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SUB-ION SCALE MEASUREMENTS OF COMPRESSIBLE TURBULENCE IN THE SOLAR WIND MMS OBSERVATIONS

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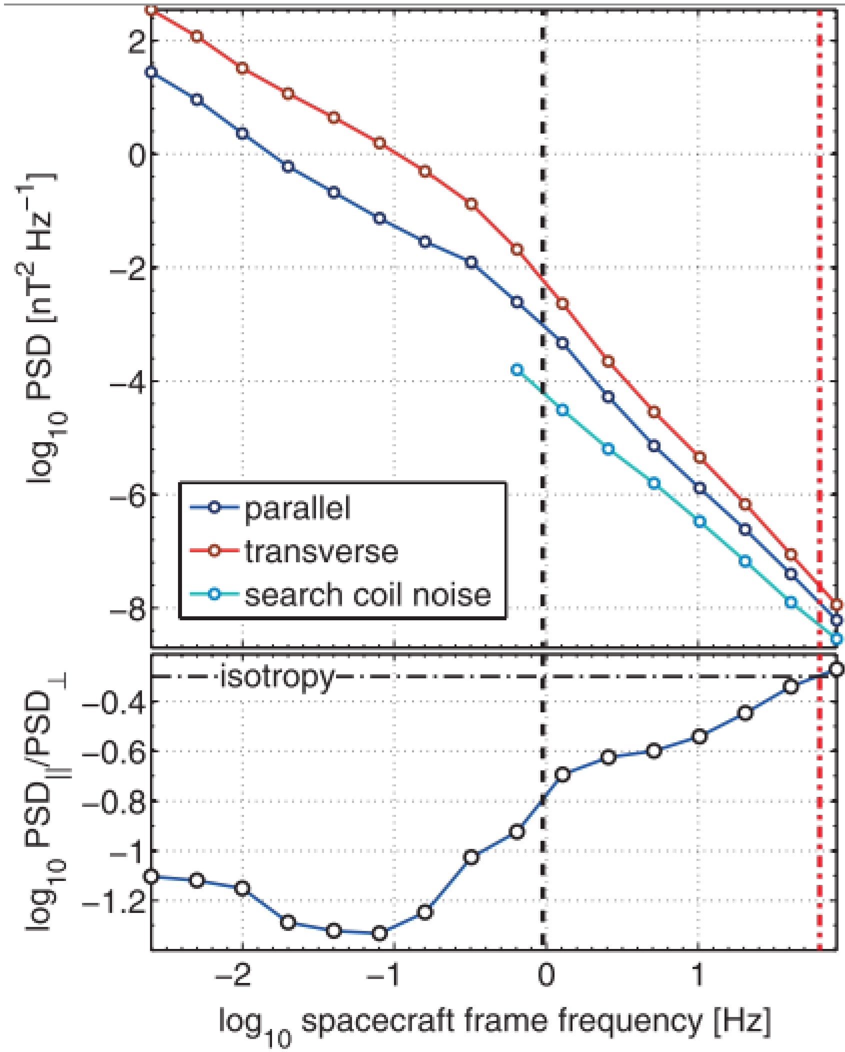
UNDERSTANDING SMALL SCALE FLUCTUATIONS

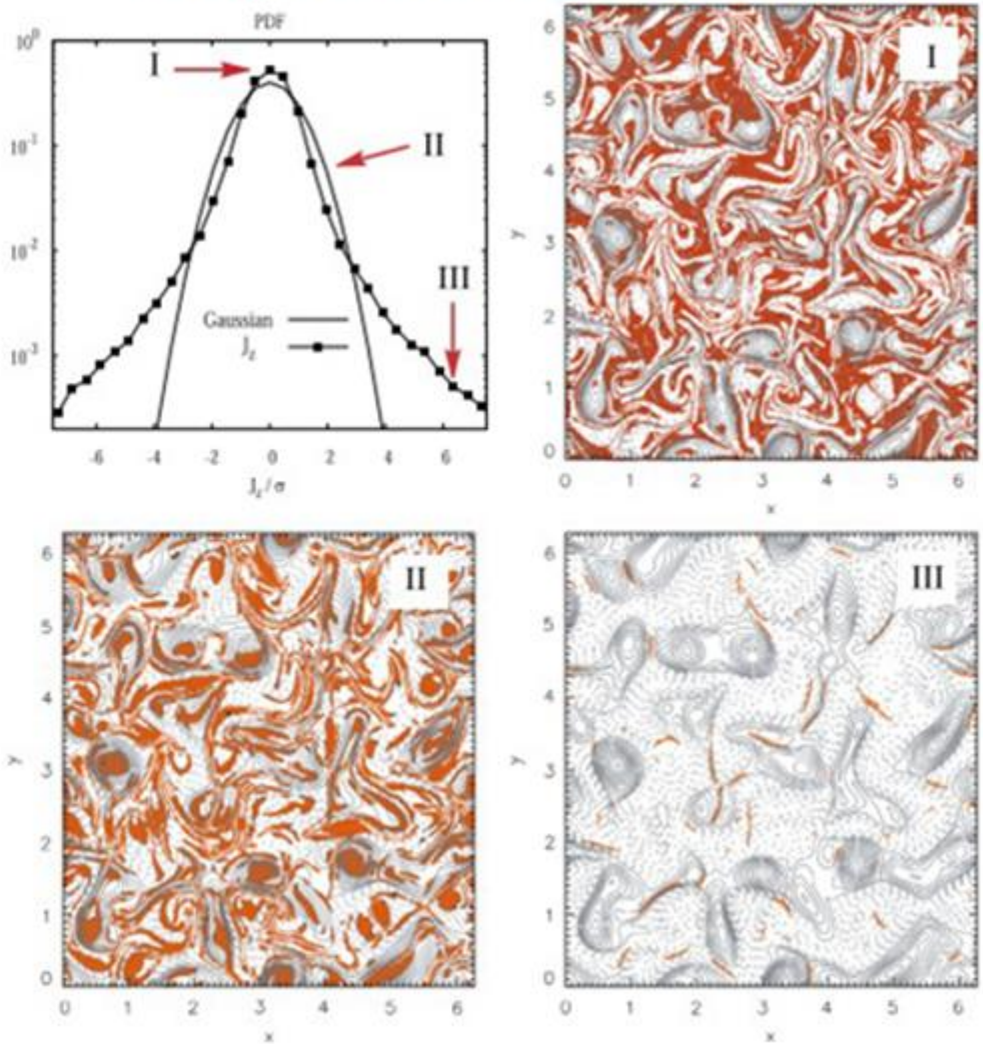
- To understand the processes of heating at electron scales it is necessary to have high time resolution measurements
- The heating may be due to quasi-linear waves e.g. KAWs which undergo Landau damping heating electrons
- Heating may be concentrated in\near coherent structures
- High time resolution\multiple close sampling points are required
- In the solar wind magnetic compressibility increases in the sub ion (f>1Hz) scale having comparable power to the transverse components
- Understanding compressible power is key



- Kiyani et al (2013)

WHAT IS INTERMITTENCY?

Intermittency is related to coherent structures



Greco et al (2017)

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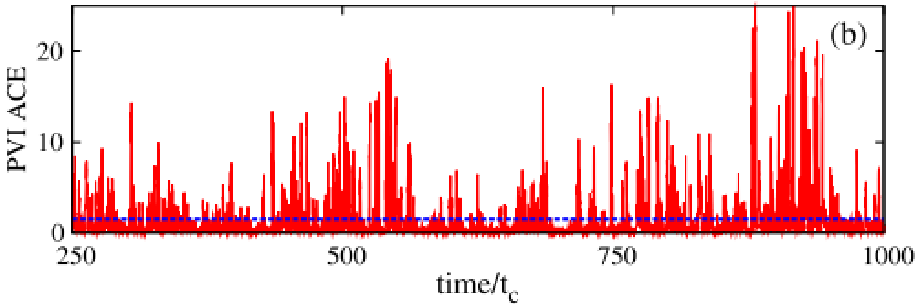
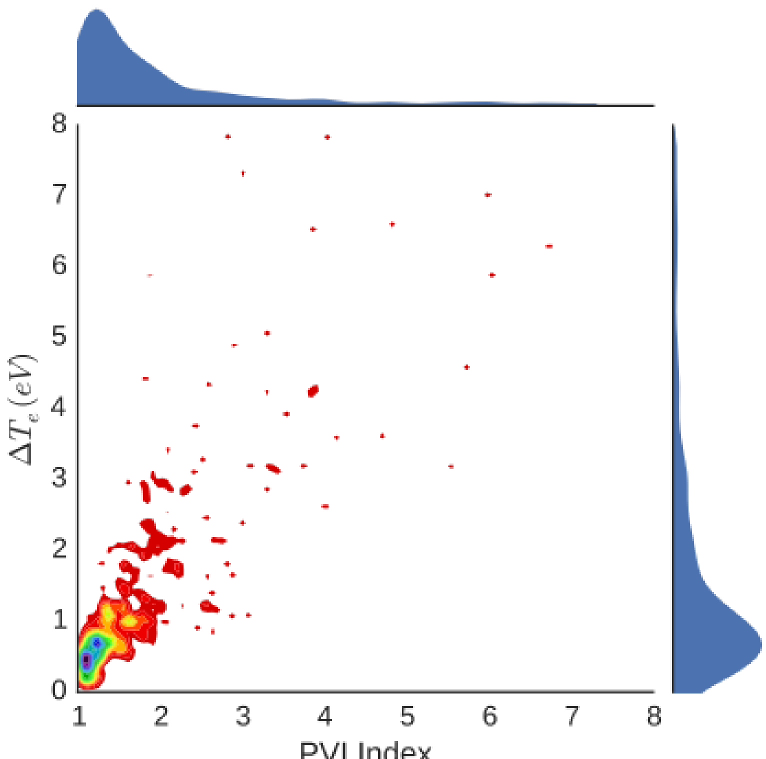
WHY IS IT IMPORTANT?



Greco et al. 2018



Coherent strutures can be identified locally by the Partial variance of increments (PVI).

High PVI is often associated with heating e.g. Chasapis et al. 2017 (left). See also Osman et al. 2011 and others

Coherent structures are an important part to understand.

$$|\Delta \mathbf{B}| = |\mathbf{B}(t+\tau) - \mathbf{B}(t)|$$

$$\Im = \frac{|\Delta \mathbf{B}|}{\langle |\Delta \mathbf{B}|^2 \rangle^{1/2}}$$

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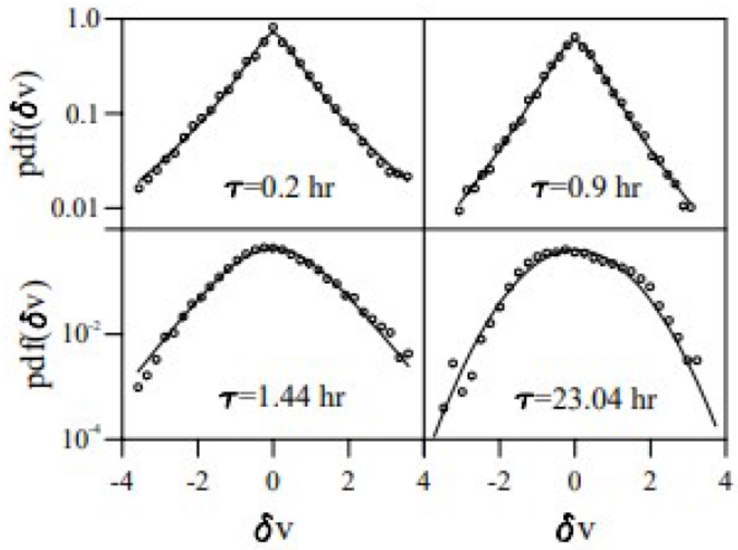
Quantifying Intermittency -Kurtosis

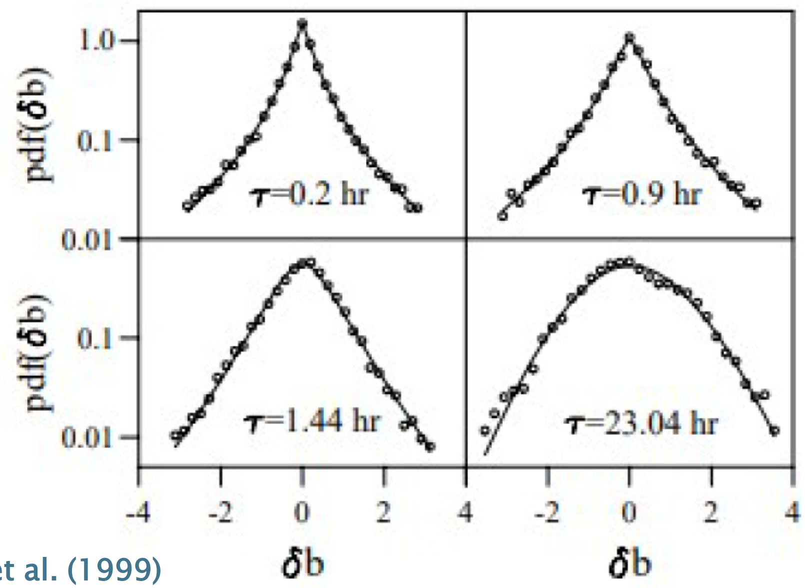
$$\delta B_i^{\ell}(t) = B_i(t+\tau) - B_i(t).$$

Time Lagged measurements

$$\delta B_i^{ab}(t) = B_i^a(t) - B_i^b(t),$$

Spatially Lagged measurements





Sorriso-Valvo et al. (1999)

$$K(\tau) = \frac{\langle \delta B(t,\tau)^4 \rangle}{\langle \delta B(t,\tau)^2 \rangle^2}$$

Deviation from Gaussian quantified by Kurtosis (flatness)

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SPACECRAFT POTENTIAL

$$I_e = -A_{\text{spac}} q n_e \sqrt{\frac{k_B T_e}{2 m_e \pi}} \left(1 + \frac{q V_{sc}}{k_B T_e}\right)$$

Get from lower resolution FPI data

$$I_{\text{phot}} = I_{\text{ph0}} \exp\left(-\frac{q V_{sc}}{k_B T_{ph0}}\right) + I_{\text{ph1}} \exp\left(-\frac{q V_{sc}}{k_B T_{ph1}}\right)$$

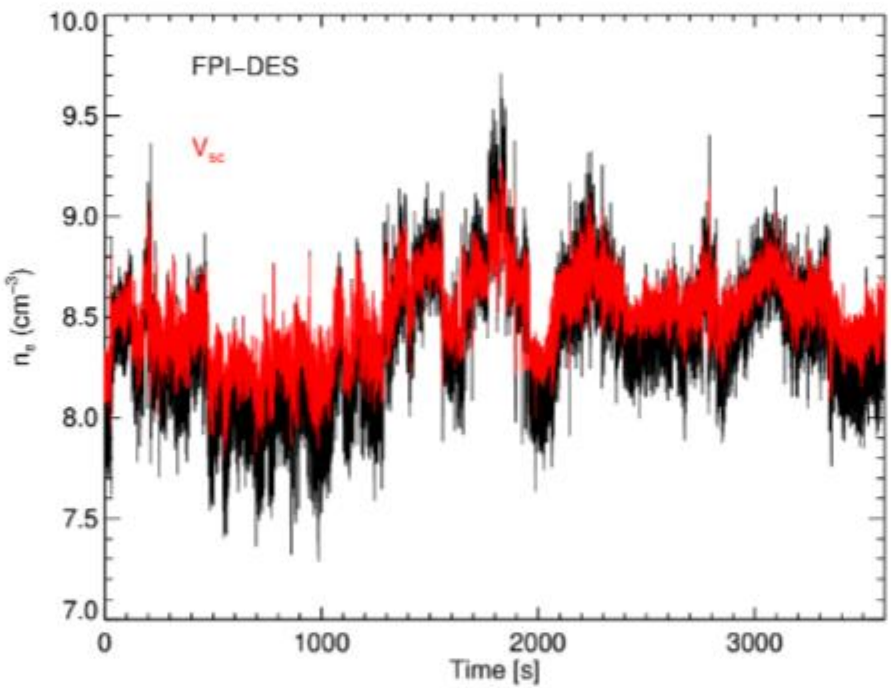
Fit Ie to Vsc to get photoelectron parameters

- The spacecraft potential is governed by the currents to and from the spacecraft
- In the solar wind (ASPOC and EDI off) the conditions are such that only the electron thermal current to the spacecraft and the photoelectron emission from the spacecraft are dominant
- They can be assumed to be equal and having opposite signs Ie=Iph allowing the density to be derived
- This allows a measurement of electron density with time resolution of 8192Hz

$$n_{e,SC} = \frac{1}{q A_{\text{spac}}} \sqrt{\left(\frac{2\pi m_e}{k_B T_e}\right)} \left(1 + \frac{q V_{sc}}{k_B T_e}\right)^{-1} \left(I_{ph0} \exp\left(\frac{-q V_{sc}}{k_B T_{ph0}}\right) + I_{ph1} \exp\left(\frac{-q V_{sc}}{k_B T_{ph1}}\right)\right)$$

SOLAR WIND DENSITY WITH MMS

- On the Magnetospheric MultiScale Mission the spacecraft potential allows a much higher time resolution (8kHz) when compared to FPI-DES (33.3Hz)
- The noise in FPI in the solar wind becomes significant in the range 3-5Hz
- The spacecraft potential can be used up to 40Hz giving an additional decade in scale



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INTERMITTENCY OF DENSITY FLUCTUATIONS

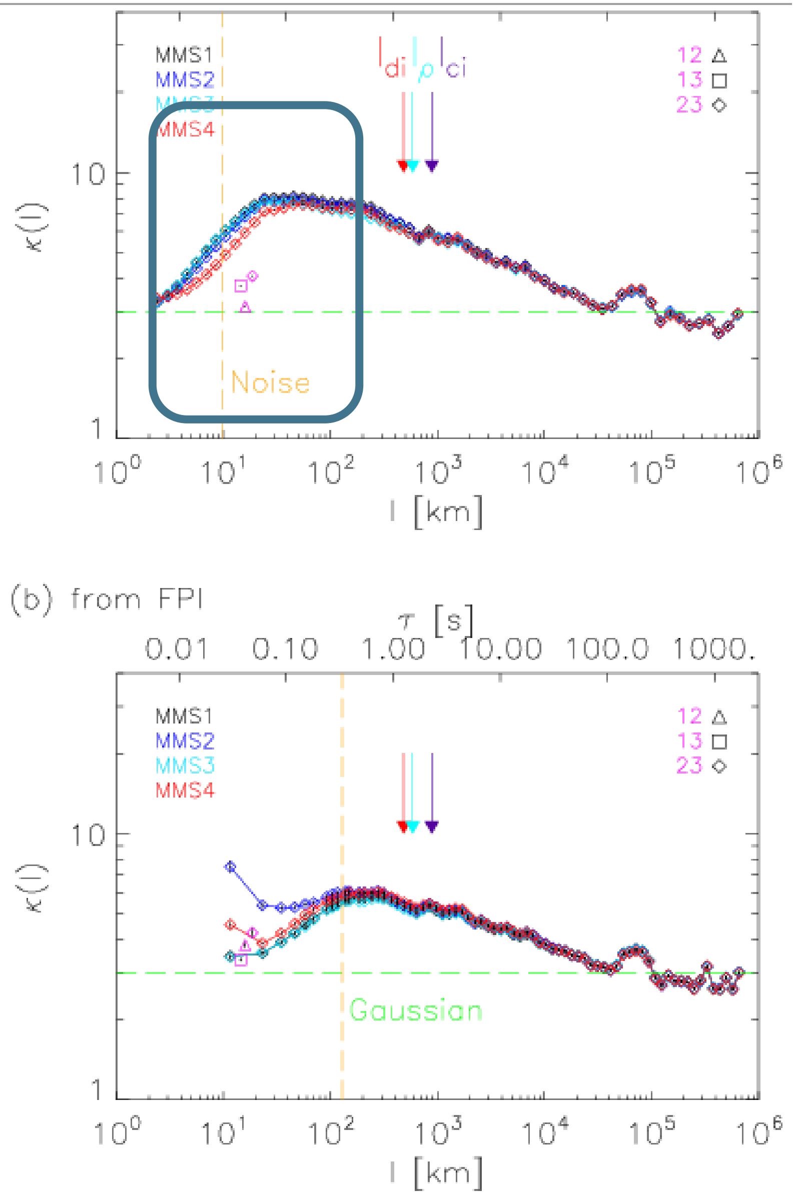
$$\delta n_e(t) = n_e(t+\tau) - n_e(t)$$

Time Lag

$$\delta n_e^{1,2}(t) = n_{e,1}(t) - n_{e,2}(t),$$

Spatial Lag

- Scale dependent Kurtosis of time lags measured by spacecraft potential and FPI DES
- Good agreement until FPI reaches the noise floor
- Agreement for FPI between time lags and spatial lags (time lags contaminated by noise)
- Disagreement between time lag and spatial lags at same scale for spacecraft potential derived density….Why?
- Something special about sampling direction?
- Larger scales affecting smaller scales?
- Breakdown of frozen in condition at small scales



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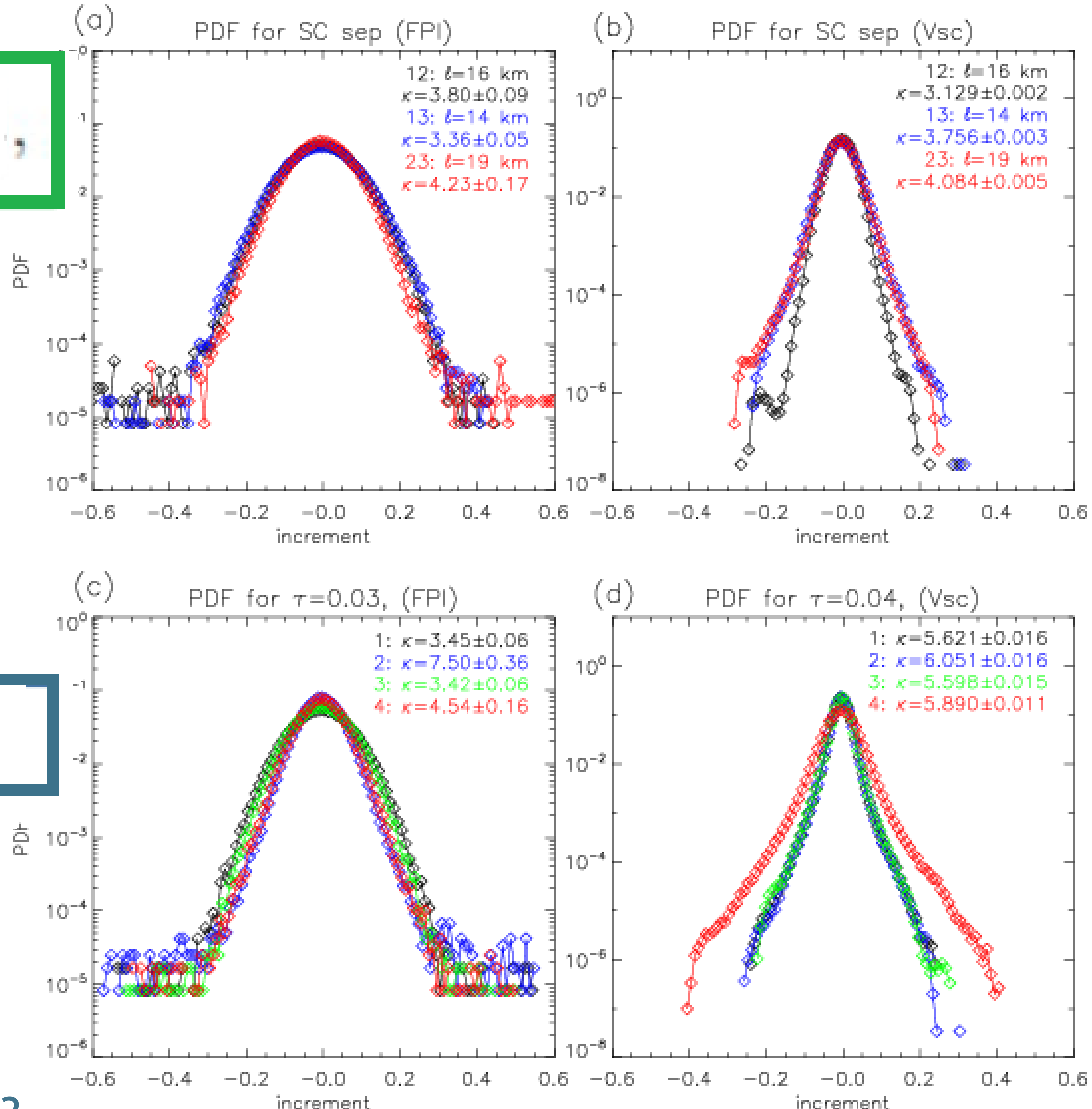
PDFS

$$\delta n_e^{1,2}(t) = n_{e,1}(t) - n_{e,2}(t),$$

- Spatial lag

$$\delta n_e(t) = n_e(t+\tau) - n_e(t)$$

- Time lag
- Time lag comparable to spatial scale seems more intermittent
- What about magnetic fields?



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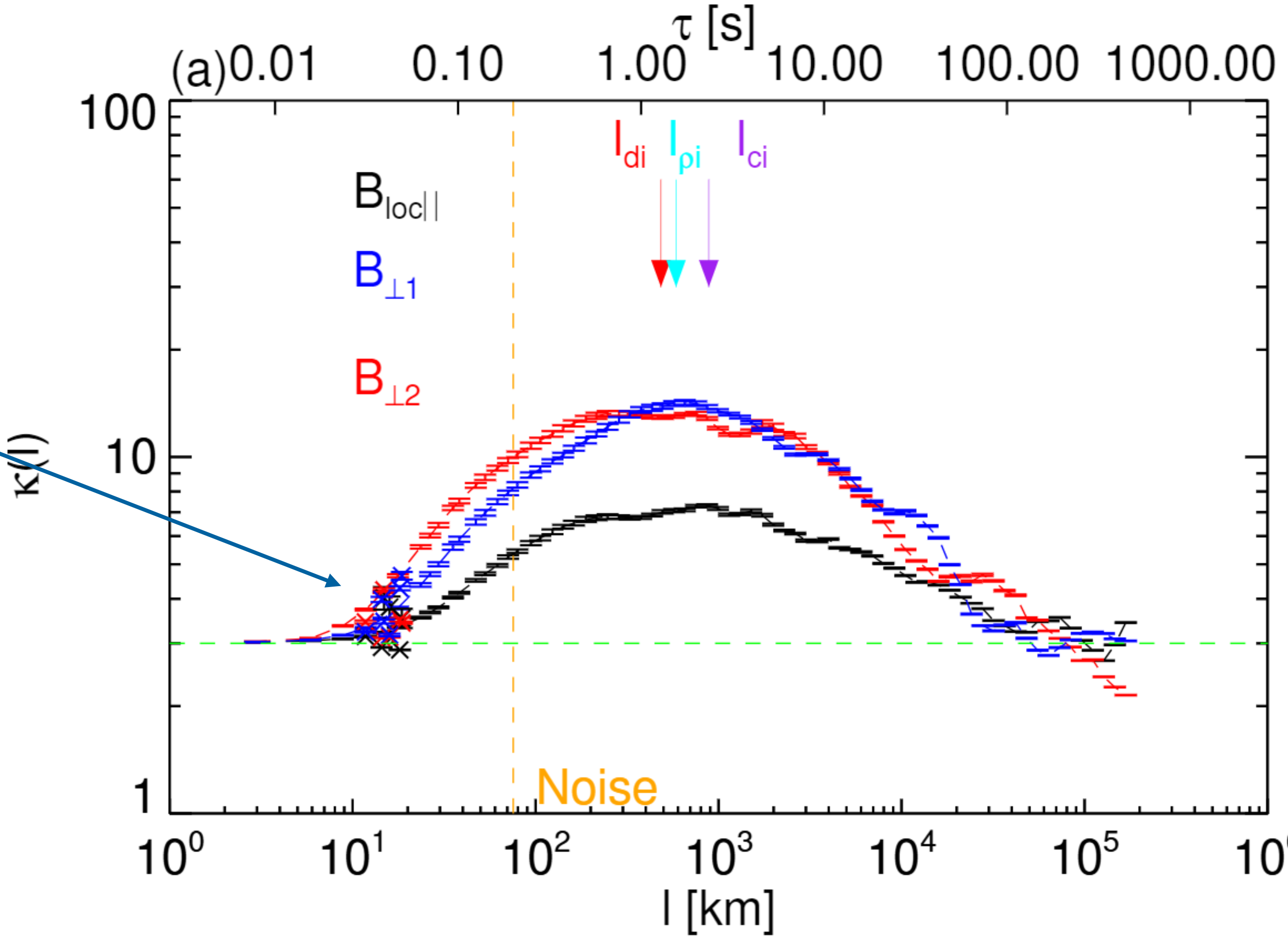
INTERMITTENCY OF THE MAGNETIC FIELD

Noise becomes an issue at 5 Hz in the magnetic field on MMS

Inter-spacecraft lags show the same result as density; very low values of kurtosis



MAGNETIC FIELD STUDY WITH CLUSTER

Merged Cluster Fluxgate magnetometer and search coil magnetometer offers better signal to noise ratio for magnetic field at sub ion scales.

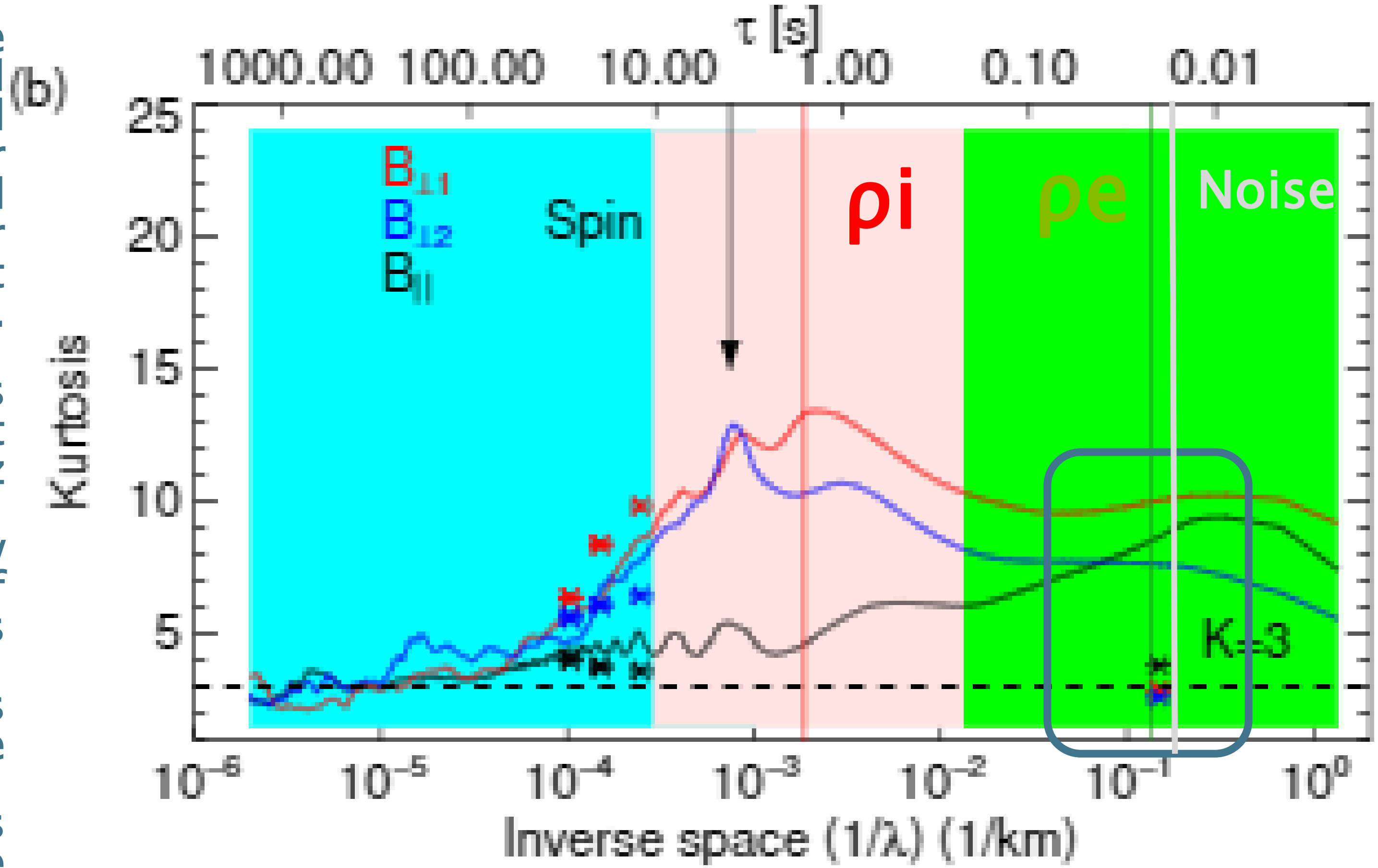
Noise becomes significant at ~60Hz

Black arrow denotes the spin of Cluster at 4s

Red line denotes proton gyroscale

Green line denotes electron gyroscale

Grey line denotes instrumental noise



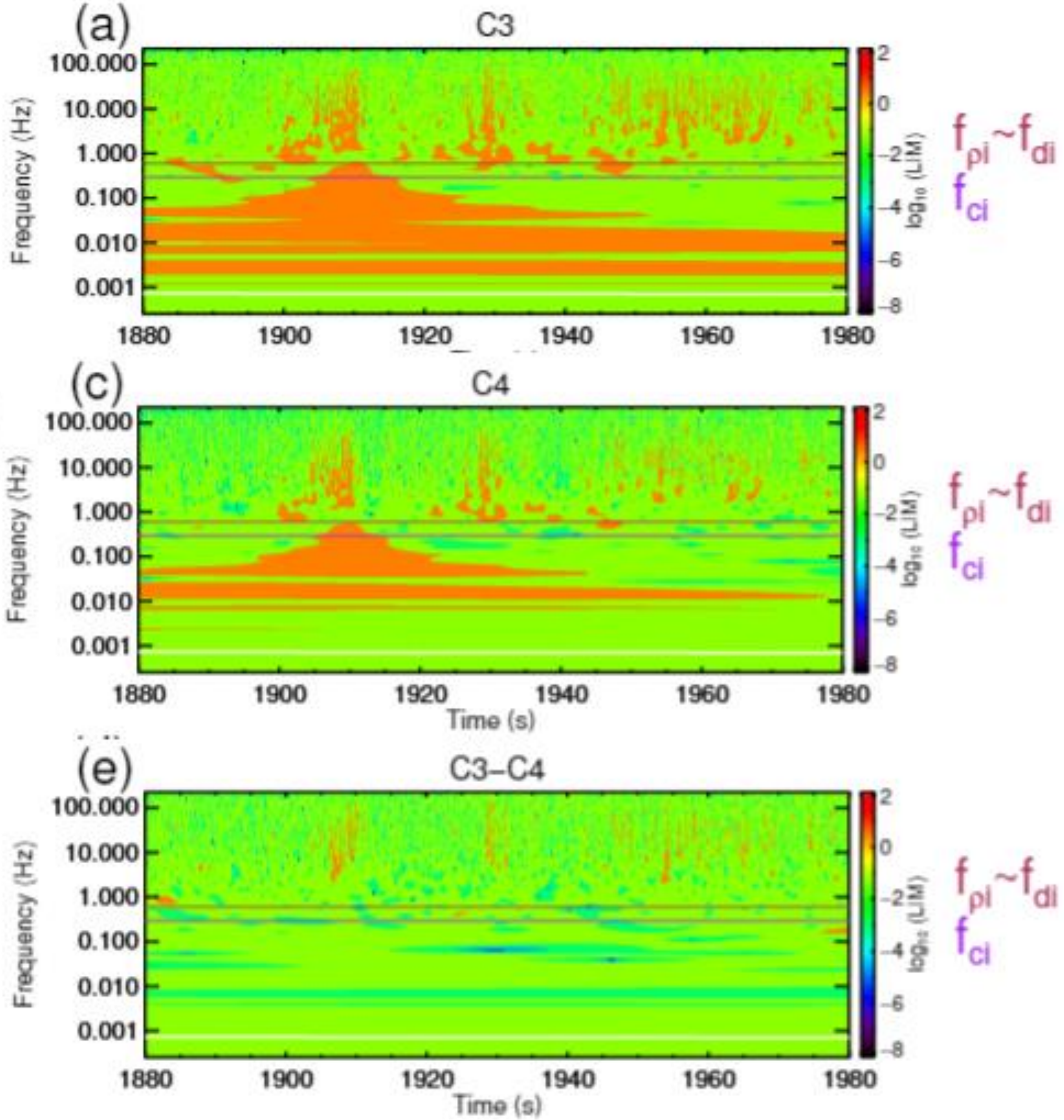
Disagreement like the MMS density measurements for time and spatial lags

LOCAL INTERMITTENCY MEASURE CLUSTER

Local intermittency measure of Cluster magnetic field and the increments

Redder colours indicate more intermittent regions

Can the large scale structure influence smaller scales?



RECONCILING TIME AND SPATIAL LAGS

In the MMS magnetic field and FPI density the time lags are dominated by noise at the smallest scales (~30Hz) giving k=3. This agrees with the inter-spacecraft lags which less affected by noise but still have k=3. However, the time lags of the Cluster magnetic field and the MMS spacecraft potential are not noisy at 30Hz and k>3. In disagreement with the all spatially lagged measurements. How can we reconcile the discrepancy between temporal and spatial lags?

Some Hypotheses

1. Taylor's hypothesis is not valid at > 30Hz i.e. we cannot convert a time lag to a spatial lag. A kinetic scale analogue to Vortex collapse?
2. Distinct difference between the bulk flow direction and the inter-spacecraft baselines. i.e. more/fewer structures seen in the bulk flow direction giving the difference.
3. Timing accuracy is not good/ or blurring of information due to low time resolution. Seems unlikely especially as advection time over constellation is 0.05s i.e. larger than the FPI data resolution, and much larger than the other data (Cluster SCM,MMS Spacecraft potential)
4. Affects of large scales (f<1Hz) affecting time lags whereas they are more effectively filtered by the spatial lag approach?
5. ???

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CONCLUSION

- Calibrated spacecraft potential gives an exceptional data set to study compressible turbulence in the sub ion range
- Disagreement between spatial and temporal lags
- Density data shows similar features to magnetic field data from Cluster. Intermittency is larger in transverse component, becomes comparable in sub ion range
- Would smaller multi-scale separations help?
- Nature of intermittency is unclear at these scales