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On the nature of MHD and kinetic scale turbulence in the magnetosheath of Saturn: Cassini observations

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Abstract

Low frequency turbulence in Saturn's magnetosheath is investigated using in-situ measurements of the Cassini spacecraft. We focus on the magnetic energy spectra computed in the frequency range $\sim [10^{-4}, 1]$Hz. Three main results are reported: 1) The magnetic energy spectra showed a $\sim f^{-1}$ scaling at MHD scales followed by an $\sim f^{-2.6}$ scaling at the sub-ion scales without forming the so-called inertial range, breaking the universality of the Kolmogorov spectrum in the magnetosheath; 2) The magnetic compressibility and the cross-correlation between the parallel component of the magnetic field and density fluctuations $C(\delta n, \delta B_{||})$ indicate the dominance of the compressible magnetosonic slow modes at MHD scales rather than the Alfvén mode [3] ; 3) Higher order statistics revealed a monofractal (resp. multifractal) behaviour of the turbulent flow behind a quasi-perpendicular (resp. quasi-parallel) shock at the sub-ion scales.

1. Introduction

In order to expand our knowledge in plasma turbulence and thanks to the Cassini spacecraft mission, we decided to explore the properties of turbulence in the Kronian magnetosheath. These properties include the magnetic field energy spectra, the magnetic compressibility and intermittency, at both MHD and kinetic scales (Not shown here)

2. Observations and results

The analysis is based on in-situ data provided by the Fluxgate Magnetometer of the MAG instrument [1], which measures the magnetic field data with 32ms time resolution and the plasma data from the CAPS/IMS (Cassini PlasmaSpectrometer) and the

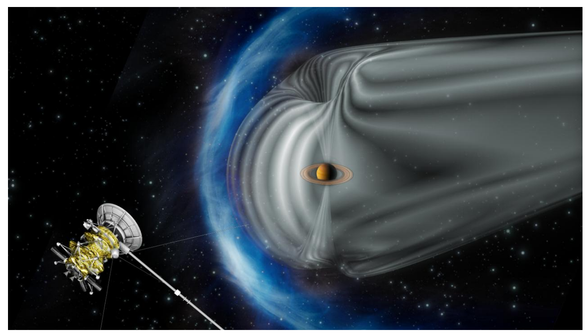

Figure 1: Saturn's magnetosphere is depicted in grey, while the shock wave in the solar wind that surrounds the magnetosphere is shown in blue. The image is not to scale.
Credit: ESA.

Electron Spectrometer (ELS) [5], during 39 shock-crossings between 2004 and 2005. Similarities and differences were found between the different media, in particular about the nature of the turbulence and its scaling laws.

2.1. Power Desnity Spectra

We first computed the power density spectra of the interplanetary magnetic fluctuations measured for a set of 39 magnetosheath crossings as have been cited earlier. As we can see from figure 2, we found that the spectra are different from those measured in the solar wind: the MHD scales show a $\sim f^{-1.26}$ spectrum rather than the Kolmogorov scaling f -5/3. And at the sub-ion scales ($f < 10^{-2}$Hz) the spectra steepen to $\sim f^{-2.6}$ similarly to previous observations in the terrestrial magnetosheath or the solar wind at 1AU [Sahraoui et al., ApJ, 2013].

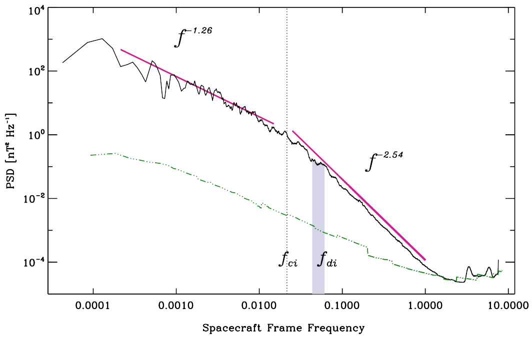

Figure 2: δB power spectral density for the analyzed time interval measured between 03:00-08:00.

2.2. Wave Modes propagation

To identify the nature of plasma modes that carry the energy cascade from the "energy-containing scales" to the sub-ion ones, we use the magnetic compressibility C_B defined as:

$$C_B(f) = \frac{|\delta B_{\|}(f)|^2}{|\delta B(f)|^2} \quad (1)$$

Figure 3 shows an example of the measured magnetic compressibility. One can see a relatively constant and high magnetic compressibility $C_B > 1/3$, which indicates the dominance of the parallel component $\delta B_{\|}$. This clearly rules out the Alfvénic fluctuations as a dominant component of the turbulence at least at MHD scales ($f < f_{ci} \sim 0.05$Hz). Studying as well the cross correlation between the magnetic field and the electron density fluctuations $C(\delta B_{||}, \delta n_e)$. We found that that locally and on average the density and the parallel component of the magnetic fluctuations are anti-correlated, i.e. $C(\delta B_{||}, \delta n_e) < 0$. This cleary rules out the fast mode fluctuation as the dominant component of the turbulence.

2.3. Higher Order Statistical study

To investigate the mono-fractal versus multi-fractal nature of the observed turbulence at MHD and sub-ion scales we analyze the Probability Density Function (PDF) of the magnetic field temporal increments and the structure functions at different orders. We find that at sub-ion scales, behind a quasi-perpendicular bow shock the turbulence is random like and self-similar however behind a quasi-parallel bowshock the fluctuations are intermittent

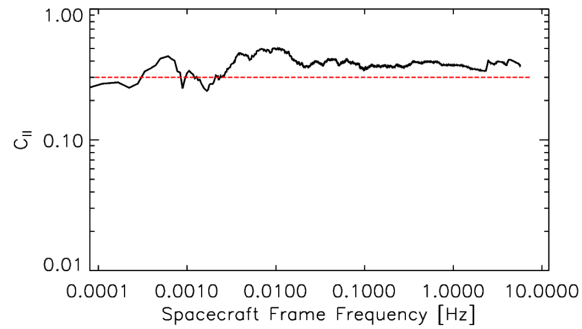

Figure 3: Magnetic compressibility of the magnetic field fluctuations.

3. Summary and Conclusions

Thanks to analyzing sufficiently long and relatively stationary time series measured by the Cassini spacecraft in the magnetosheath of Saturn away from the flanks we showed the absence of the Kolmogorov scaling $\sim f^{-5/3}$ at MHD scales, which scale as $\sim f^{-1}$ suggesting the random-like nature of the fluctuations, contrary to known results on the solar wind turbulence [2]. The spectra steepen above the spectral break to $\sim f^{-2.6}$. Moreover by studying the magnetic compressibility and the cross-correation between the density and the parallel magnetic field, our results suggest that turbulence in the magnetosheath of Saturn is dominated by compressible Slow magnetosonic modes.

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