Small-scale turbulence in the terrestrial magnetosheath

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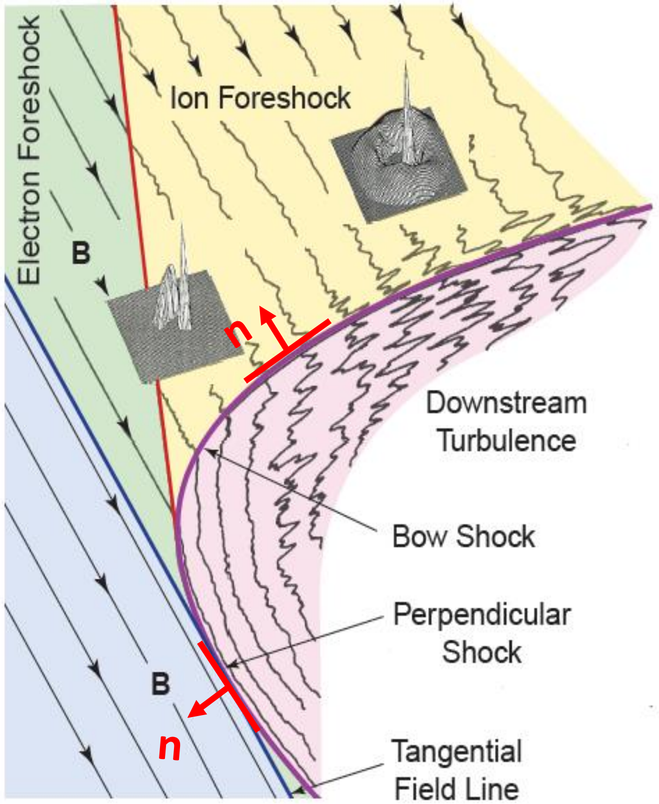
Outline

- Introduction (Magnetosheath vs Solar Wind)
- Data analysis tools
- Turbulence evolution
- Conclusions

The near Earth' space



Eastwood et al., SSR, 2005

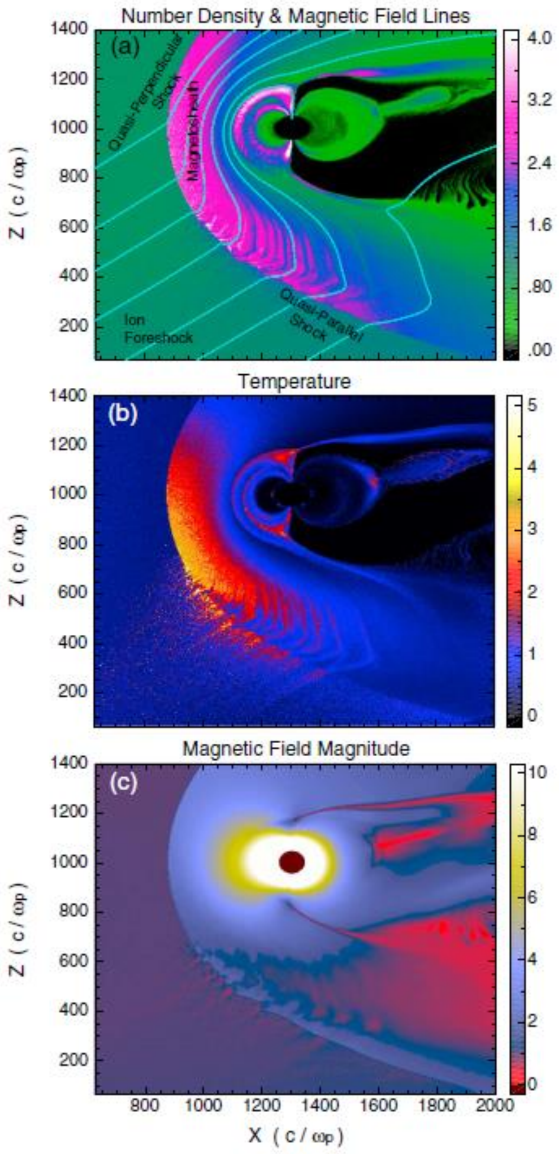
Disconnected solar wind

Solar wind – supersonic and superalfvén outflow of *e*- and *p*+

Foreshock – reflected by the bow shock electrons and ions; ULF waves; wave-particle interactions

Magnetosheath – heated and slowed down solar wind plasma

Magnetosheath vs solar wind



Sub-sonic sun-alfvénic flow

Higher:

- mean field
- density
- temperature
- higher beta plasma

Sources of free energy:

Temperature anisotropy: $T_{i\perp} > T_{i\|}$
(Plasma instabilities and low f waves)

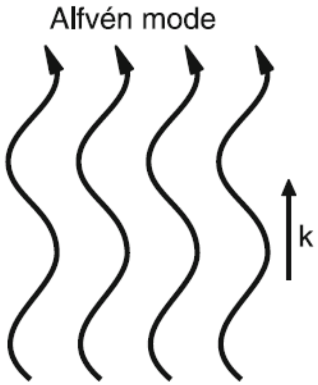
Bowshock and magnetopause

[Omidi et al., JGR, 2014]

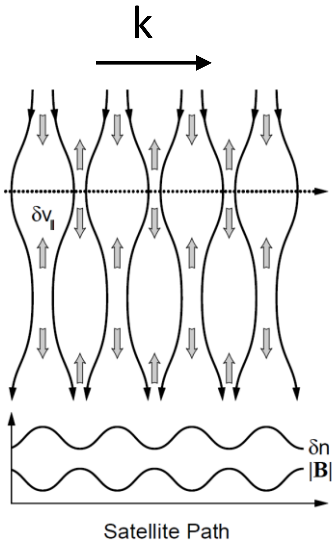
2.5-D EM hybrid simulations – MA=3 MF cone angle=35°

Waves in the MSH

Rich variety of low-frequency waves in the magnetosheath:



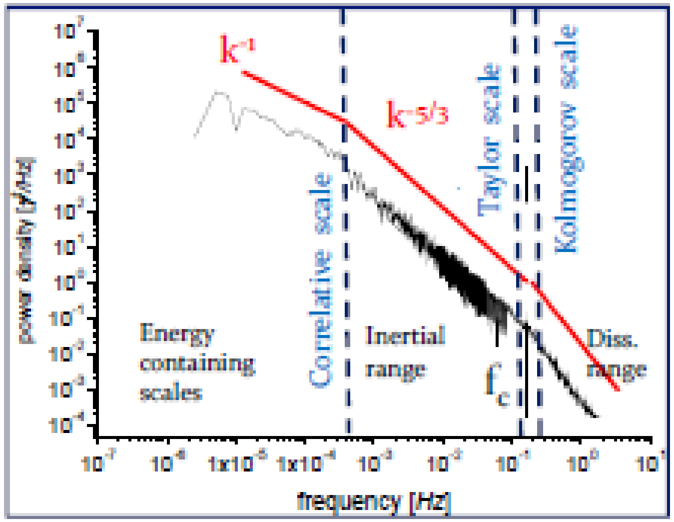
- Alfvén/ion-cyclotron : transverse mode, **k||B**

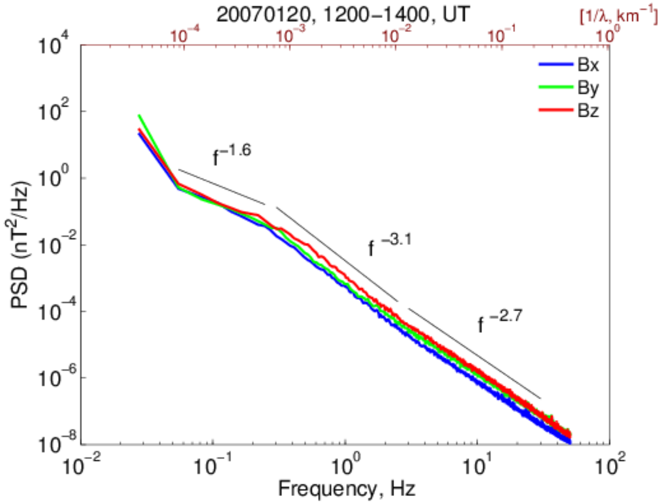


- Mirror-modes : compressible slow mode, **k⊥B**

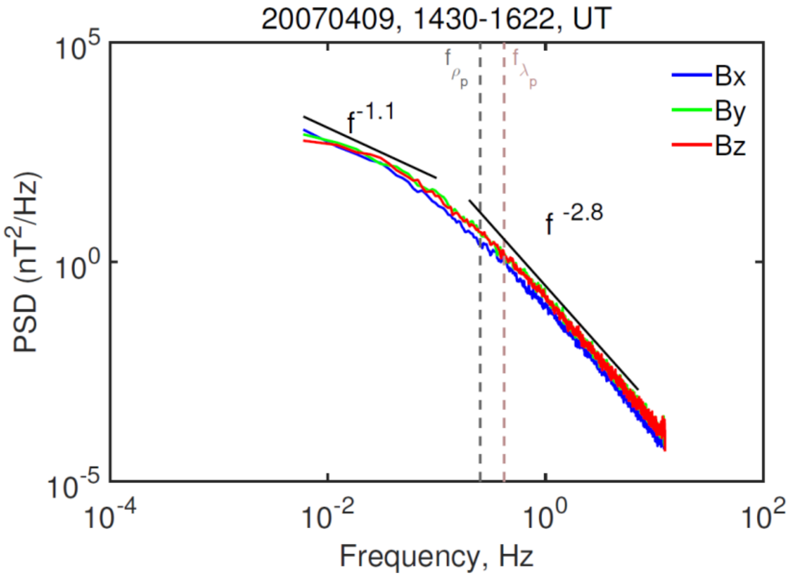
Magnetosheath vs solar wind

[Bruno and Carbone, Living Review, 2014]





[Yordanova et al., EPL, 2015]



Solar wind PSD:

3 regimes – energy injection, inertial and dissipation

Magnetosheath PSD:

Energy injection at proton scale; no clear inertial range

Parameters controlling the state of magnetosheath

1. Angle ϑ_{Bn} - ($B_{upstream}$, n_{BS}); **2.** System size and **3.** Mach number

Quasi-perpendicular Configuration[1]

- Stable steep ('ramp') short transition upstream/downstream region
- Small fluctuations in plasma parameters
- Particle heating
- Characteristic scale – gyro-scale

Quasi-parallel Configuration[2]

- Broad (1-2 Re) turbulent transition upstream/downstream region
- Large fluctuations in all parameters
- Wave/particle interactions
- Current sheets, vortices and islands

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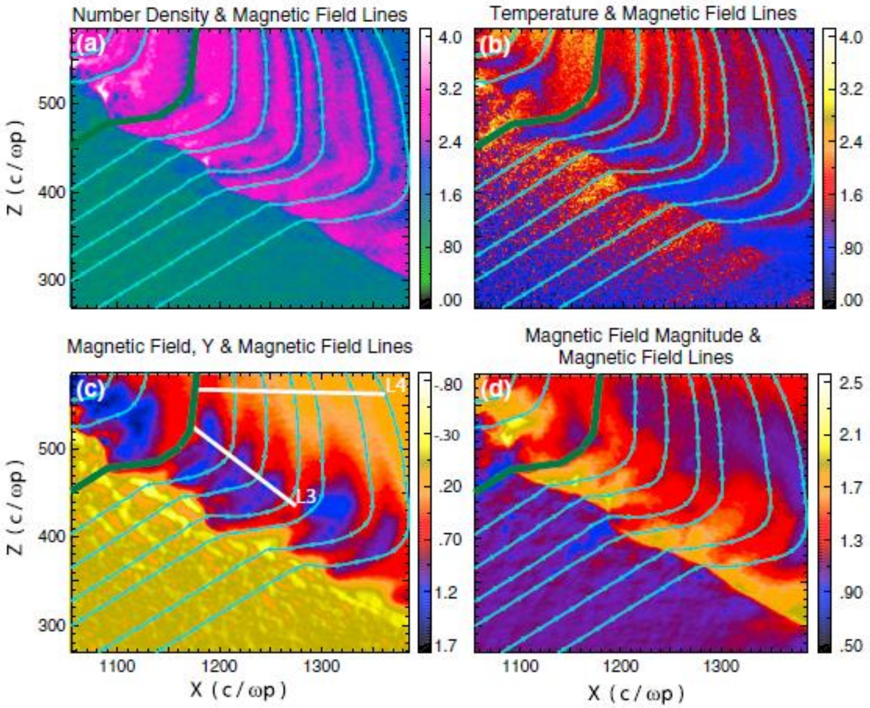
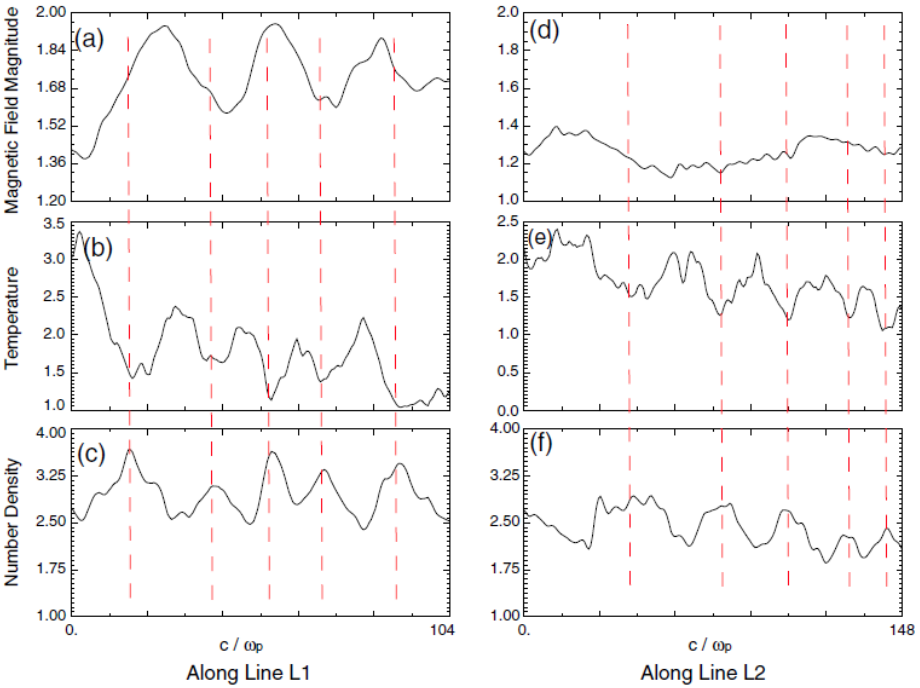
[1] When the angle between the bow shock normal and the interplanetary magnetic field is larger than 45°

[2] When the angle is smaller than 45°

Magnetosheath filamentary structures at $Q_{||}^{BS}$

[Omidi et al., JGR, 2014]

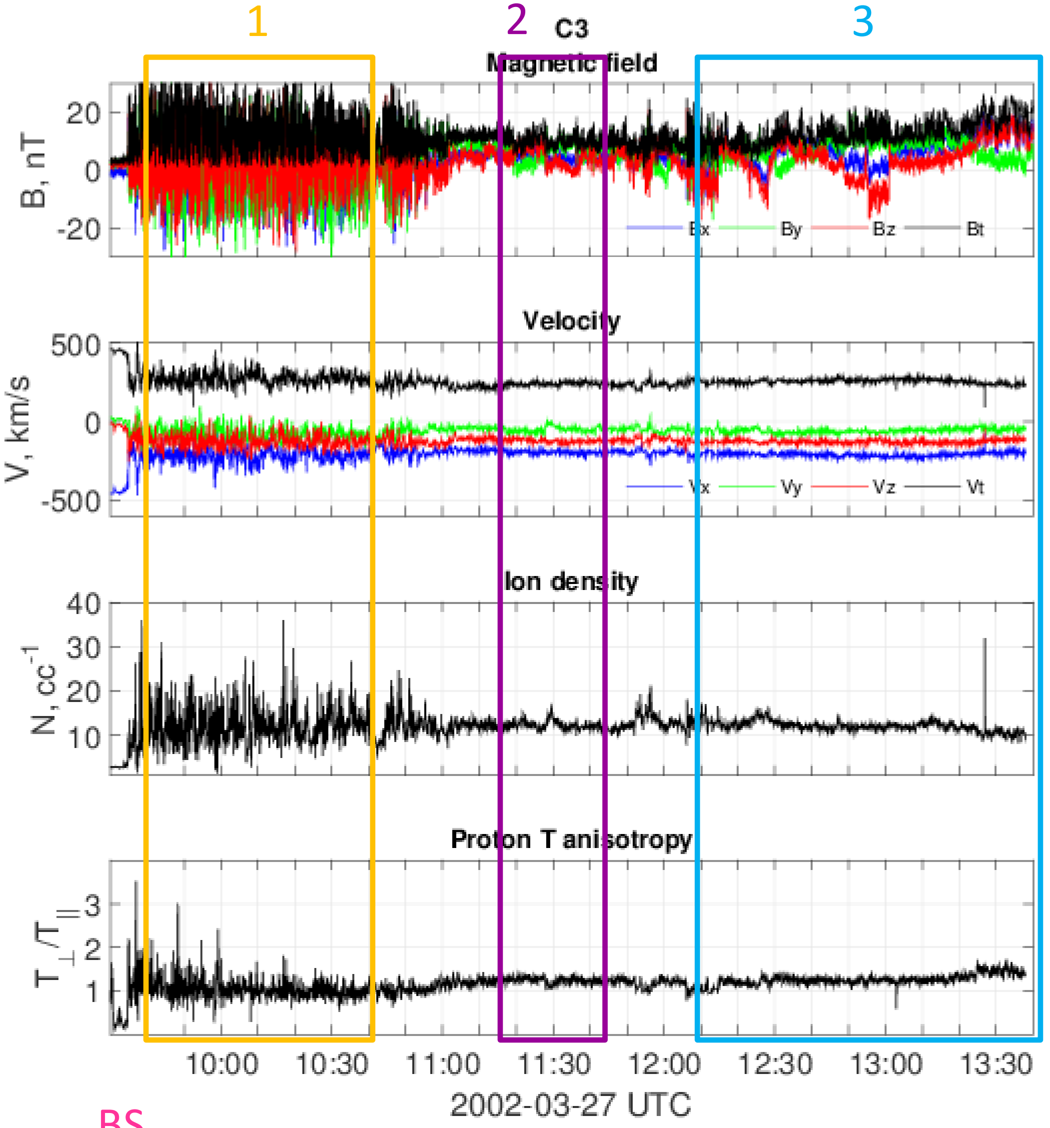




Magnetosheath filamentary (MF: anti-correlated field aligned density and temperature) structures form over a wide range of solar wind Mach numbers and IMF cone angles

Due to the presence of localized regions of enhanced ion temperature at and upstream of the quasi-parallel bow shock

Cluster observations



1. $Q_{||}$ behind BS; $\vartheta_{Bn} \leq 20°$
2. $Q_{||}$ MSH proper; $\vartheta_{Bn} > 20°$
3. $Q_\perp$ close to MP ; ϑ_{Bn} :(60°-110°)

BS

MP 0.5 R_E

← 4 – 4.5 R_E →

Plasma parameters

Date	Time interval		$<T_{|}/T_{||}>$	$\delta(T_{|}/T_{||})$	$<B>$	δB	$<V>$	δV	$<N_p>$	δN_p
20020327	09:40	10:40	1.04	0.25	14.1	6	270.8	41.8	12.3	4.2
20020327	11:16	11:45	1.24	0.06	10.2	2.2	239	9.2	12.3	1
20020327	12:10	13:40	1.27	0.11	13.4	4.3	254.7	13.4	12.1	1.3

Time interval		$<T_{||}>$	$\delta T_{||}$	$<T_{|}>$	$\delta T_{|}$	ρ_p	f_ρ	λ	f_λ	$<V_A>$	β
09:40	10:40	170	57.5	171	50	131.1	0.329	65.6	0.657	80.4	4.2
11:16	11:45	179.1	13	222.2	15.1	199	0.191	65.7	0.579	58.5	9.7
12:10	13:40	177	36.9	222.5	22.1	152.2	0.266	66.2	0.612	77	5.6

- The variability of the parameters decreases in the MSH proper and increases again towards the MP

- The T anisotropy increases towards the MP

PSD

Power spectral density by Welch method

Kurtosis (Flatness)

Measure of intermittency (inhomogeneous fluctuations of a parameter, i.e. magnetic field). It results in increasing non-Gaussian shape of PDF with scale decrease:

$$K(\tau_i) = \frac{\left\langle X_{\tau_i}(t)^4 \right\rangle_t}{\left\langle X_{\tau_i}(t)^2 \right\rangle_t}$$

$$\Delta X_{\tau_i} = X\left(t+\tau_i\right) - X(t)$$

representing the characteristic fluctuations of *X* at a scale $\boldsymbol{\tau}$):

Data analysis tools

Temperature anisotropy

Source for free energy for plasma instabilities. The stability of the system depends on plasma parameters, mainly temperature anisotropy and proton plasma beta:

$$\frac{T_\perp}{T_\parallel} = 1 + \frac{a}{\left(\beta_\parallel - \beta_0\right)^b}$$

- a, b, β_0 are fit coefficients

$$\frac{T_\perp}{T_\parallel} > 1,$$

mirror and proton cyclotron instabilities

$$\frac{T_\perp}{T_\parallel} < 1,$$

fire house instabilities

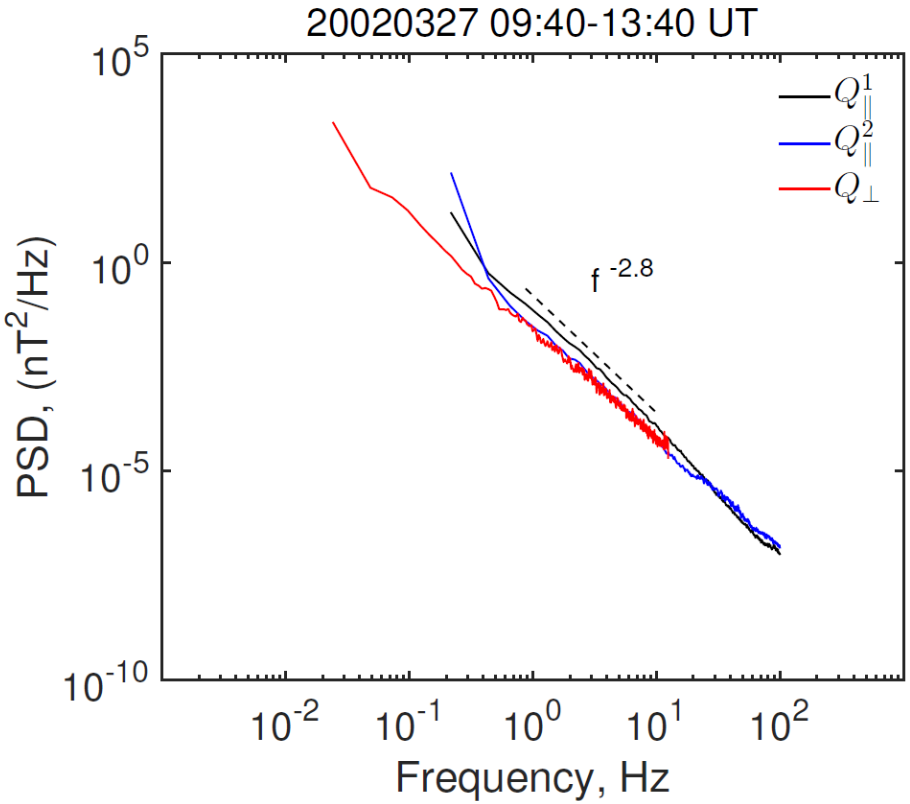
Magnetic compressibility

Indicates the relative energy in the fluctuations parallel and perpendicular to the mean magnetic field:

$$C_\parallel = \frac{\delta B_\parallel^2}{\delta B_\parallel^2 + \delta B_\perp^2}$$

[Bale et al., 2009, Hellinger et al., 2006]

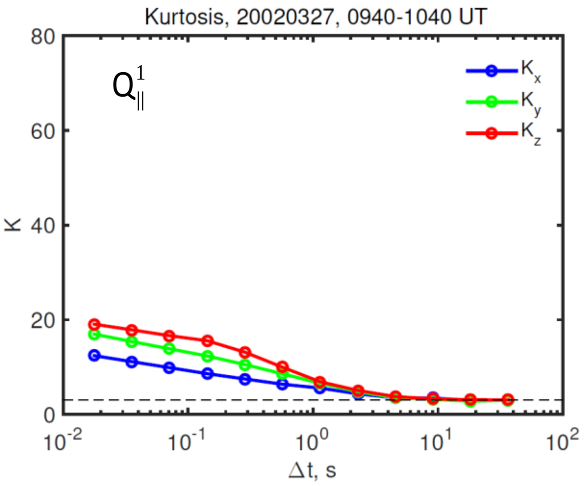
Power Spectral Density (PSD)

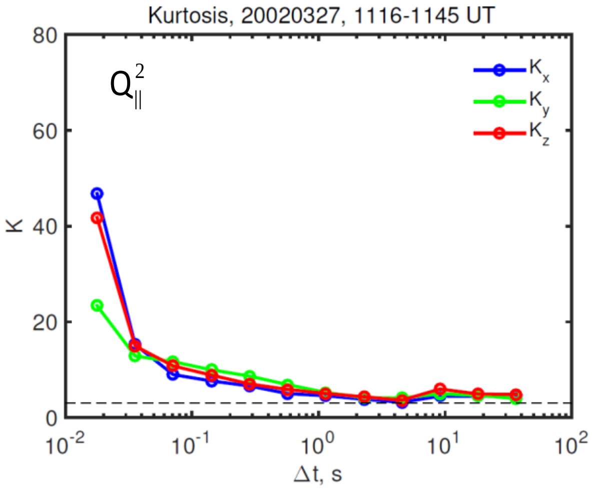


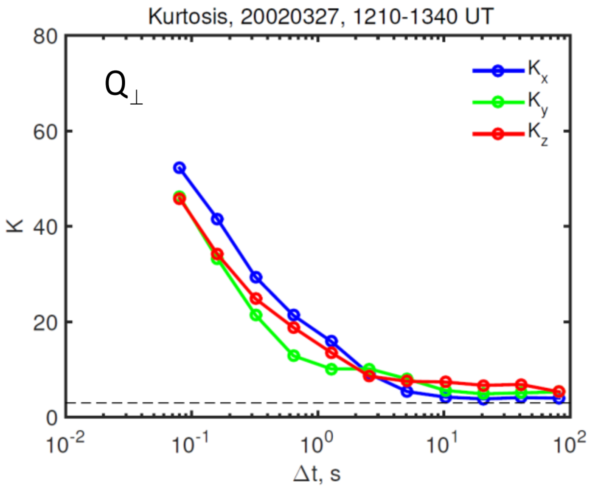
PSD - same in both BS configurations as observed before [Fuselier et al., 1994]

Intermittency (Kurtosis)

Intermittency – Inhomogeneous (bursty) fluctuations in the observed quantity in space and/or time

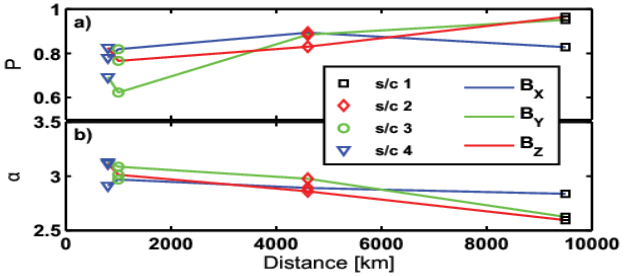






- Intermittency increases away from the BS
- Intermittency higher in quasi-perpendicular magnetosheath

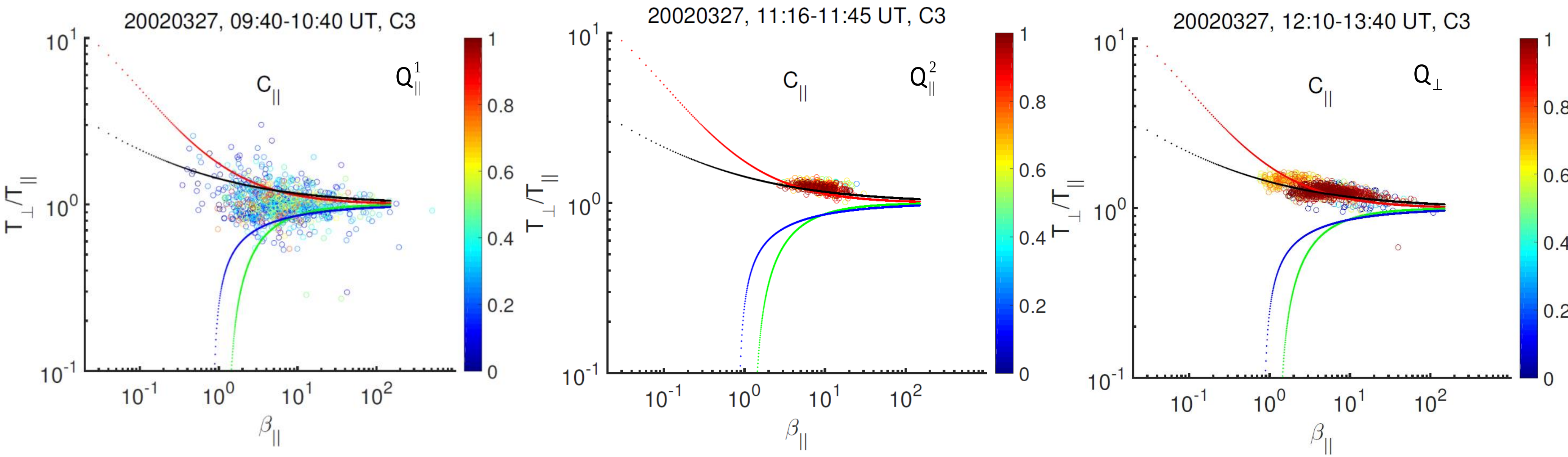
P and α vs distance from the bow shock



[Yordanova et al., 2009]

Compressibility in $(T_\perp / T_\parallel, \beta_\parallel)$ plane

········ Mirror
········ Proton cyclotron
········ Oblique firehose
········ Parallel firehose



- $Q_\parallel^1$: broad range of $(T_\perp / T_\parallel, \beta_\parallel)$ - plasma is unstable (fluctuations exceed all thresholds);
- $Q_\parallel^2$: concentration along the mirror and proton cyclotron threshold;
- $Q_\perp$: two populations with different compressibility concentrated around the proton-cyclotron and mirror thresholds

Conclusion

- Intermittency increases from the bow shock to the magnetopause
- Magnetic compressibility also increases away from the bow shock
- Temperature anisotropy also increase with the distance from BS, giving rise to plasma instabilities and waves