Intermittent structures in solar wind turbulence from MHD to sub-ion scales at 0.17 AU from the Sun

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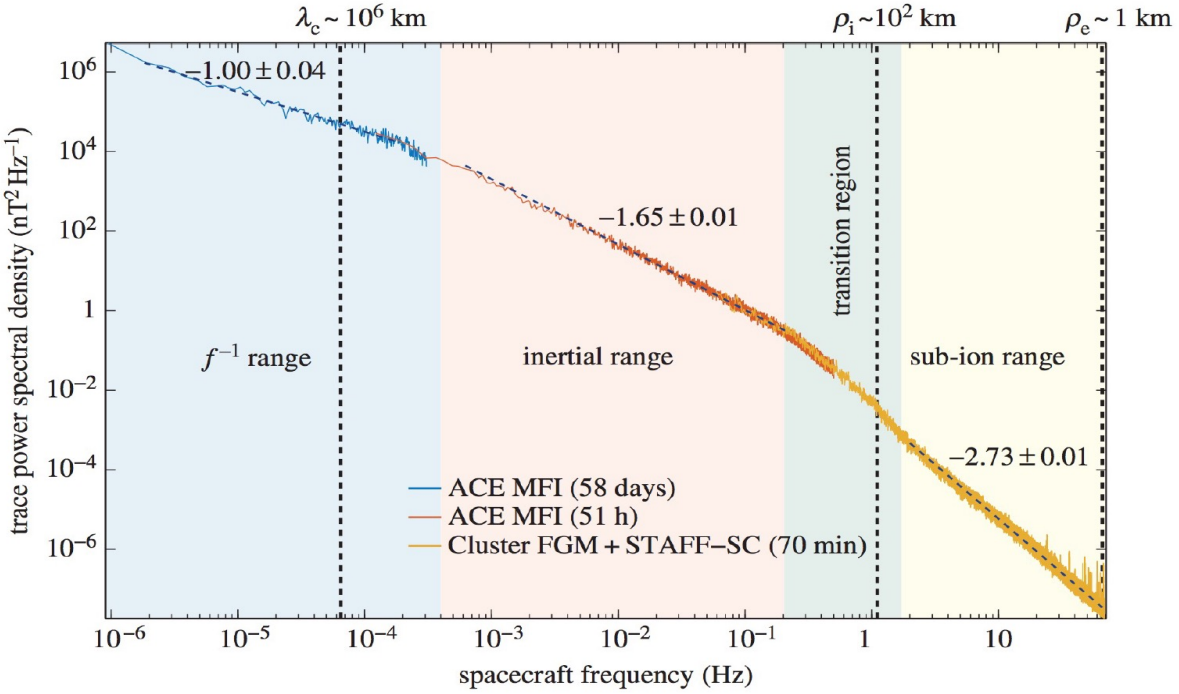
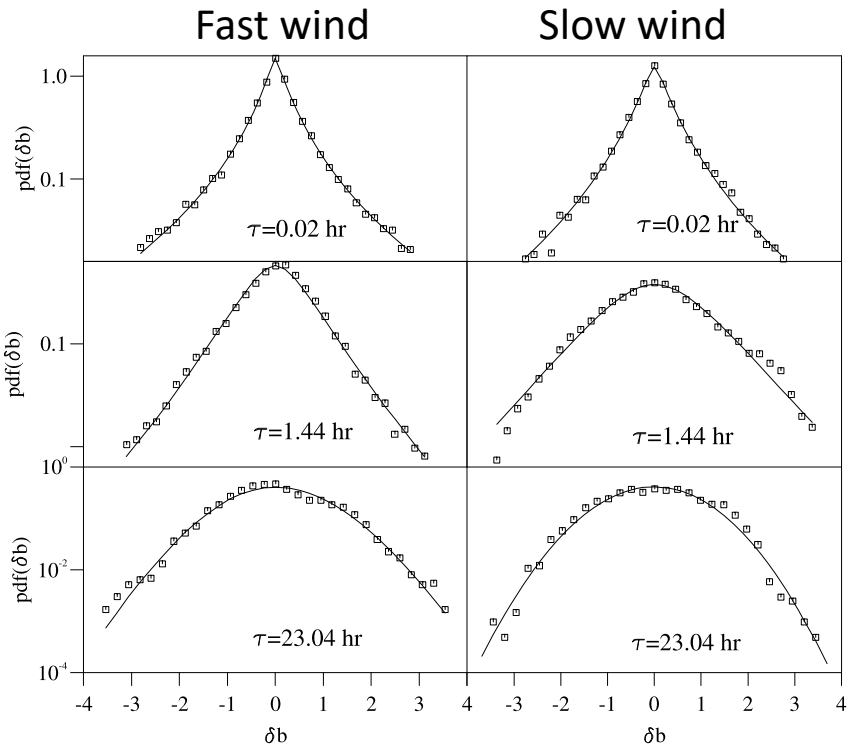
Solar wind turbulence

[Kiyani et al. 2015]

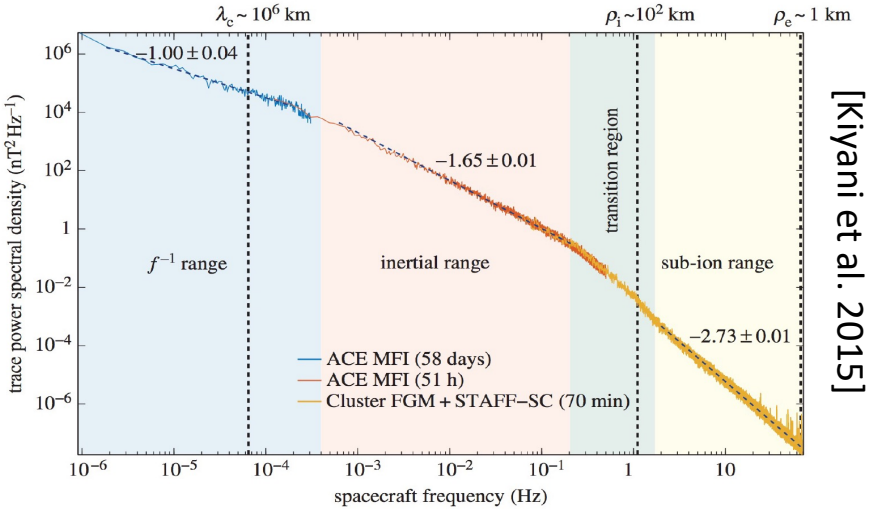


[Sorriso-Valvo et al. 1999]



$$|\Delta \mathbf{b}| = |\mathbf{b}(s + \Delta s) - \mathbf{b}(s)|$$

Structures in the solar wind



[Kiyani et al. 2015]

F-1 range: Flux ropes [Zhao 2020],[Janvier 2014]
Flux tubes [Borovsky2008]

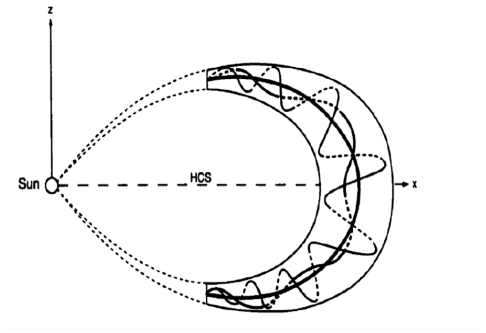
Inertial range: Discontinuities [Knetter 2004],
Magnetic holes [Stewens2007], [Karlsson 2021]
Alfven vortex [Lion 2016]

Ion scales: Discontinuities, shocks, magnetic holes,
Alfven vortices [Perrone 2016, 2017]

Sub-ion range: Discontinuities [Perri 2012], [Greco 2016]
Magnetic hole [Liu 2019]

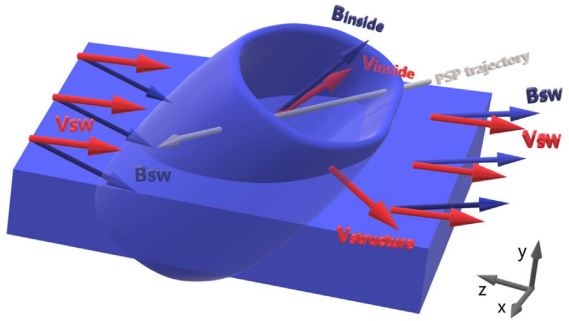
Is there a relation between all these structures across the cascade?

F^{-1} range
Flux rope



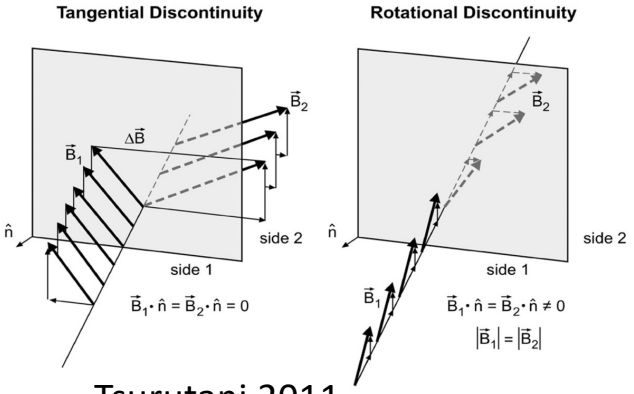
Burlaga 1990

Inertial range
Alfvénic-type magnetic structure



Krasnoselskikh 2020

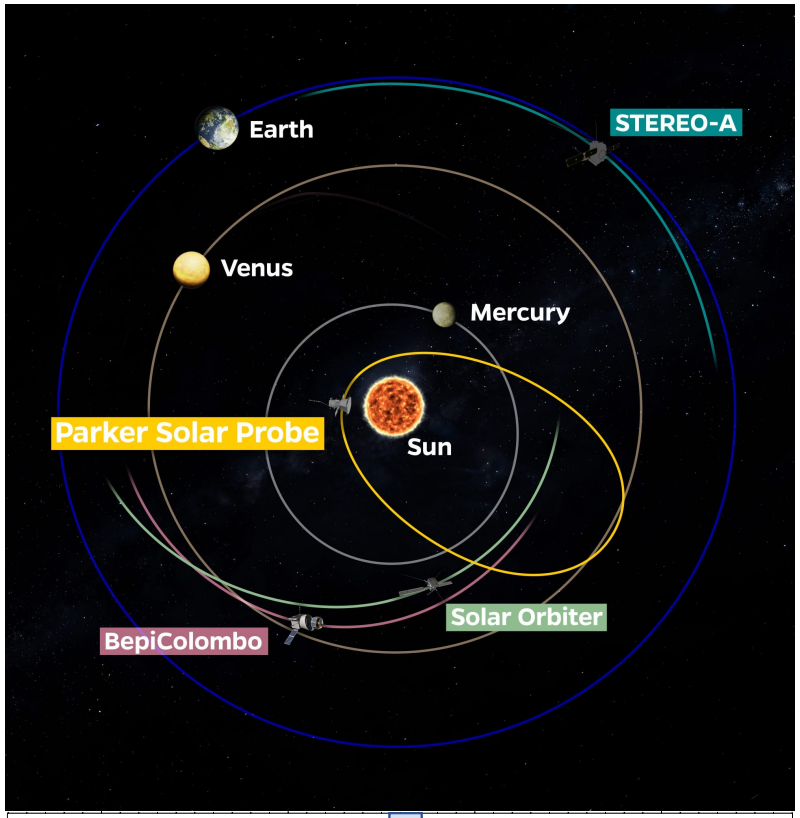
Ion-scale
discontinuities

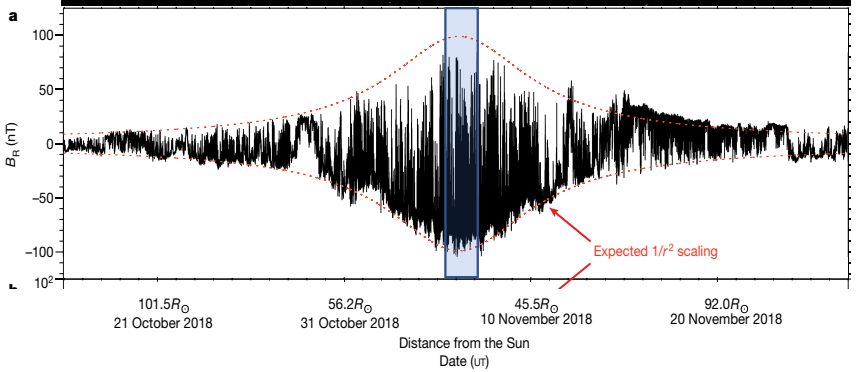


Tsurutani 2011

Parker Solar Probe First encounter: 2018-11-06

- Unique opportunity exploring the turbulence in the “young” solar wind Radial distance R~25*10^9 m ~ 0.17 au
- The main goal of our investigation is to characterize solar wind coherent structures from MHD to sub-ion scales





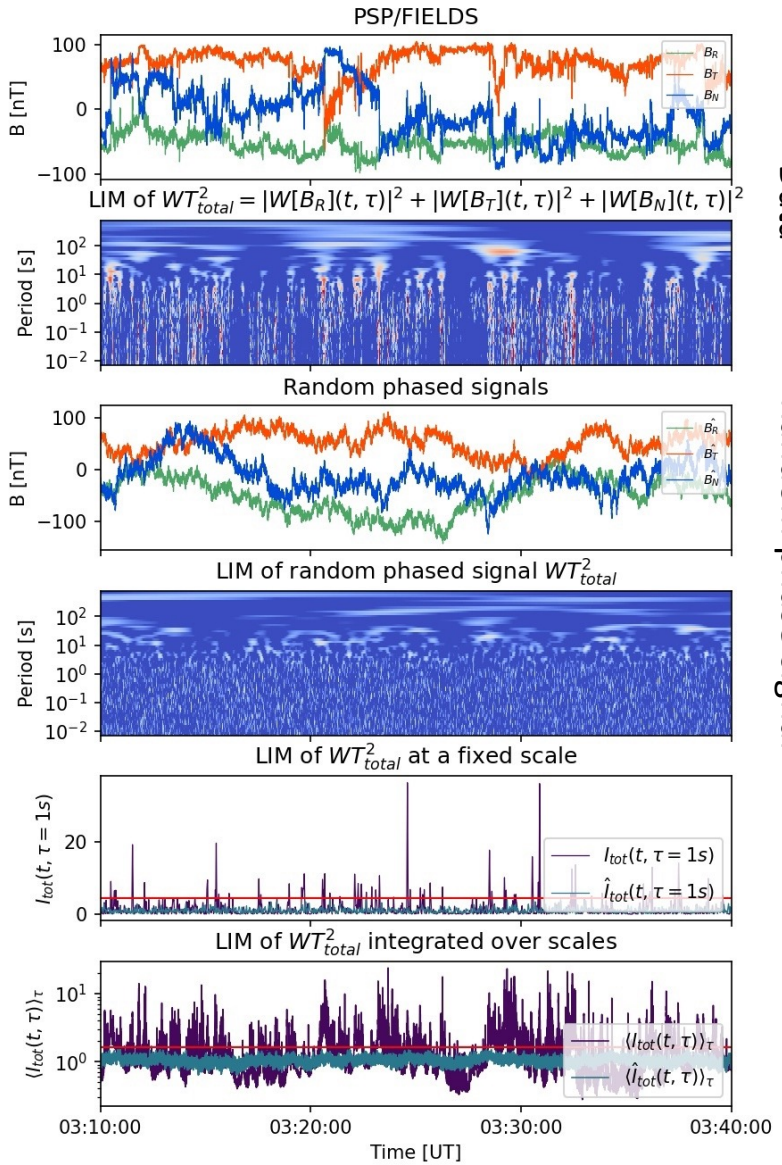
Bale et al., 2019, Nature

Detection of coherent structures at 0.17 AU

- Morlet Wavelet
- Total local intermittency measure $I(t,\tau)_{tot}$ shows the relative total energy of fluctuations at a given moment in time at a given scale τ

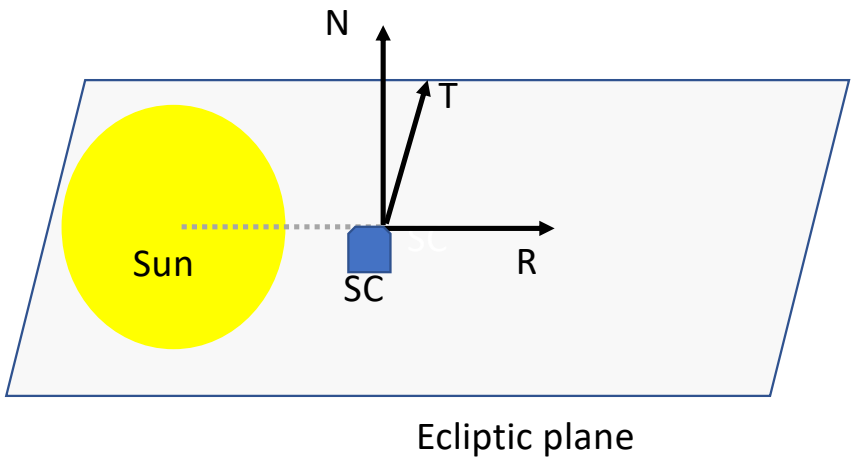
$$I(t,\tau)_{tot} = \frac{\sum_{i=R,T,N} |W[B_i](t,\tau)|^2}{\langle \sum_{i=R,T,N} |W[B_i](t,\tau)|^2 \rangle_{t \in T'}}$$

- To detect the structures we compare magnetic field measurements with an random-phased signal
- **Vertical lines: coupled phases across scales -> Coherent structures**

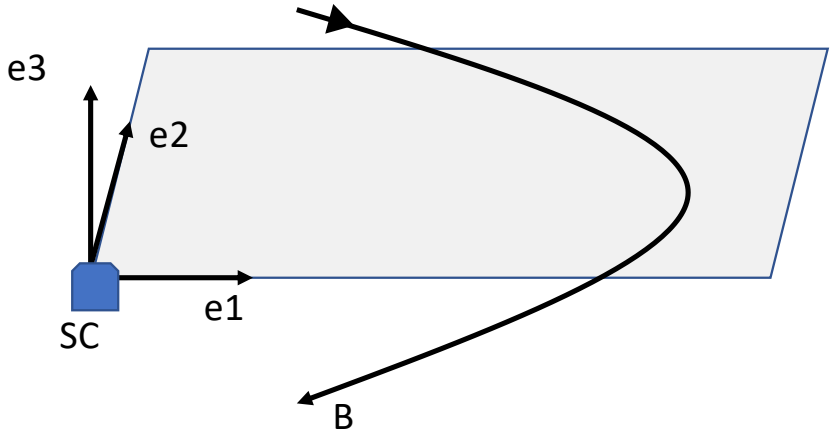


Reference frames

Radial Tangential Normal
(RTN) reference frame



Local Minimum variance
(MVA) Reference frame



$\mathbf{e_1,e_2,e_3}$ are eigenvectors of the magnetic field covariation matrix

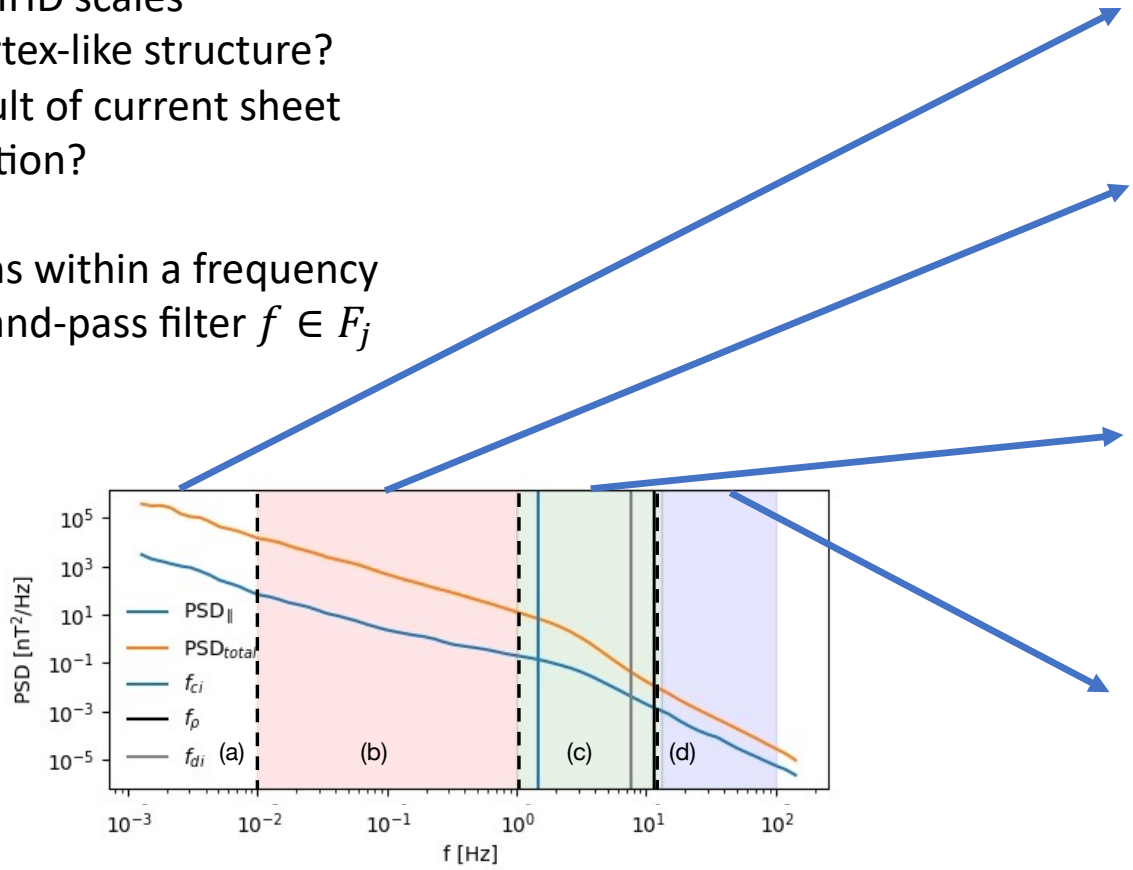
Relations of the corresponding eigenvalues λ_2/λ_1, λ_3/λ_2 show if $\mathbf{e_1,e_2,e_3}$ directions are well-defined

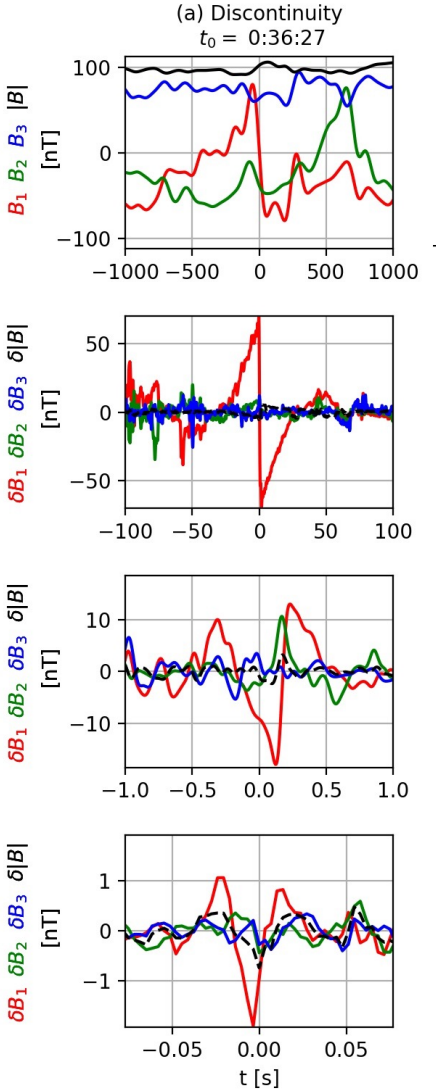
Examples of coherent structures
1. Planar discontinuity

- Current sheet at MHD scales
- Sub-ion scales: vortex-like structure?

Is it formed as a result of current sheet instability/reconnection?

To define fluctuations within a frequency range, we apply a band-pass filter $f \in F_j$





2. Alfven vortex like event

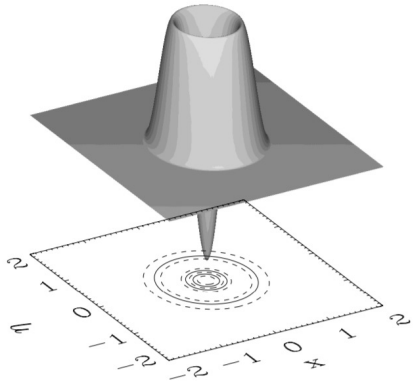
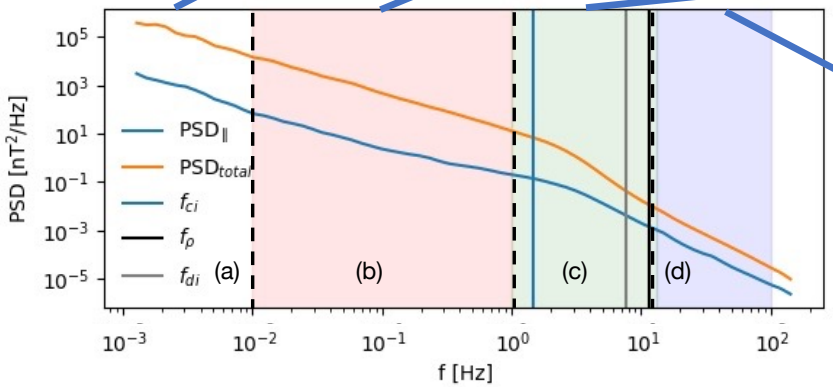
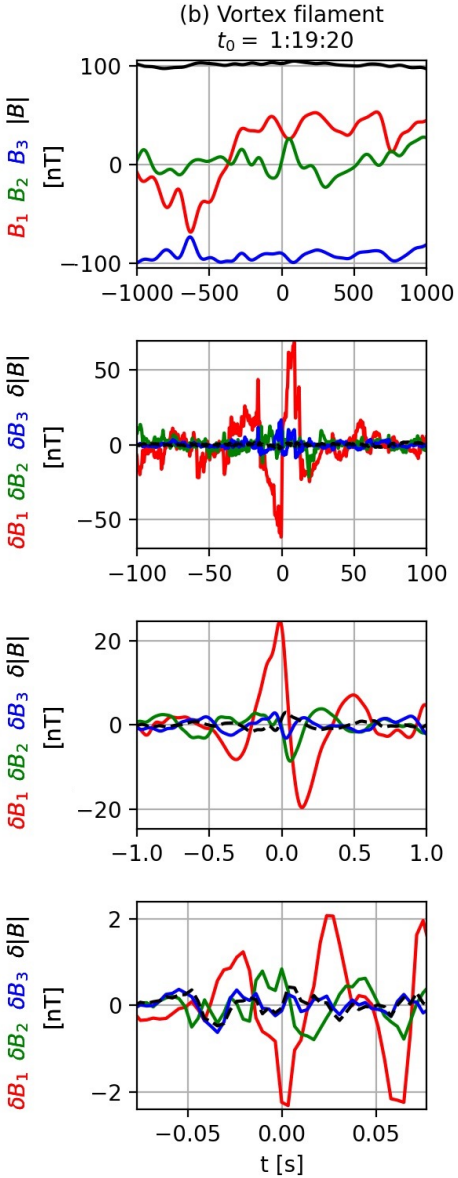


Figure from Alexandrova 2008

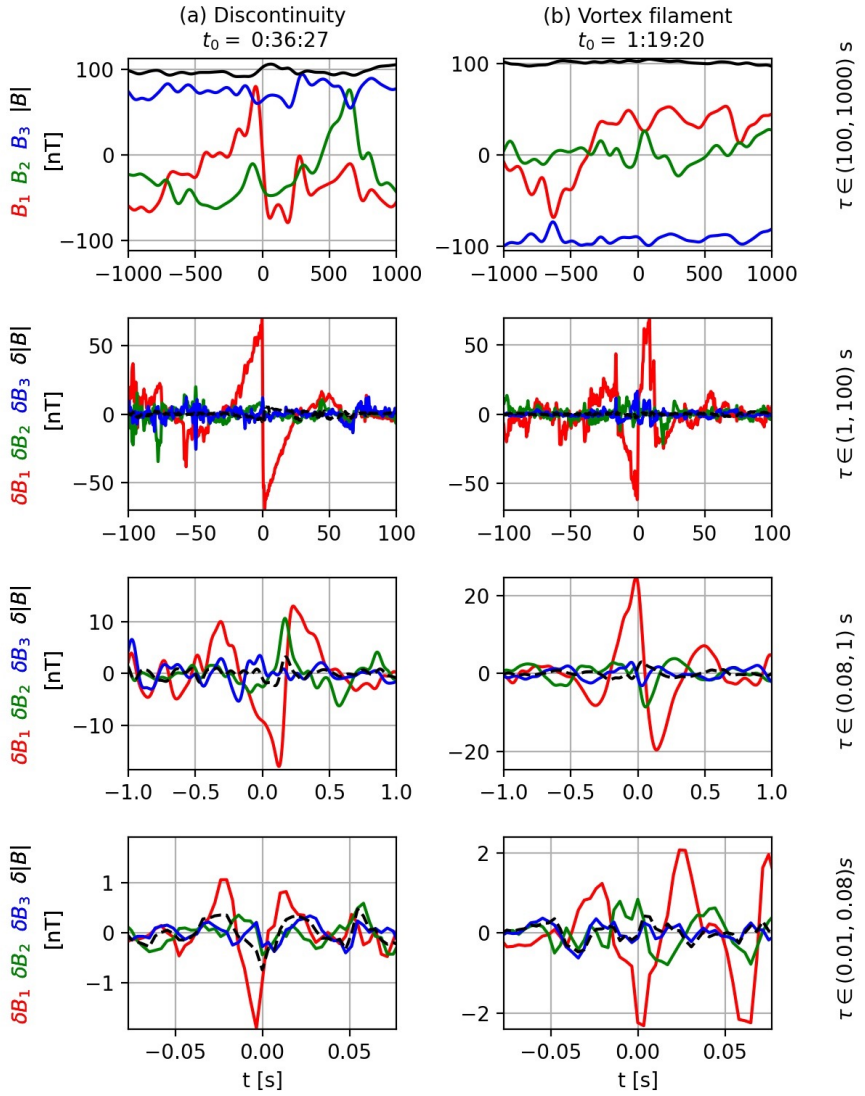
- Incompressible MHD vortex [Petviashvilli & Pokhotelov 1992]
- Compressible MHD + Ion-scales vortex model: Jovanovic et al. 2020;

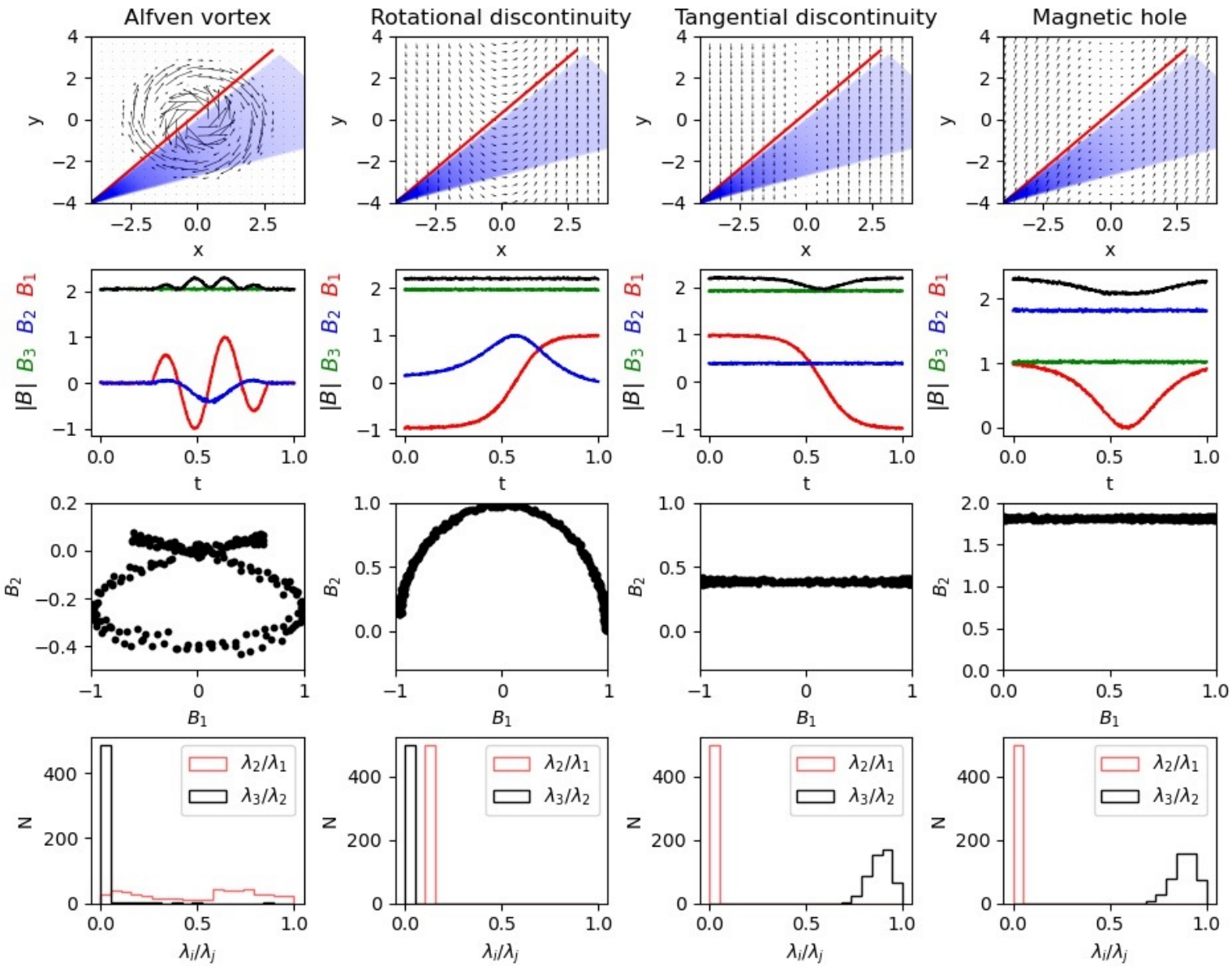




Two examples of coherent structures across cascade

- Small scale events are substructure of large scales ?
- We observe a large number of small scale events within a large scale structure.
- Topology of the observed events depends strongly on the satellite trajectory.





Simulation of coherent structures crossings

λ_1– maximum variation

λ_2– intermediate variation

λ_3– minimum variation

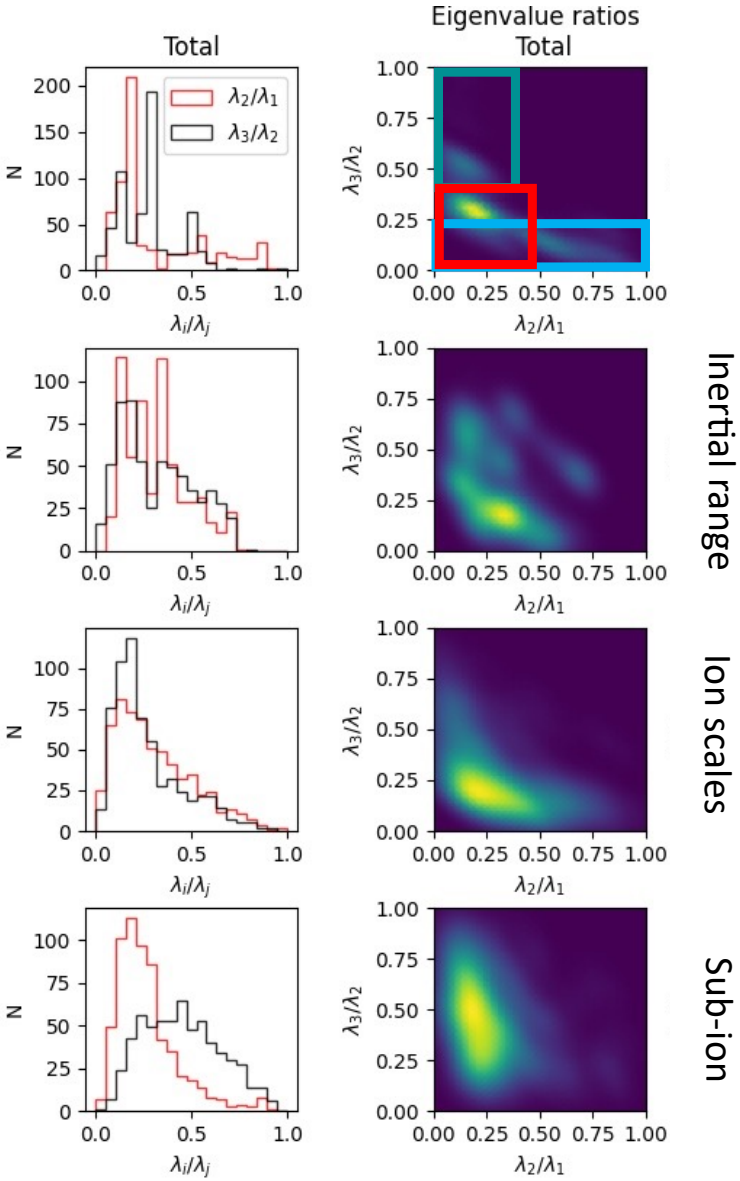
Dipole Vortex ~ RD

Statistics: 600 structures for 6h of observation

MVA eigenvalue ratios λ_2/λ_1, λ_3/λ_2 allow to distinguish between different types of structures:

- Upper left area – tangential discontinuities/magnetic holes
- Lower elongated rectangle – monopole Alfven vortices
- Area at the zero vicinity – rotational discontinuities/dipole vortex

So we have:
- MHD: rotational discontinuities and vortices dominate
- ion scales: RD & increasing population of vortices
- The population of tangential discontinuities/magnetic holes increases towards the smallest scales.



Conclusion

- We observe solar wind coherent structures from MHD to ion kinetic scales and below.
- We try to determine topology of the structures using minimal variance analysis applied on the data and on the model structures.
- We observe evolution of the topology of magnetic fluctuaitons from MHD to sub-ion scales.

Range of scales	Possible dominant type of structures
MHD Inertal range	**Rotational discontinuities/Dipole vortex**
Ion scales	**Alfven vortexes & rotational discontinuities**
Sub-ion scales	**Tangential discontinuities/ Magnetic holes**