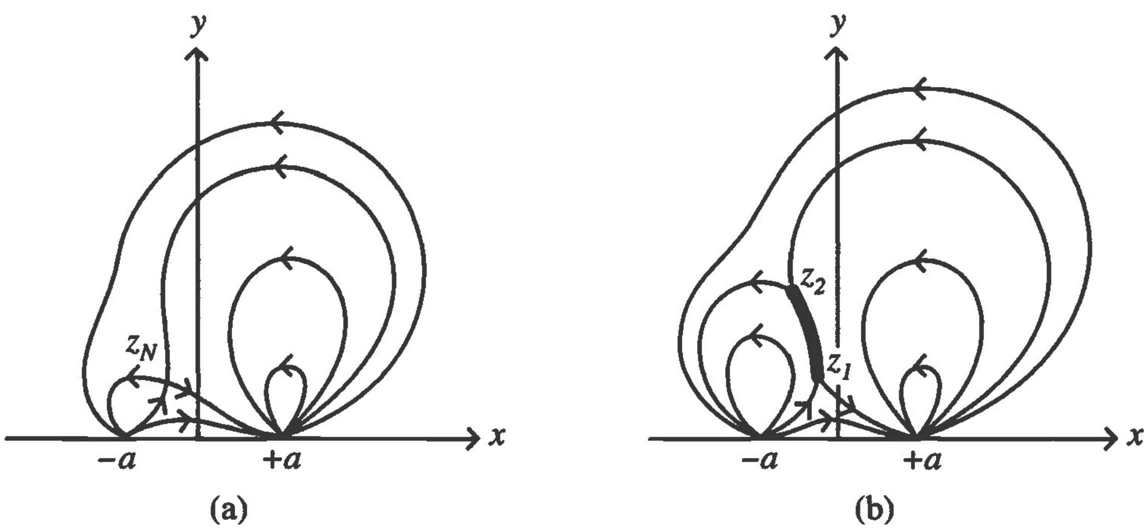
After Landi, Hellinger, & Velli (2006)



Typical fast wind profiles at different R



Current Sheets naturally arise in the coronal magnetic field



Forbes&Priest 07

This configuration CAN NOT be imagined as a static equilibrium configuration. Almost ALL configurations must be intrinsically dynamic. Are there really FF fields or are all fields dynamic with low-level “turbulence”???

“Ideal” Tearing Mode Instability

- *A critical aspect ratio $(L/a)_c$ must exist provides a “sup” for current sheets that can naturally form*
- *Onset of “ideal” tearing can provide a scenario for the trigger of fast reconnection*

THE ASTROPHYSICAL JOURNAL LETTERS, 780:L19 (4pp), 2014 January 10 doi:10.1088/2041-8205/780/2/L19

RECONNECTION OF QUASI-SINGULAR CURRENT SHEETS: THE “IDEAL” TEARING MODE

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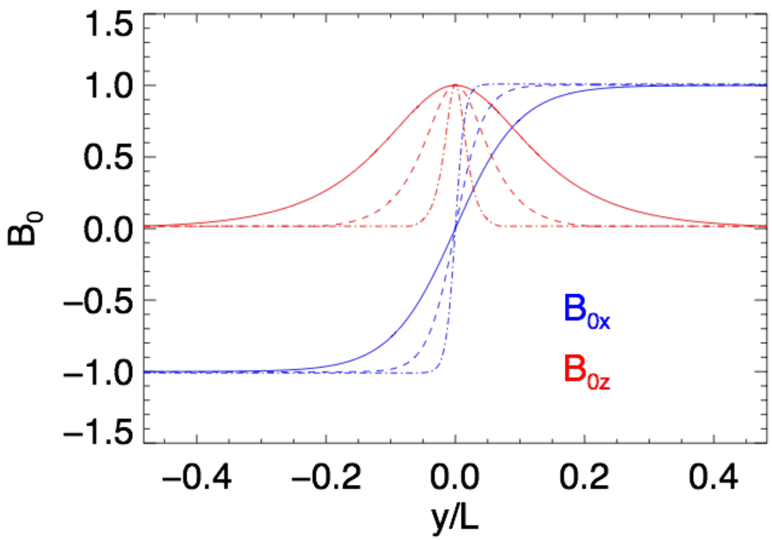
Timing for Fast Magnetic Reconnection?



$$\vec{B}_0(y) = B_0 tanh\left(\frac{y}{a(t)}\right)\hat{\mathbf{x}} + B_0 sech\left(\frac{y}{a(t)}\right)\hat{\mathbf{z}}$$

$$a(t) = a_0\, e^{-t/\tau_c}$$

Earth Planets Space, **53**, 473–482, 2001

Plasmoid-induced-reconnection and fractal reconnection

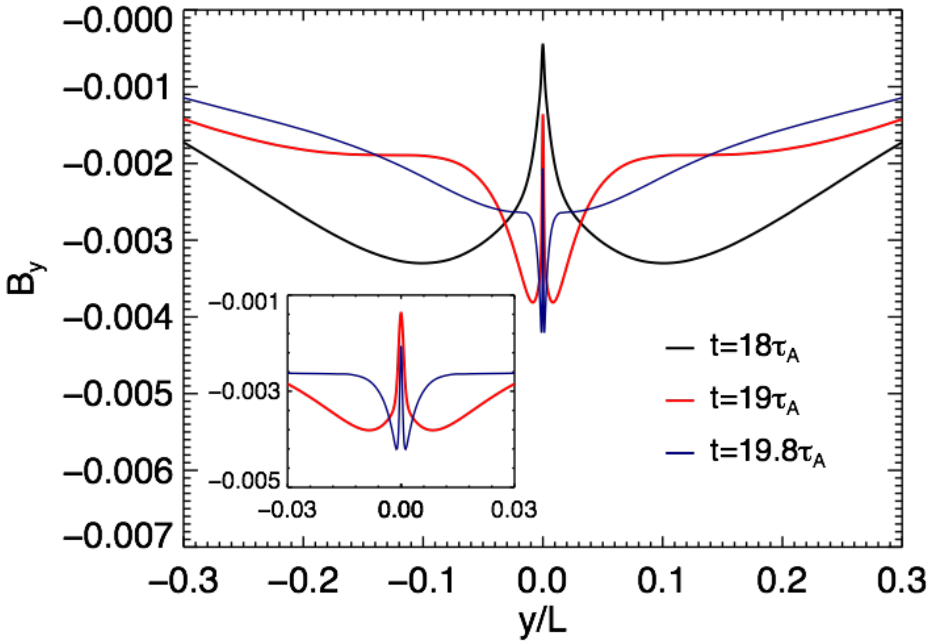
Kazunari Shibata[1] and Syuniti Tanuma[2]

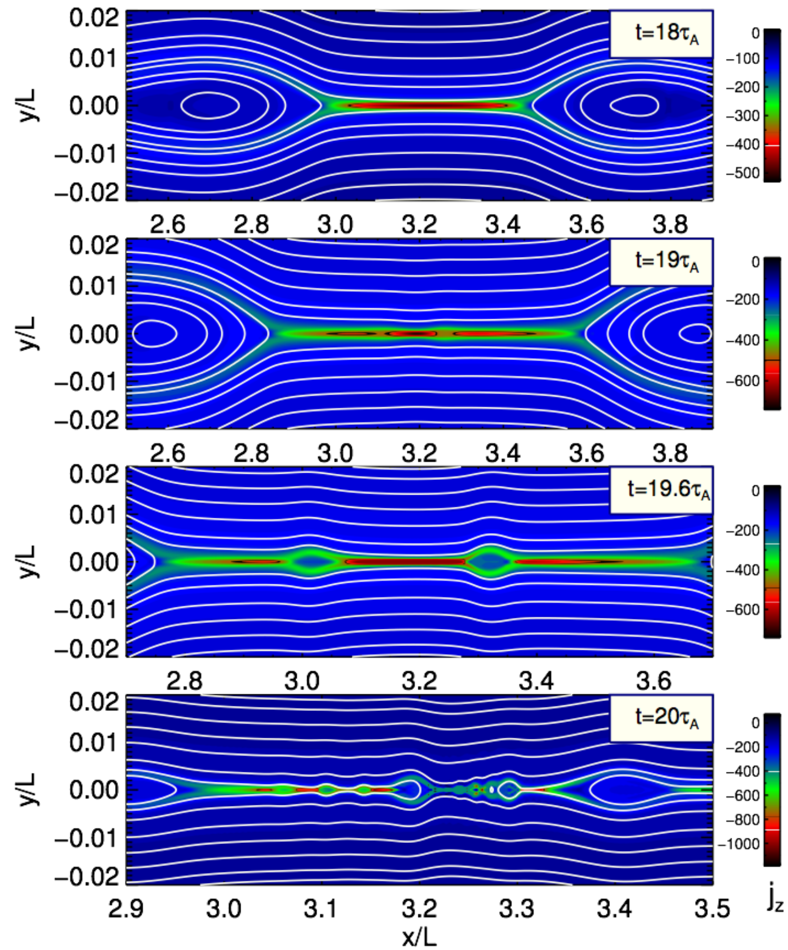
[1]*Kwasan Observatory, Kyoto University, Yamashina, Kyoto 607-8471, Japan*
[2]*STE Laboratory, Nagoya University, Toyokawa, Aichi 442-8507, Japan*

(Received June 28, 2000; Revised November 10, 2000; Accepted February 28, 2001)

UCLA

The fractal reconnection scenario revisited



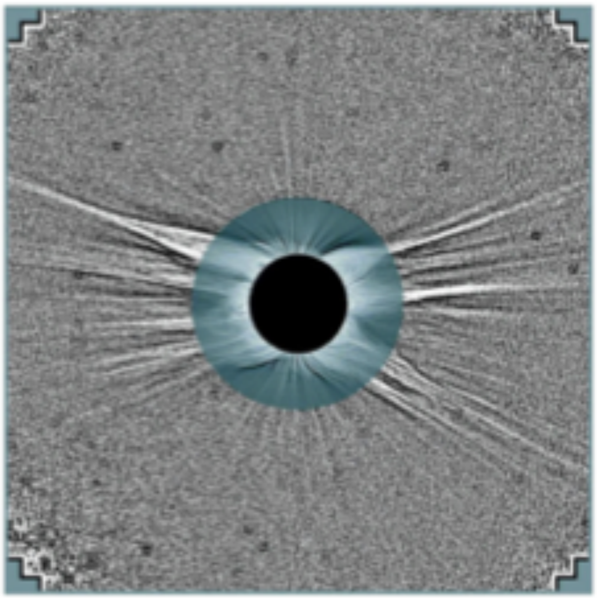


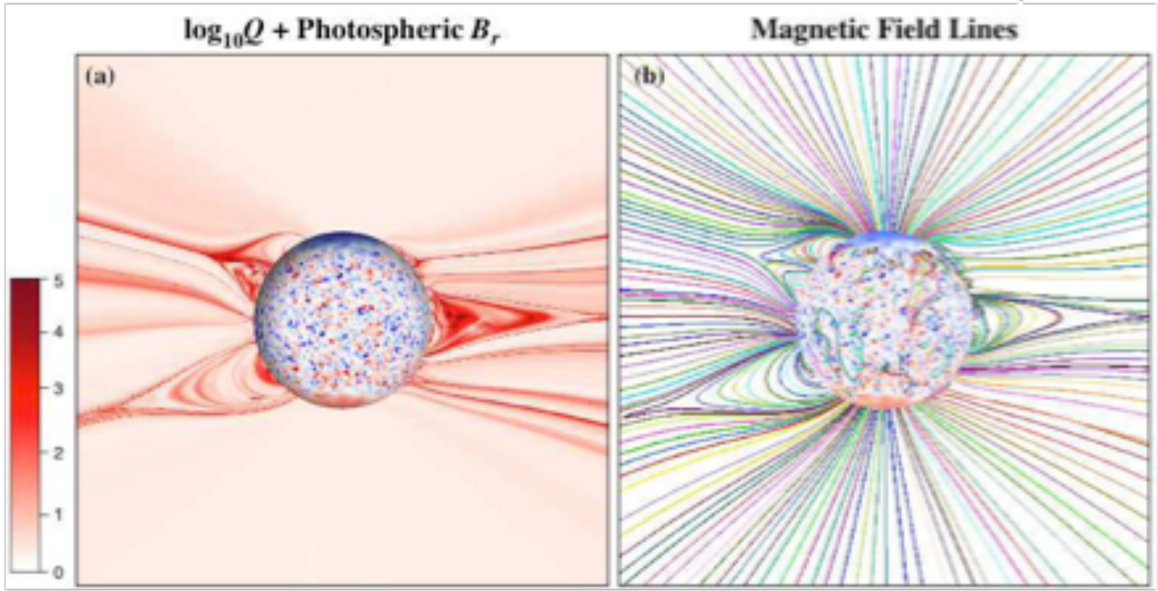
Evidence of "recursive" tearing mode-like instabilities during the nonlinear stage of a primary tearing mode within a Harris current sheet. New plasmoids appear to be generated, at each *n*th step, within smaller and smaller current sheets (CS), that consistently correspond to the inner layer of the (*n*-1)th unstable CS.

Tenerani et al. 2015b, ApJ inspired by Shibata&Tanuma 2001

Pseudostreamers, Sweb, Solar Wind speed

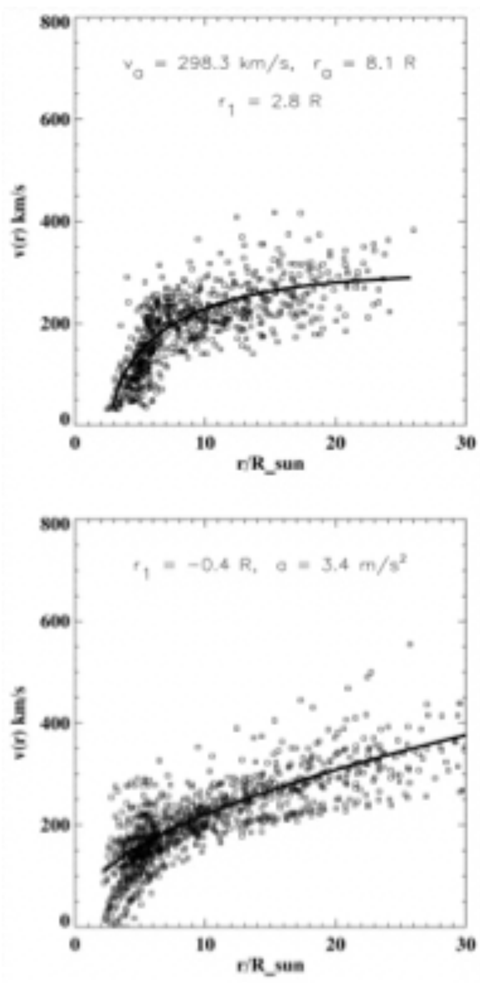
Antiochos et al., 2011

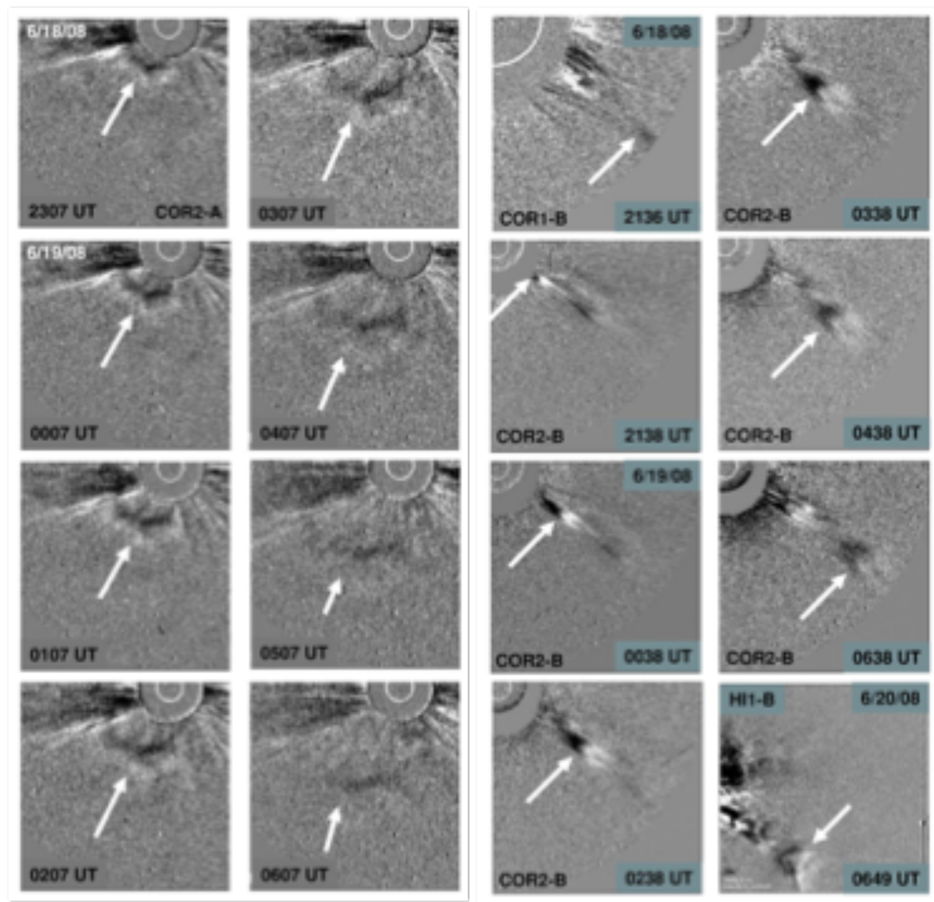




- In situ measurements of solar wind state: temperature, density, velocity, He/H, magnetic field strength, turbulence
- Remote imaging of local and global structures with WISPR
- Connect to solar observations and models

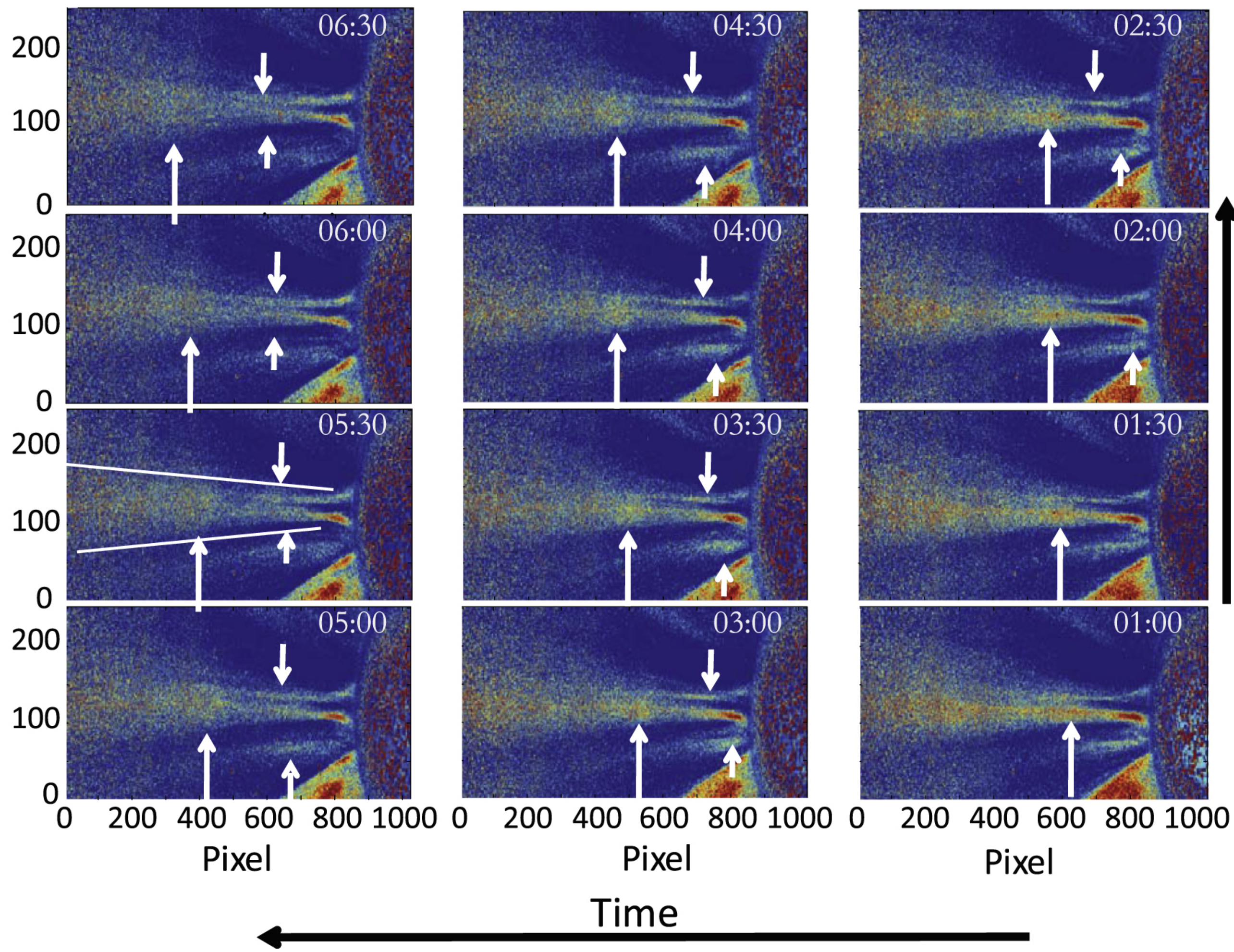
"Blobs" from Heliospheric current sheet have flux-rope like nature





Periodic density structures and "blobs"

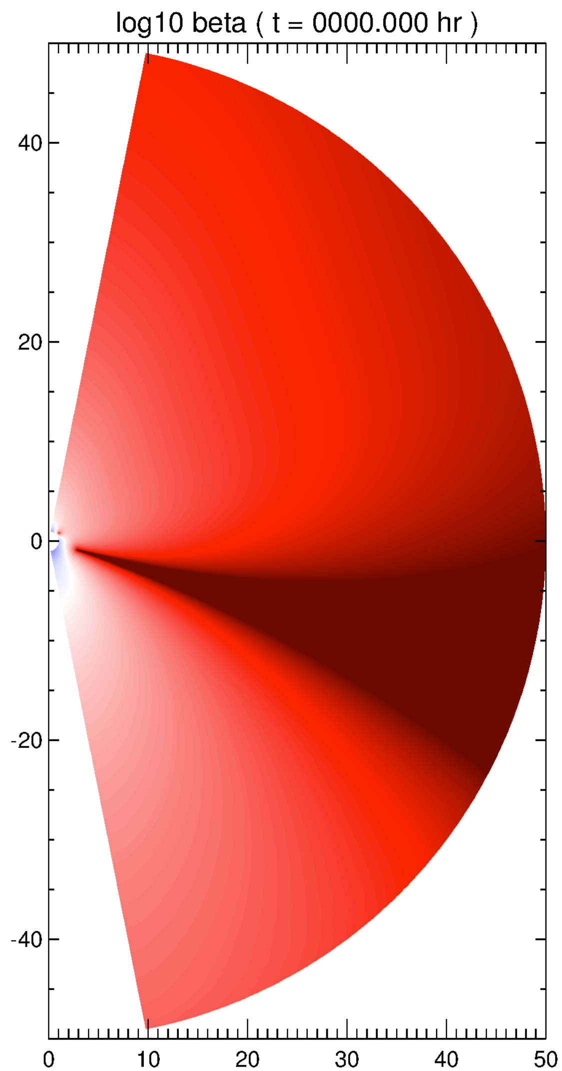
COR 2 Images Jan 20, 2008



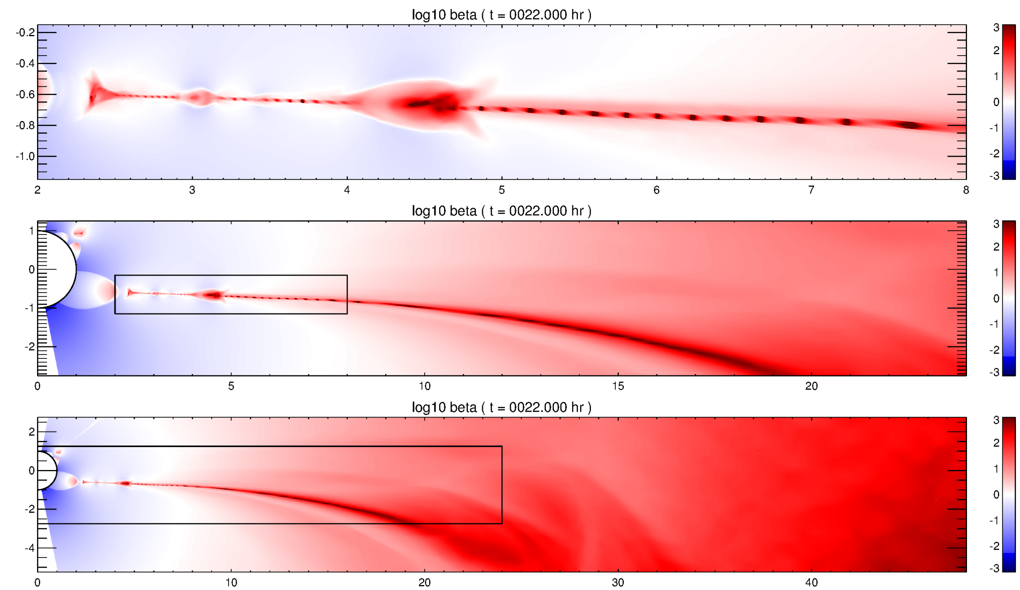
Structures with length scales of hundreds to several thousands of megameters and frequencies of tens to hundreds of minutes.

PDSs are formed in the solar corona as part of the slow solar wind release and/or acceleration processes. (Viall and Vourlidas 2015)

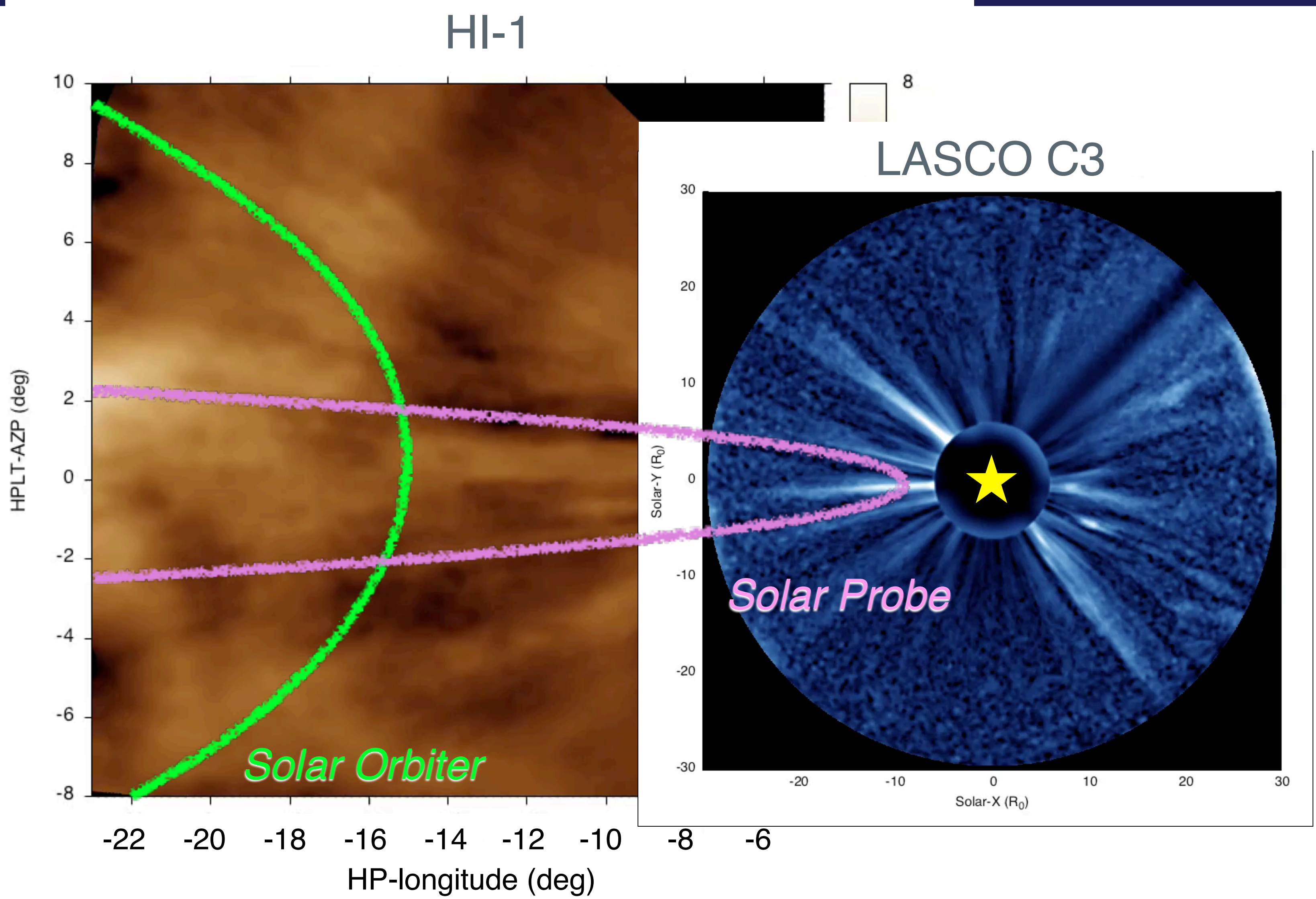
Periodic density structures and "blobs"



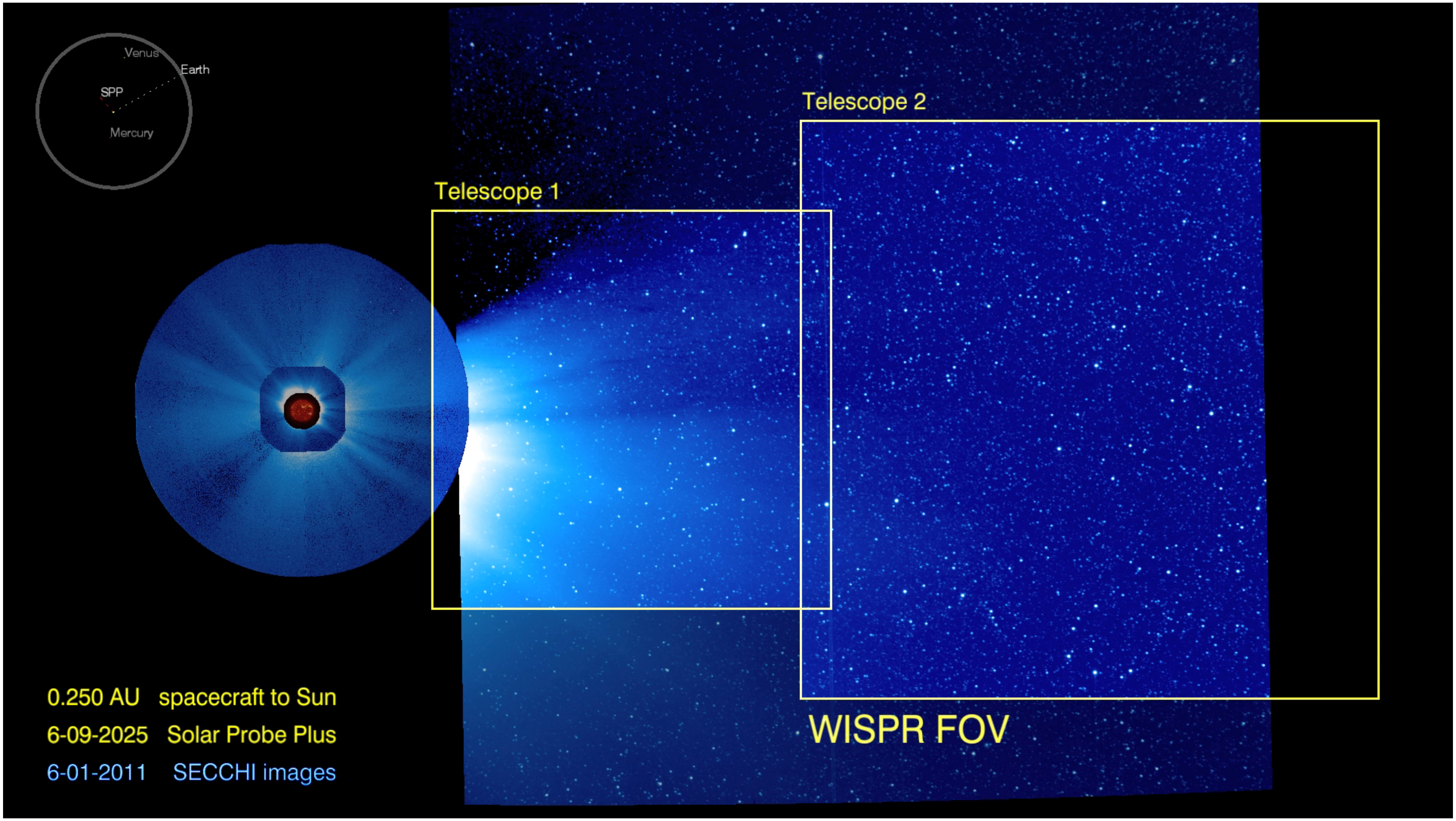
Edmondson and Lynch (2015)



Box blow-up


HI-1
8
LASCO C3
HPLT-AZP (deg)
HP-longitude (deg)
Solar-Y (R_0)
Solar-X (R_0)
Solar Probe
Solar Orbiter
-22 -20 -18 -16 -14 -12 -10 -8 -6
10 8 6 4 2 0 -2 -4 -6 -8
30 20 10 0 -10 -20 -30
-20 -10 0 10 20 30

WISPR Field of View in orbit



PSP website/science

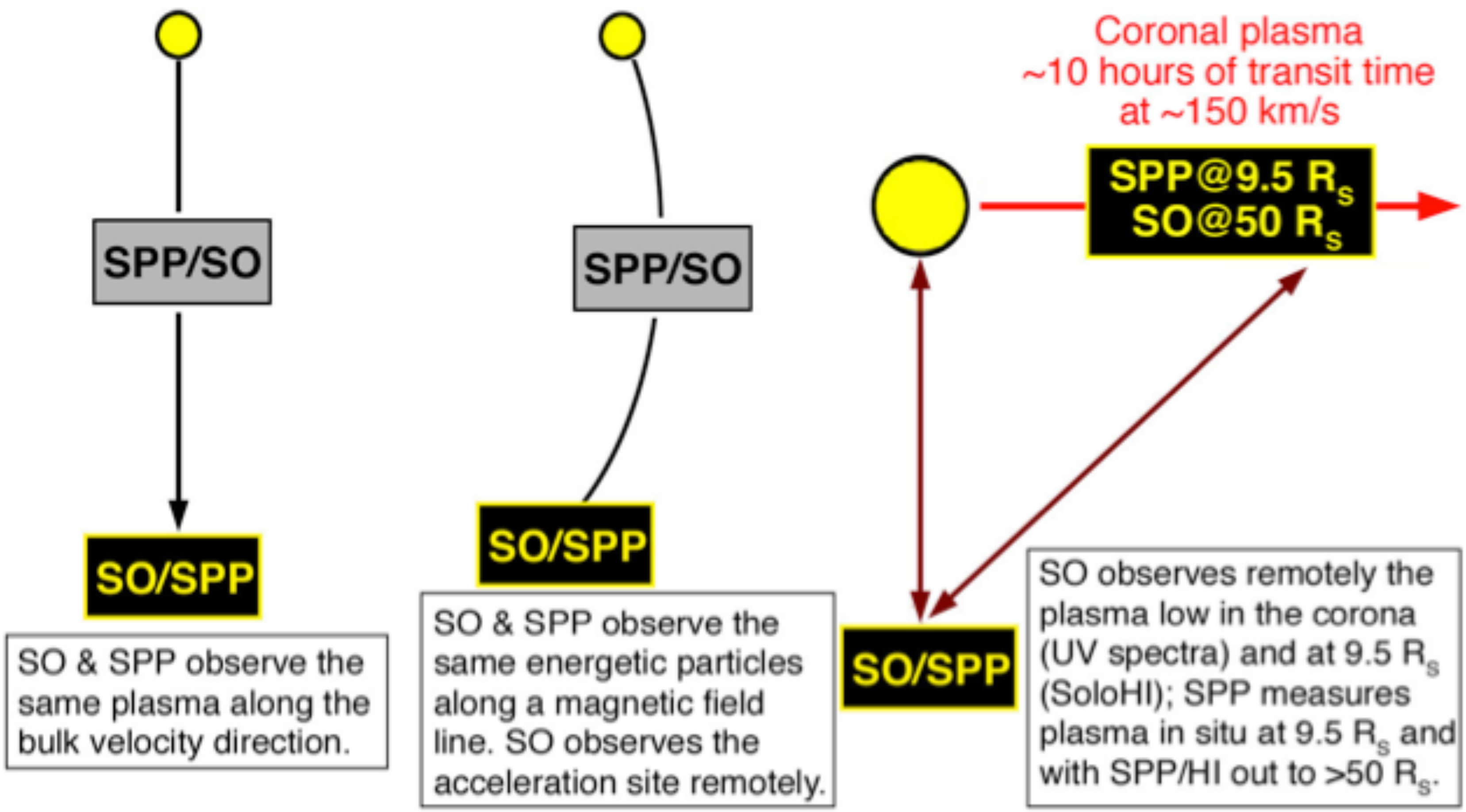
Webpage: ***http://solarprobe.jhuapl.edu***

Theory/Science

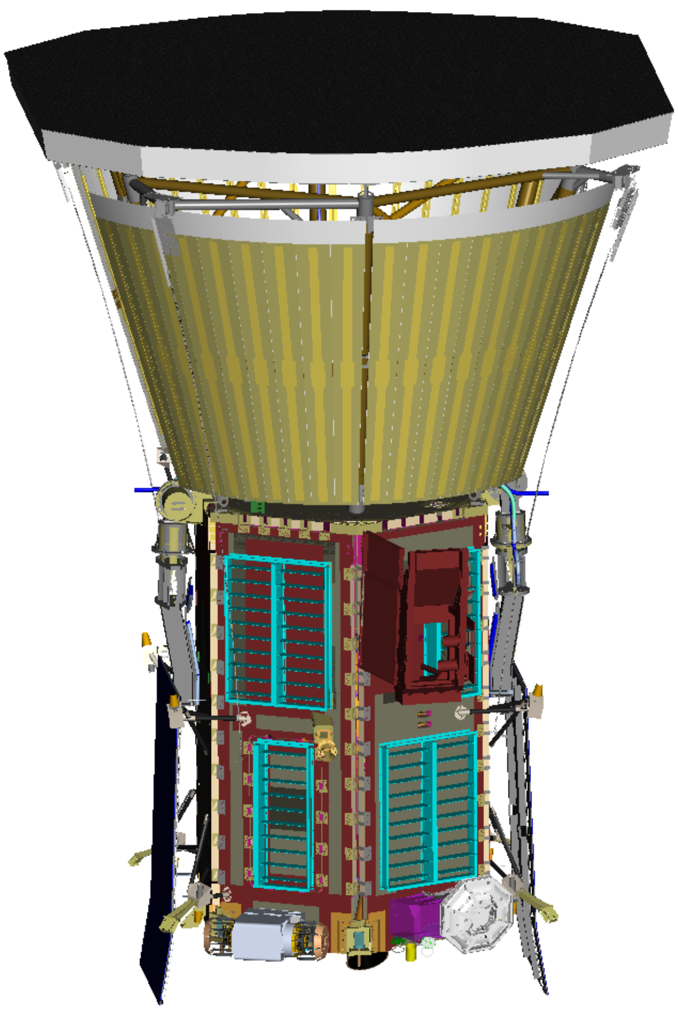
Cadence: monthly – every 4th Thursday
Time: 12:00 – 13:30 (EST)
Audience: open to anyone interested: drop me an email!
mvelli@ucla.edu

Webpage: ***http://sppgway.jhuapl.edu/TG_Telecons***

Conclusions: Orbiter and Probe



Spacecraft Overview



- NASA selected instrument suites
- 618kg max launch wet mass
- Reference Dimensions:
  - S/C height: 3m (TBR)
  - TPS max diameter:2.3m (TBR)
  - S/C bus diameter: 1m (TBR)
- C-C Thermal protection system
- Hexagonal prism s/c bus configuration
- Actively cooled solar arrays
- HGA, TWTA Ka-band science DL
- Science downlink rate: ~150kb/s at 1AU
- Blowdown monoprop hydrazine propulsion
- Wheels for attitude control

Fields and Waves Measurement Table

REQ#	Measurement	Baseline	Threshold
4.1.1.1	**Magnetic Field**		
	Dynamic Range	140 dB	125 dB
	Cadence	100k vectors/sec	256 vectors/sec
	Bandwidth	DC - 50 kHz	DC - 128 Hz
4.1.1.2	**Electric Field**		
	Dynamic Range	140 dB	125 dB
	Cadence	2M vectors/sec	256 vectors/sec
	Bandwidth	DC - 1 MHz	DC - 128 Hz
4.1.1.3	**Plasma Waves**		
	Dynamic Range	140 dB	90 dB
	Cadence	1 spectrum/sec	1 spectrum/ 10 sec
	Bandwidth	~ 5 Hz - 1 MHz	~ 5 Hz - 50 kHz
4.1.1.4	**Quasi-Thermal Noise/Radio**		
	Dynamic Range	100 dB for QTN 80 dB for radio	70 dB for QTN 70 dB for radio
	Cadence	1 spectrum/4 sec QTN * 1 spectrum/16 sec radio	1 spectrum/32 sec QTN 1 spectrum/32 sec radio
	Bandwidth	10-2500 kHz QTN 1-16 MHz radio	10-2500 kHz QTN 1-16 MHz radio

*plasma density to better than 1% accuracy over the whole orbit & temperature to better than 5%

Thermal Particle Measurement Requirements Table

REQ#	Measurement	Baseline	Threshold
4.1.1.5	**Thermal Ions**		
	Ion energy range	10 eV – 20 keV	100 eV – 10 keV
	Ion energy resolution	< 20%	< 30%
	FOV	Includes nadir and ram directions	Includes nadir and ram directions
	Ion angular resolution	10 deg x 25 deg	20 x 25 degrees
	Ion VDF measurement cadence	1 Hz	1 Hz
	Mass resolution	dM/M < 25%	None
4.1.1.6	**Thermal Electrons**		
	Energy range	5 eV – 20 keV	5 eV – 2 keV
	Energy resolution	< 20%	< 30%
	FOV	> 75% of the sky	> 65% of the sky
	Angular resolution	10 deg x 10 deg	20 x 20 degrees
	Electron VDF measurement cadence	1 Hz	1 Hz

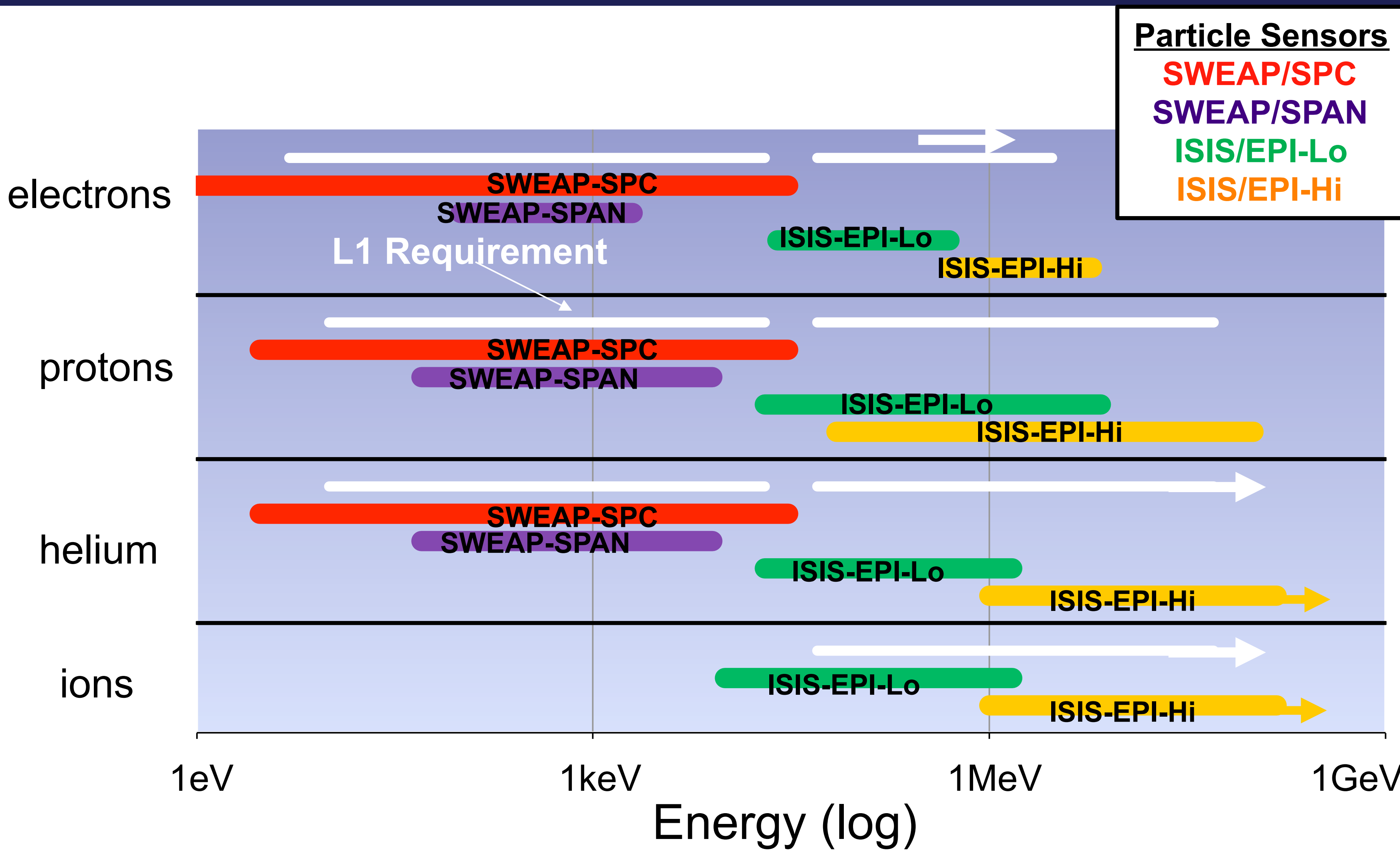
White Light Measurement Requirements Table

REQ#	Measurement	Baseline	Threshold
4.1.1.7	**Visible Broadband**		
	Cadence	≤ 15 min	≤ 15 min
	Field of View	< 76° x 76°	< 72° x 45°
	Inner FOV boundary (solar elongation)	≥ 14°	≥ 18°
	Spatial Resolution	≤ 6.4 arcmin	≤ 6.4 arcmin
	Photometric Sensitivity (Signal-to-Noise Ratio per pixel)	≥ 20	≥ 15

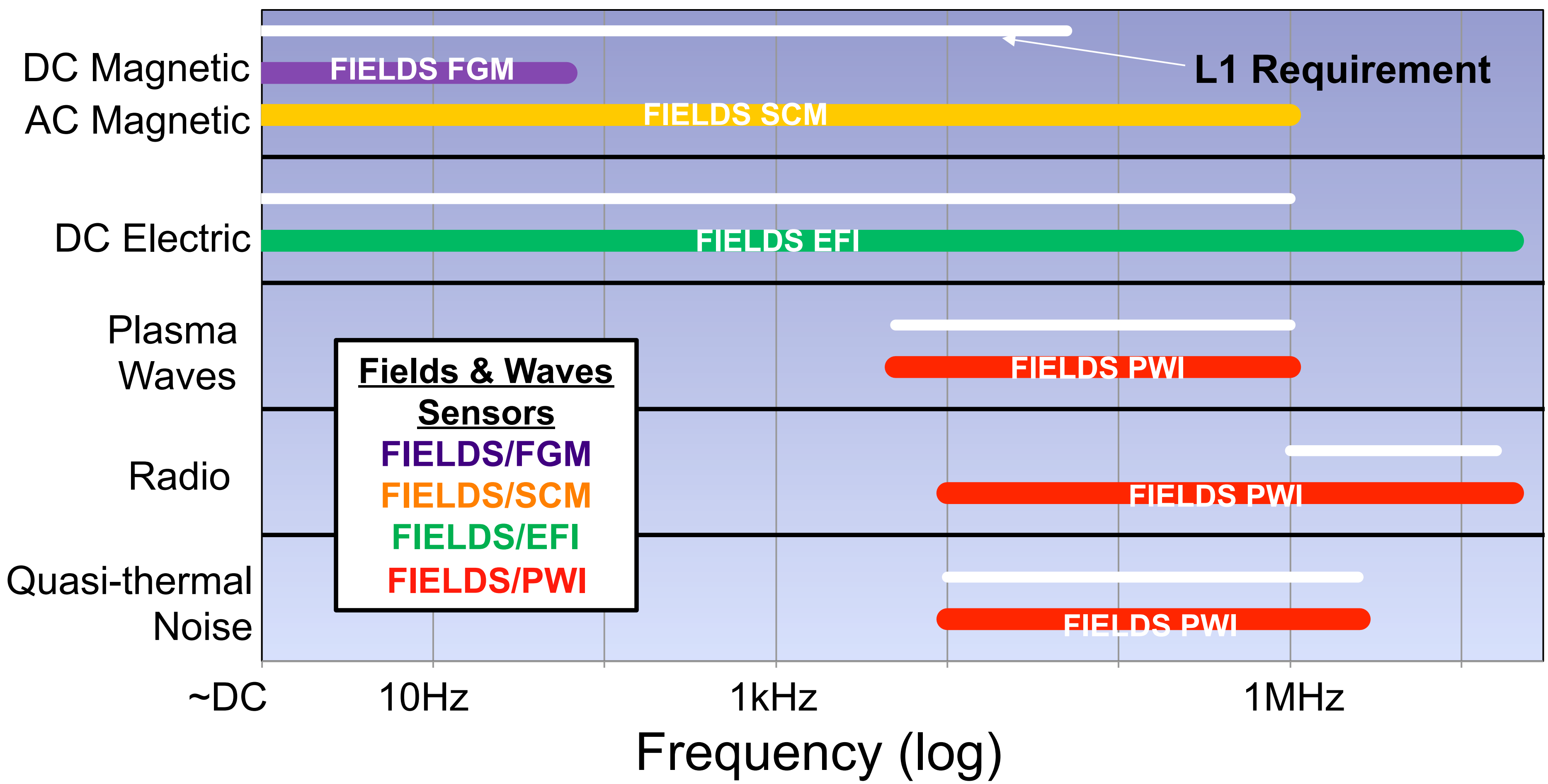
Energetic Particle Measurement Requirements Table

REQ#	Measurement	Baseline	Threshold
4.1.1.8	**Energetic electrons**		
	Energy range	≤0.05 to ≥3 MeV	≥1.5 decade, 0.02 - 6 MeV
	Highest cadence	≤1 sec (selected rates)	≤10 sec
	FOV	≥π/2 sr in sunward & anti-sunward hemispheres	≥π/4 sr in sunward & anti-sunward hemispheres
	Angular sectoring	≤45° sectors	sunward vs anti-sunward
4.1.1.9	**Energetic protons and heavy ions**		
	Energy range	≤0.05 to ≥50 MeV/nuc	≥2 decades, ,0.02 to 100 MeV/nuc,
	Highest cadence	≤5 sec (selected rates)	≤10s, protons; 1 minute, ion rates
	FOV	≥π/2 sr in sunward & anti-sunward hemispheres	≥π/4 sr in sunward & anti-sunward hemispheres
	Angular sectoring	≤30° sectors	sunward vs anti-sunward
	Composition	at least H, He, ^{3}He, C, O, Ne, Mg, Si, Fe	protons, heavy ion groups (He, CNO, NeMgSi, Fe)

Particle Instrument capabilities exceed Level 1 required measurements



Fields & Waves Instrument capabilities exceed Level 1 required measurements



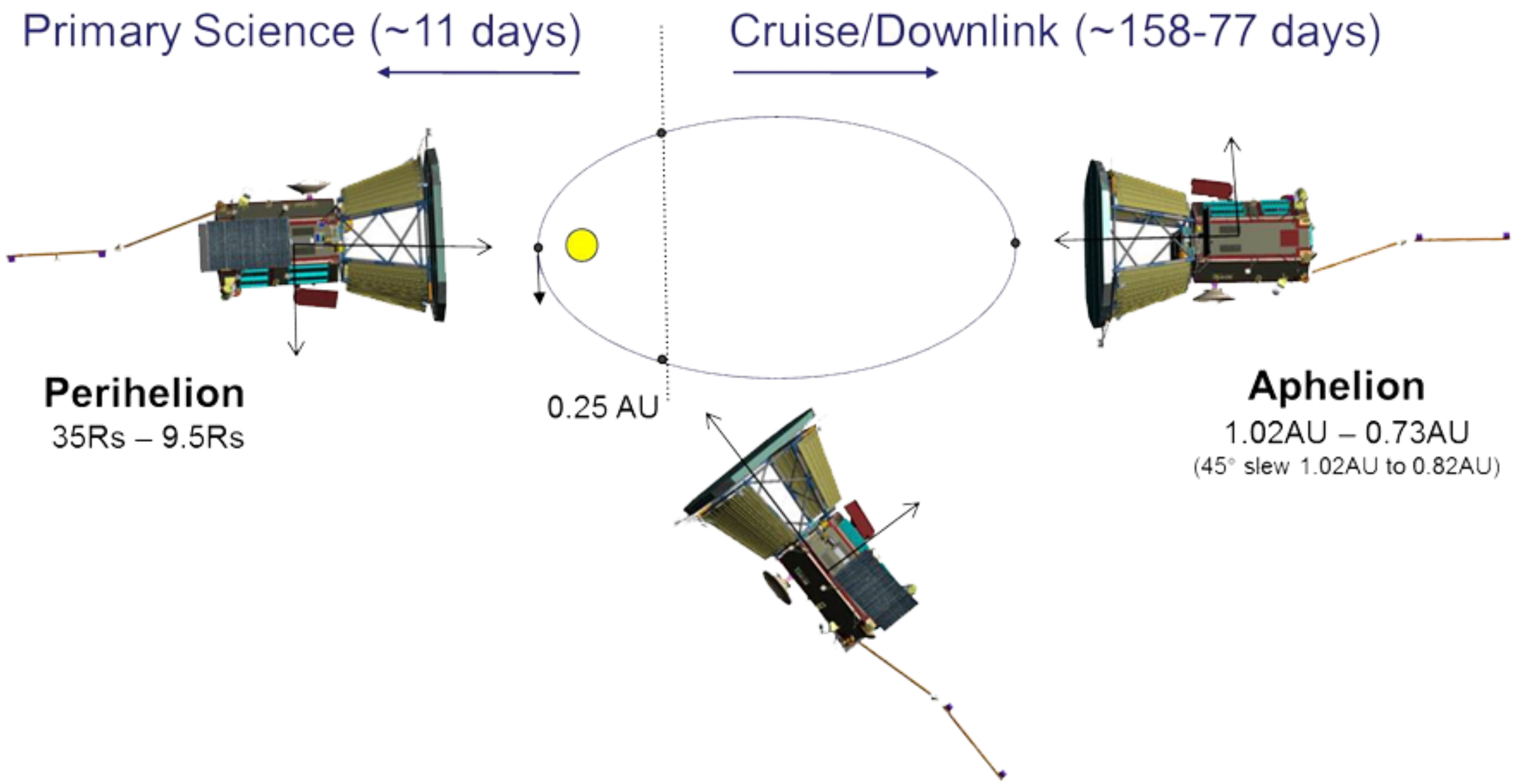
Mission Success Requirements

- ***The criteria that must be met after launch to declare mission success. Sufficient flexibility to allow for degradation of the spacecraft and instruments.***

- ***In order for Solar Probe Plus to achieve mission success at the end of prime mission, progress on at least two of the three science objectives must be made. The science can be addressed with different combinations of measurements and, furthermore, there are multiple methods of obtaining the measurements using different instrumentation.***
- ***Thus, the mission is robust against the failure of any instrument and the loss of any given measurement after launch.***

- ***Therefore, Solar Probe Plus will achieve mission success at the end of prime mission by returning no less than 64 Gb of science data composed of at least 7 out of 9 of the required (threshold) measurements collected during 150 hours below 20 Rs, including no less than 5 hours below 10 Rs.***

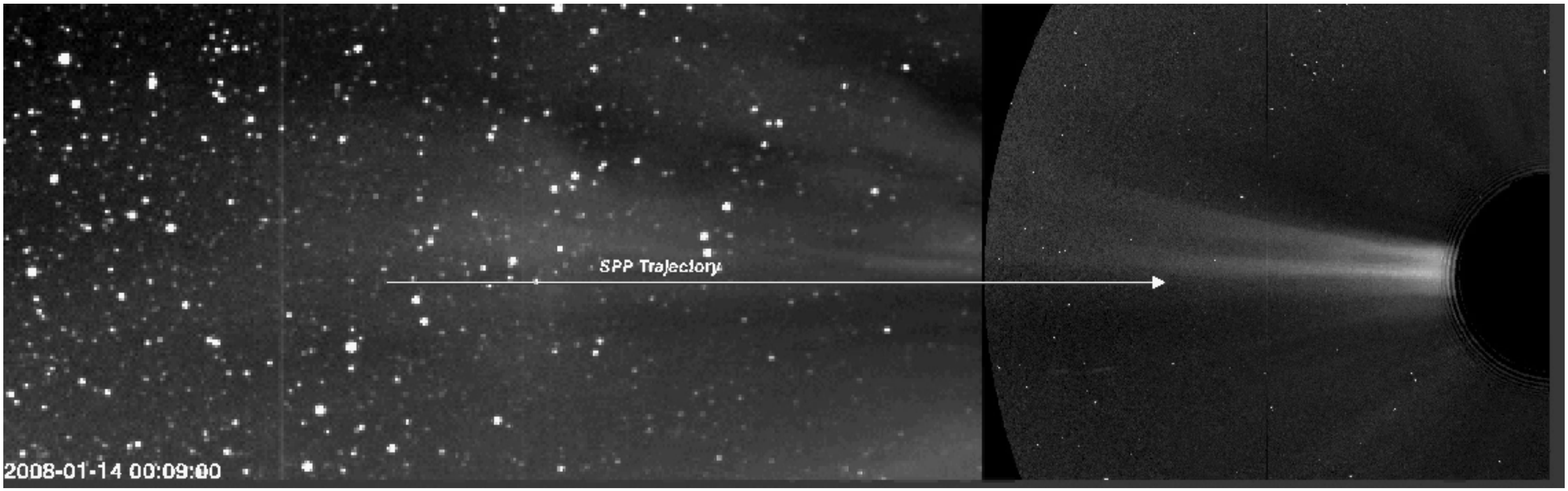
Reference Vehicle: Concept of Operations



Opportunity for World-Wide Community to Collaborate in PSP!

- **Full-disk magnetograms of the photosphere and chromosphere**
  - NSO Mount Wilson Observatory, GONG, Wilcox Solar Observatory SDO, Solar Orbiter
- **High-resolution spectro-polarimetry and imaging spectroscopy of dynamic solar atmosphere (photosphere to corona)**
  - ATST; GREGOR; NJIT's Big Bear Solar Observatory New Solar Telescope (NST), Solar Orbiter
- **Coronagraph observations**
  - MLSO White light coronagraph, Solar Orbiter
- **UV/X-ray imaging and spectroscopy**
  - Solar Dynamics Observatory, IRIS. Solar Orbiter
- **Radio observations**
  - VLA, Green Bank Solar Radio Burst Spectrometer, Nançay radioheliograph, Nobeyama Radioheliograph; Owens Valley Solar Array, Siberian Solar Radiotelescope; Atacama Large Millimeter Array, FASR
- **Interplanetary scintillation for tomography of solar wind and ICMEs;**
  - Differential Faraday rotation of background sources constraining magnetic field strength of outer corona and SW. –EISCAT, LWA, MWA, ORT

Solar Probe will directly sample wind



Coronal Magnetic Topology: Streamers and Pseudostreamers. Fast, slow and hybrid wind.
Presence of pseudostreamers (PS)
a) extreme-high and extreme-low-proton-flux wind is associated with PS; "hybrid" type of outflow;
b) intermediate proton speed but high electron temperature; c) spikes of proton density may represent PS plasma sheets; d) wind measurements; All above will allow to determine the structure and dynamic of the plasma and mag. fields at the sources of the solar wind. And also will answer the question how the processes in the corona affect the properties of the solar wind in heliosphere.
Presence of streamers. a) not extreme-high densities and regular slow solar wind

PSP

PARKER SOLAR PROBE
A MISSION TO TOUCH THE SUN