Young solar wind coherent structures from inertial to sub-ion range

Alexander Vinogradov[1,2], Olga Alexandrova[1], Anton Artemyev[3,2], Milan Maksimovich[1], Alexei Vasiliev[2], Anatoly Petrukovich[2], Stuart Bale[4,5], Karine Issautier[1], Michel Moncuquet[1]

[1]LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université de Paris, 5 place Jules Janssen, 92195 Meudon, France
[2]Space Research Institute of the Russian Academy of Sciences, Moscow, Russia
[3]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA, USA
[4]Space Science Laboratory, University of California, Berkeley, USA
[5]Physics department, University of California, Berkeley, CA, USA

Abstract

We study intermittency of turbulence in the young solar wind at 0.17 au with NASA/Parker Solar Probe during the first perihelion. We observe localised enhancements in power density that form corresponding peaks in Local Intermittency Measure (LIM) going from MHD to kinetic scales. This indicates the presence of coherent structures in the observed signal. We observe a variety of coherent events from MHD to kinetic scales. We estimate the filling factor of the structures as well as their local topology.

Data

We use a merged FIELDS/Search Coil and Fluxgate Magnetometers data for magnetic field, SWEAP/SPC instrument for ions and RFS/FIELDS quasi thermal noise data (Moncuquet et al 2020 ApJS) for electrons to characterise the plasma environment. The merged magnetic waveforms have 3.4 ms time resolution, which allows us to resolve a wide range of scales, going from MHD inertial range to sub-ion range.

Overview

We apply a wavelet transform to the magnetic waveforms and we observe localised enhancements in power density that form corresponding peaks in Local Intermittency Measure (LIM) going from MHD to kinetic scales (Fig.1). These LIM peaks are not present in the random-phase signal with the same Fourier amplitudes. These vertical LIM lines are signatures of coherent intermittent events (Lion et al. 2016 APJ, Alexandrova et al. 2020 arXiv).

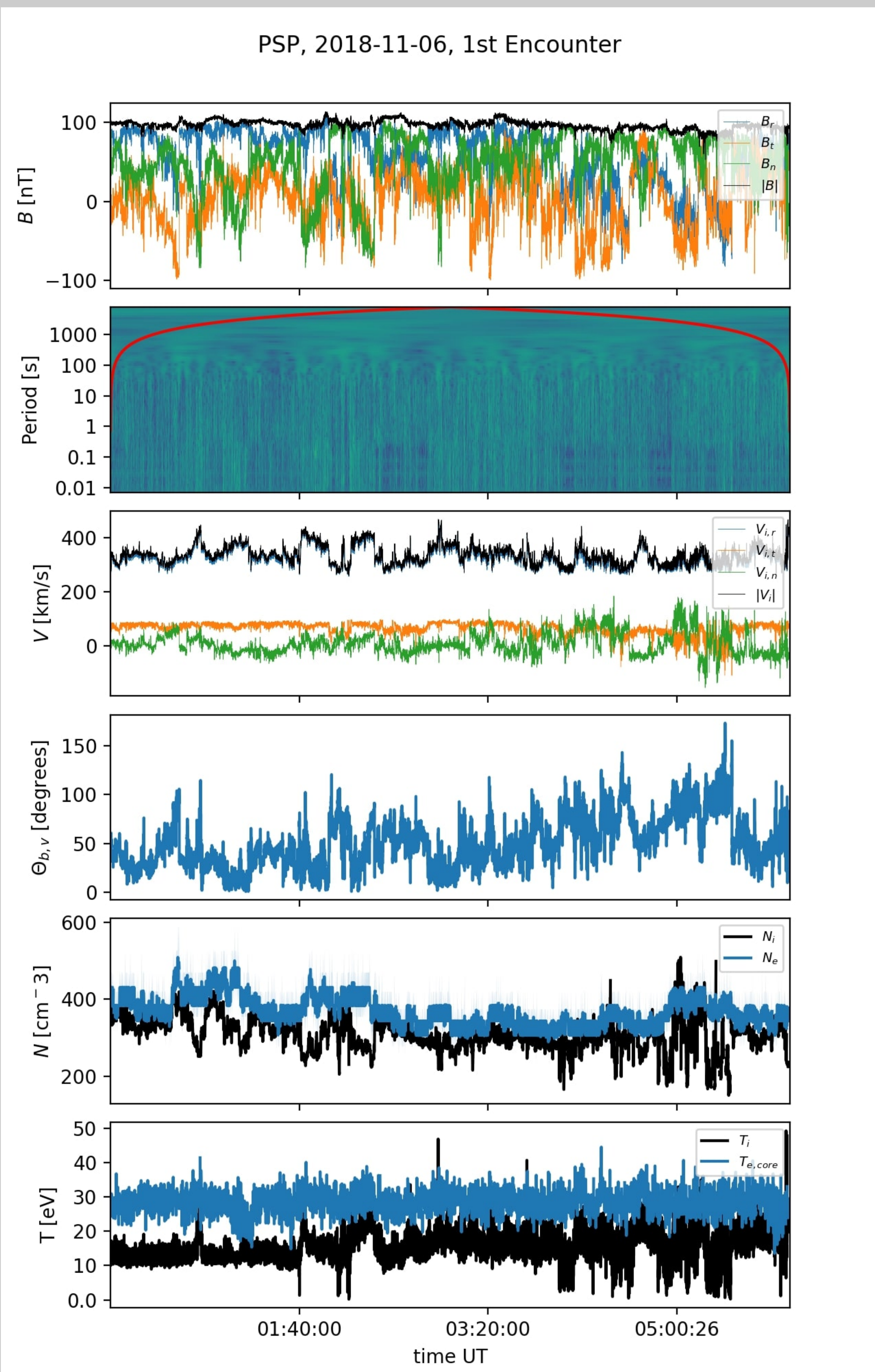

Fig. 1: (1) Magnetic field fluctuations (2) Local intermittency measure of the magnetic fluctuations (3) SWEAP/SPC ion velocity (4) Angle between the magnetic field and the solar wind velocity (5) quasi-thermal noise SWEAP/SPC ion density.

Magnetic field spectral properties

Magnetic field fluctuations are different at different scales, that can best be seen from the spectrum.
The first panel of Fig. 1 shows the spectrum of magnetic fluctuations. Let's define the characteristic frequencies separating the spectral ranges.
The bottom panel of Fig. 2 shows the kurtosis of the magnetic field, kurtosis is a measure of the "tailedness" of the probability distribution of a random variable. The difference between the magnetic field kurtosis and kurtosis value for a Gaussian random variable means the presence of substantially non-Gaussian fluctuations starting from $f > 0.01Hz$.
Kurtosis saturates at the $f = 0.4Hz$, this frequency corresponds to the end of the inertial scales.()
The ratio of compressible fluctuations to the total power spectral density increases at the ion scales (panel 2 from the top). At $f > 12Hz$ (sub-ion scales) the spectral index reaches -2.8.
As a result, we define the frequency ranges the following way:

1. Low frequency MHD scales $10^{-4}Hz < f < 10^{-2}Hz$ (Fig. 2 in white) (spectral index -1.6)
2. High frequency MHD scales $10^{-2}Hz < f < 10^{-2}Hz$ (Fig. 2 in green) (spectral index -1.6)
3. Ion scales $0.4Hz < f < 12Hz$ (Fig. 2 in blue)
4. Sub-ion scales $12Hz < f < 100Hz$ (Fig. 2 in red) (spectral index -2.8)

How do the structures look like at different scales?
Is it possible to observe how the discovered structures evolve as a result of nonlinear effects and how a turbulent cascade develops?

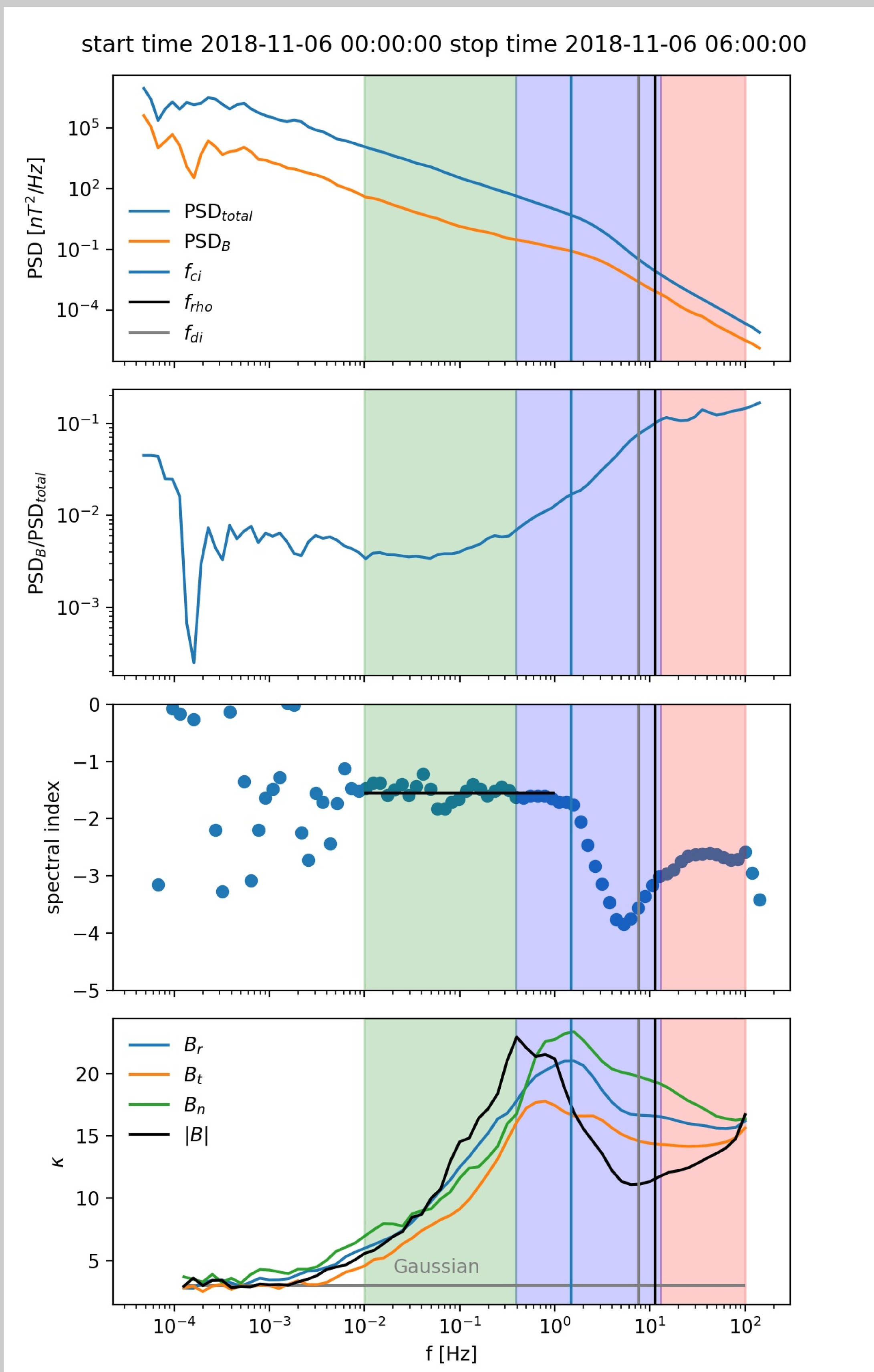

Fig. 2: (1) The total magnetic field power spectral density (PSD) in blue and the compressional part of the PSD in orange. (2) fraction of the compressional part to total PSD increases as frequency reach ion characteristic frequencies. (3) The spectral index. (4) The kurtosis. Vertical lines: blue - cyclotron frequency, grey - Doppler-shifted gyroradius, black - Doppler-shifted ion inertial length.

Multi-scale nature of the structures

Our main goal is to study the properties of coherent structures at different scales. To do this, we filter the magnetic field over the spectral ranges corresponding to the spectral ranges defined according to the magnetic field spectral properties (Fig.2 white, green, blue, and red ranges).

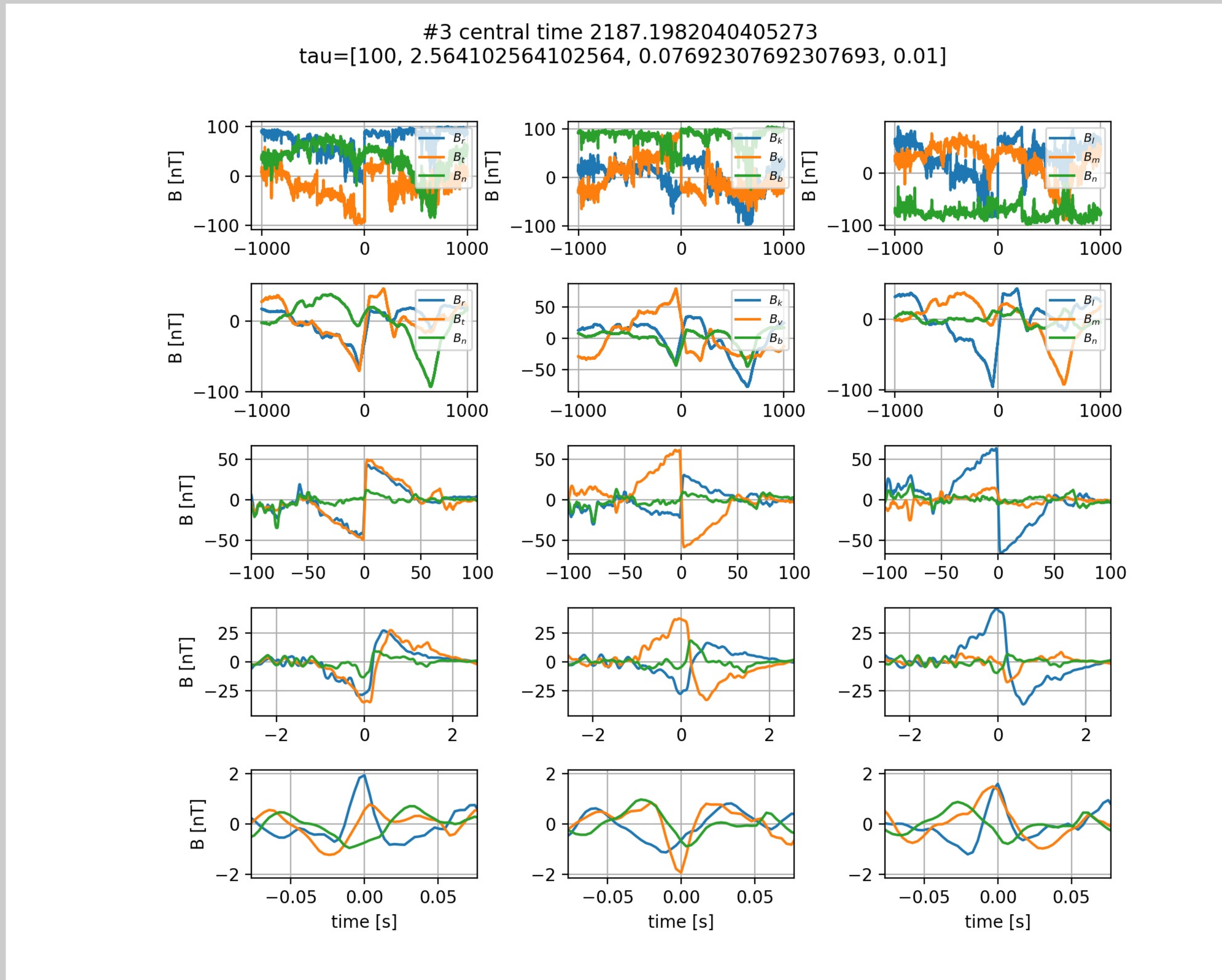

Fig. 3: Current sheet magnetic field fluctuations. Columns correspond to RTN (radial tangential normal) coordinate frame, local KVB coordinate frame and the minimum variance frame LMN. Raws: (1) original magnetic field (2) low frequency filtered B fluctuations (3) MHD range filtered fluctuations (4) ion scales filtered fluctuations (5) sub-ion scales filtered fluctuations

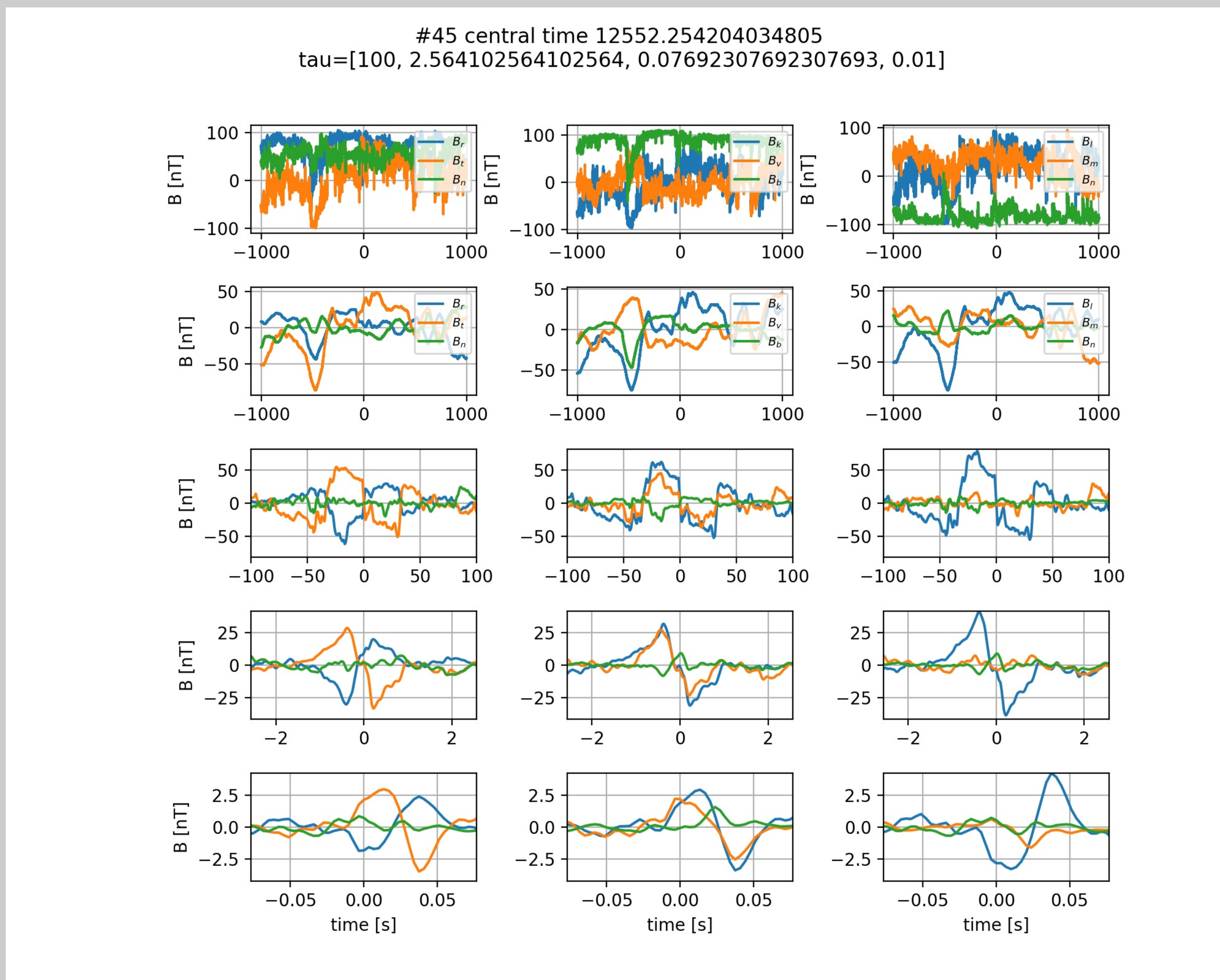

Fig. 4: One-dimensional structure probably being an Alfvén vortex. The figure format format is identical to Fig. 3

Conclusion

1. We observe enhancements in the power spectral density and in local intermittency measure (LIM), signatures of coherent structures from 100 sec to the smallest resolved time scale.
2. No particular changes in LIM at ion scales. This means, that most of the structures don't dissipate at the ion scales.
3. We observe ion-scale structures that have twice the amplitude than MHD scale fluctuations.
4. The filling factor of the structures is up to 10 percent.

Opened questions:

1. How to interpret some of the detected structures?
2. What is the dominant coherent structure?