Magnétosphères planétaires comparées

Planetary Turbulence: Exploring Plasma Turbulence in the Kronian Magnetosheath Using Cassini Data

Meudon-FRANCE

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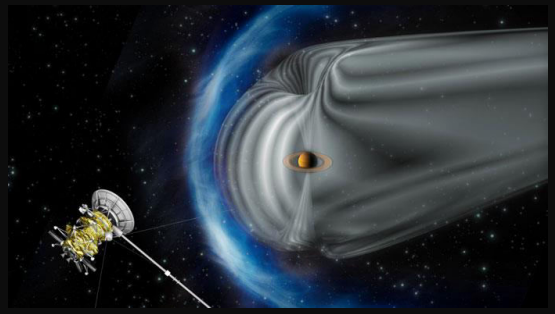


2015/02/04

Laboratoire de Physique des Plasmas [LPP]

Motivations:

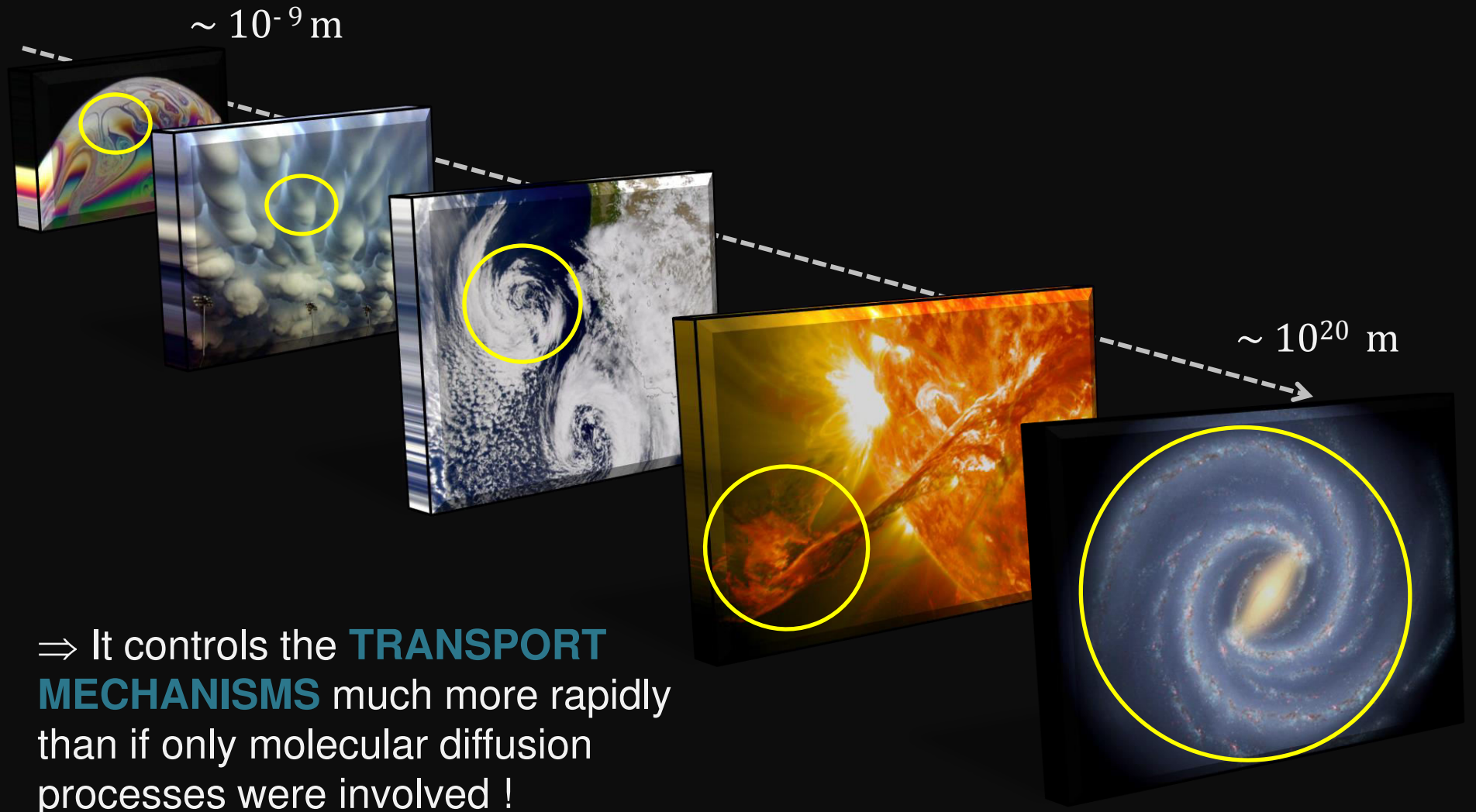
- Detailed observations of turbulence and the underlying microphysics in planetary systems other than Earth are scarce

- Plasma conditions around Saturn are different than the ones around Earth (plasma beta, Mach number, plasma composition etc…) → Possibility to study turbulence in a broader range of parameters and to compare to near Earth space.

- Analyzing Cassini data can help to improve space instrumentation of future planetary missions under preparation.

Turbulence Overview

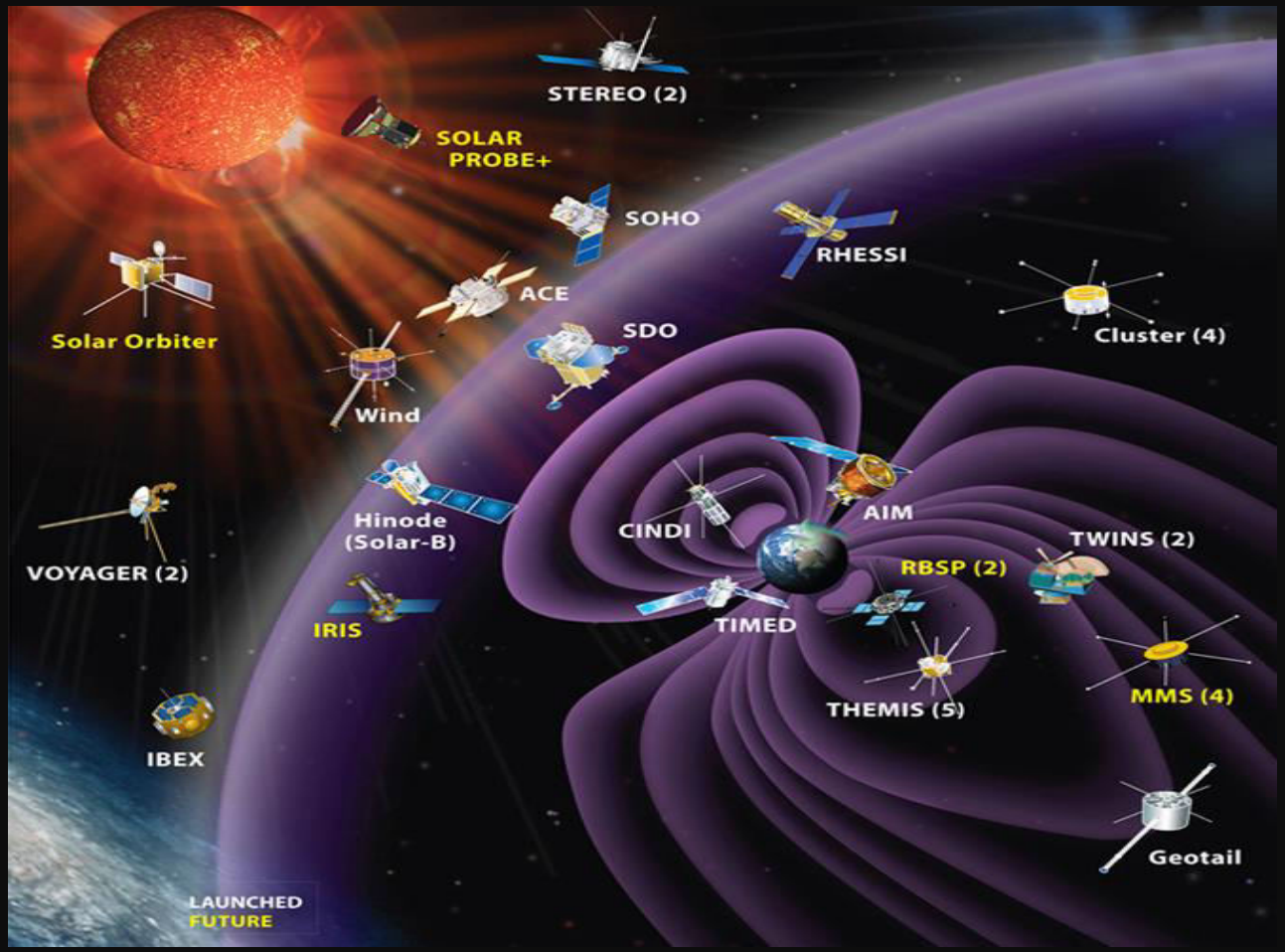
Main Features & Definition of Turbulence



⇒ It controls the **TRANSPORT MECHANISMS** much more rapidly than if only molecular diffusion processes were involved !

Turbulence Overview

Measuring Turbulence around Earth

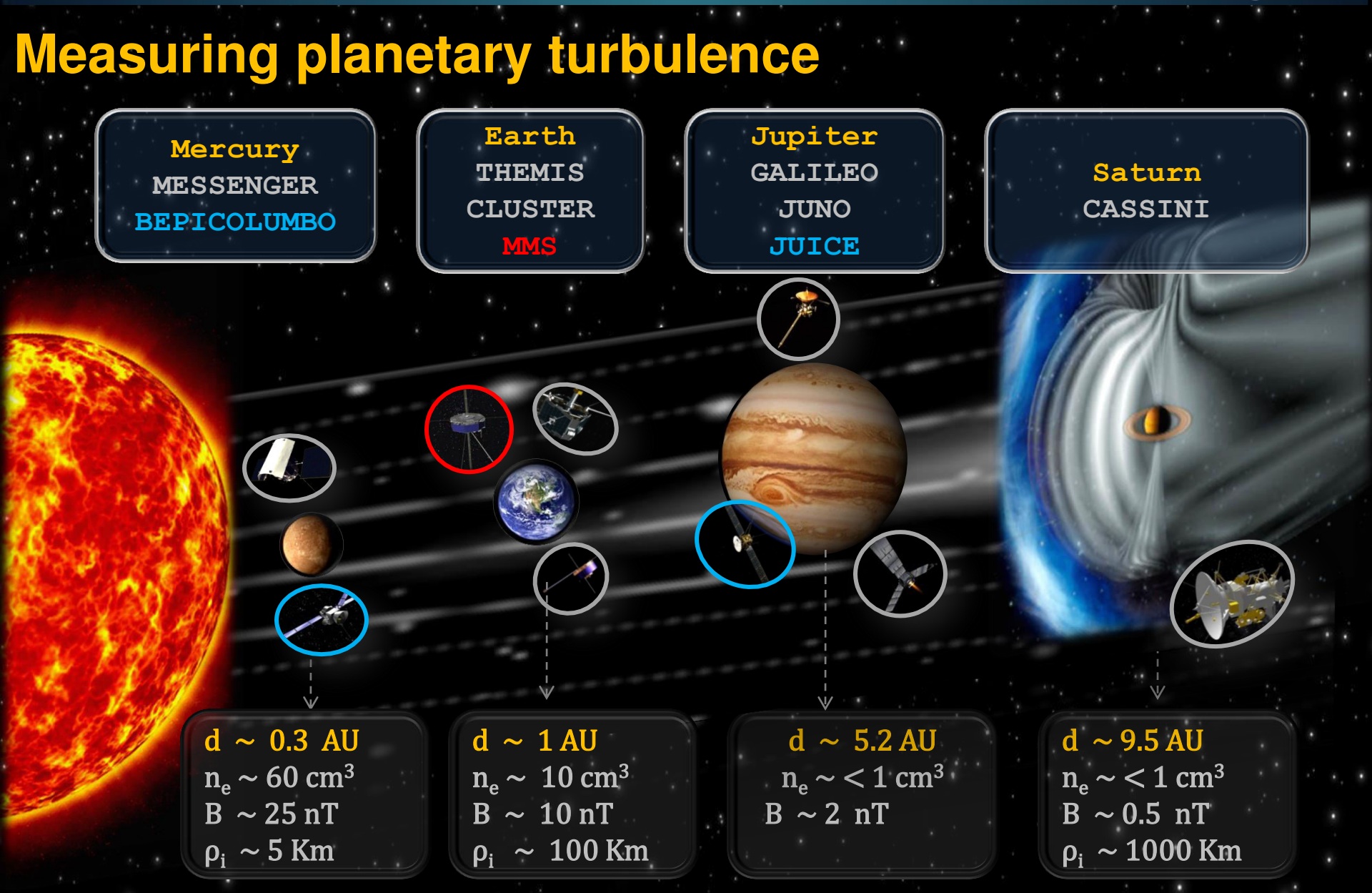


In-Situ Measurements

- **Magnetic & Electric Fields**
- **VDFs (e,p) → fluid moments: n, V, T**

Turbulence Overview

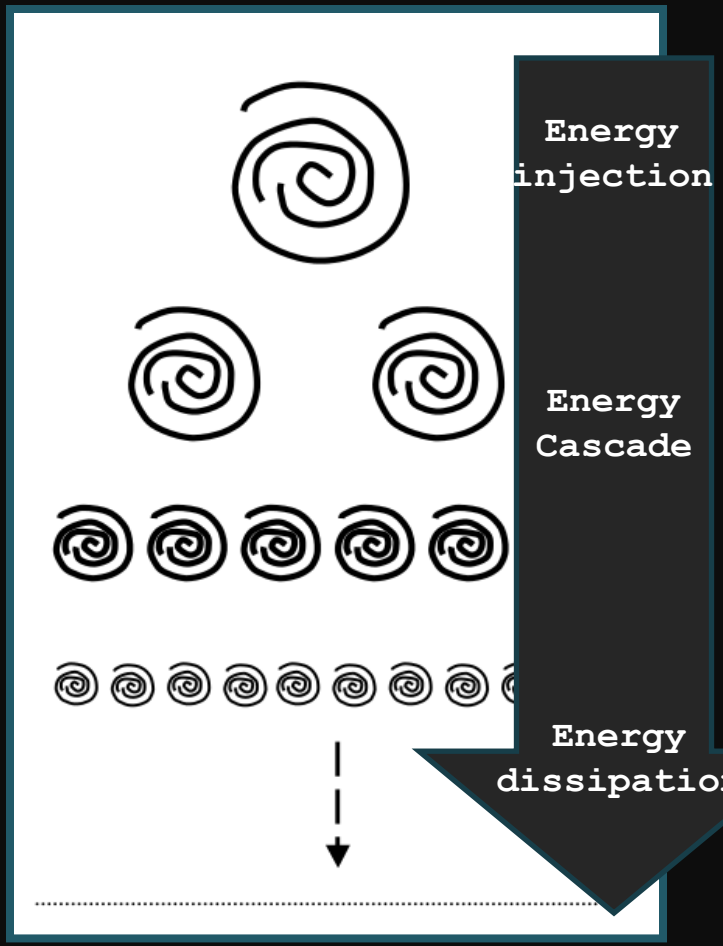
Measuring planetary turbulence

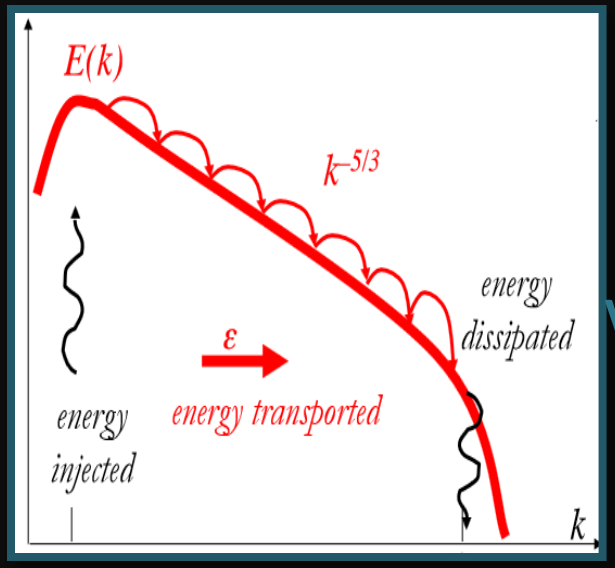


Turbulence Overview

Kolmogorov's (1941) 5/3 Universal Law

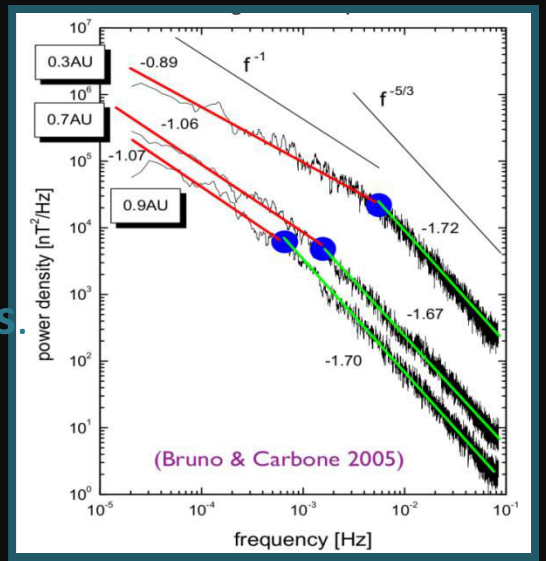
« Richardson cascade »





Hydrodynamics

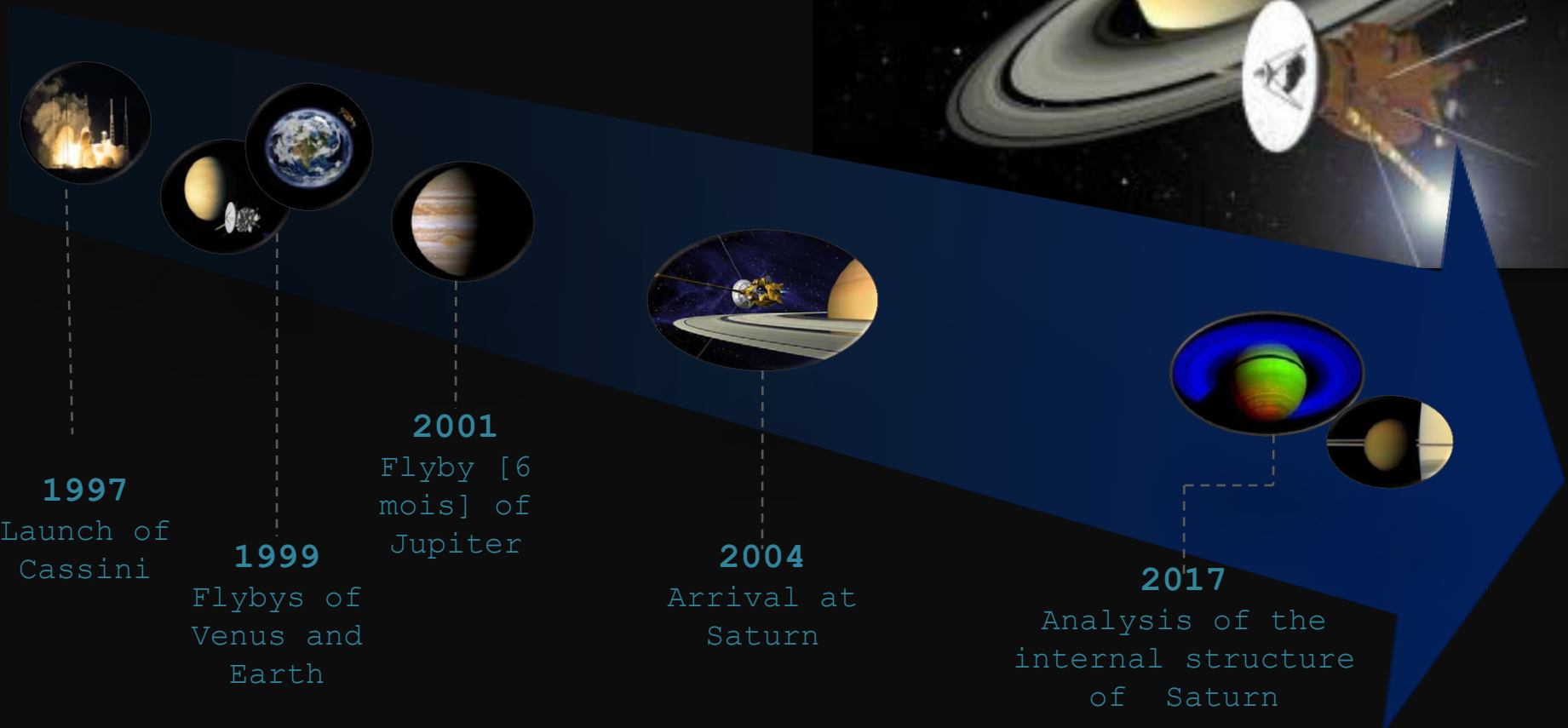
Vs.



Solar Wind

Cassini-Huygens Mission

Mission Overview



1997
Launch of Cassini

1999
Flybys of Venus and Earth

2001
Flyby [6 mois] of Jupiter

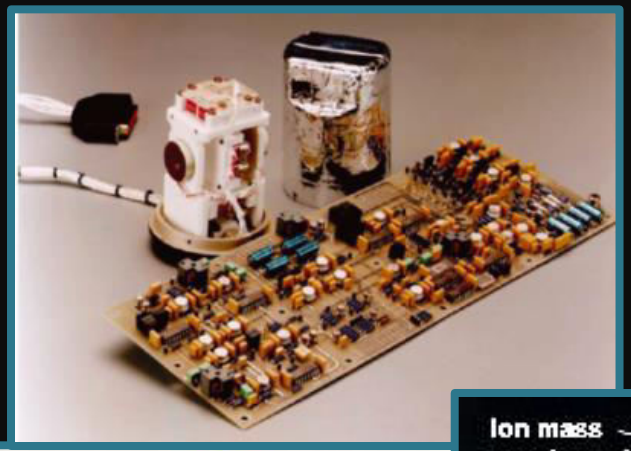
2004
Arrival at Saturn

2017
Analysis of the internal structure of Saturn

Cassini-Huygens Mission

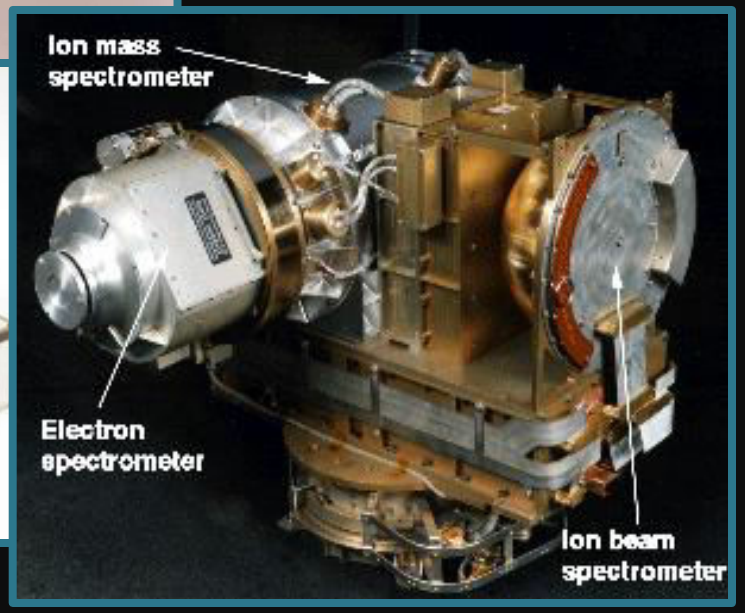
In-Situ Fields and Particles Instruments

MAG:
(Magnetometer)
[DC,1Hz]



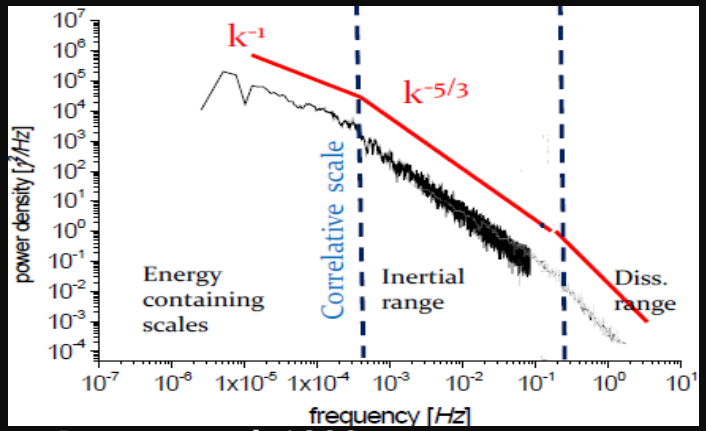
CAPS:
Cassini Plasma Spectrometer

Search Coils:
Fluctuations of the magnetic field (high frequencies)
1Hz -20KHz



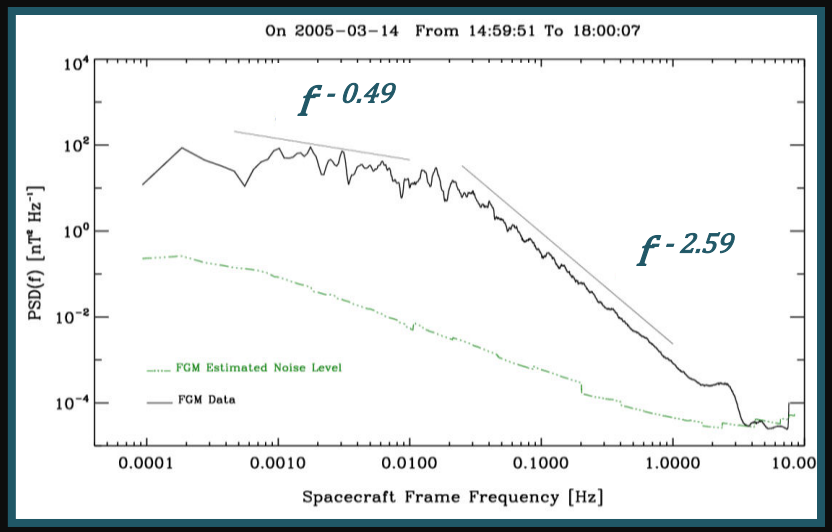
Data Analysis and Results

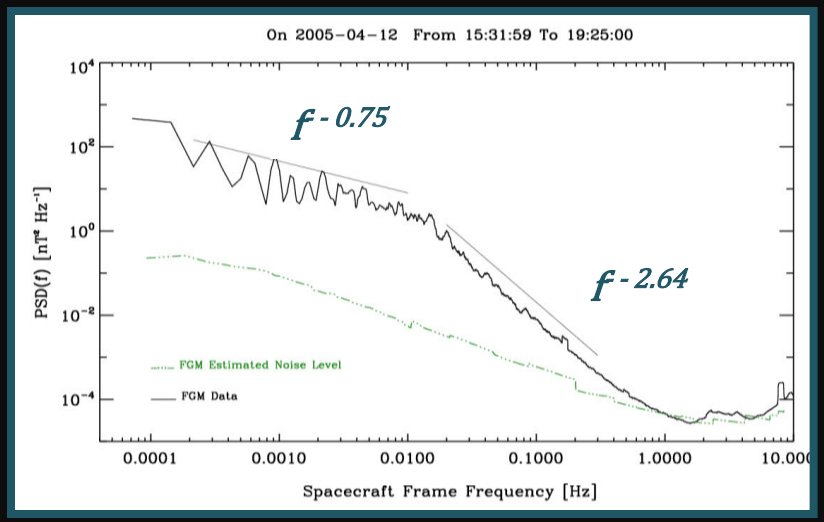
Example of magnetic energy spectra in the magnetosheath :



Leamon et al. 1999

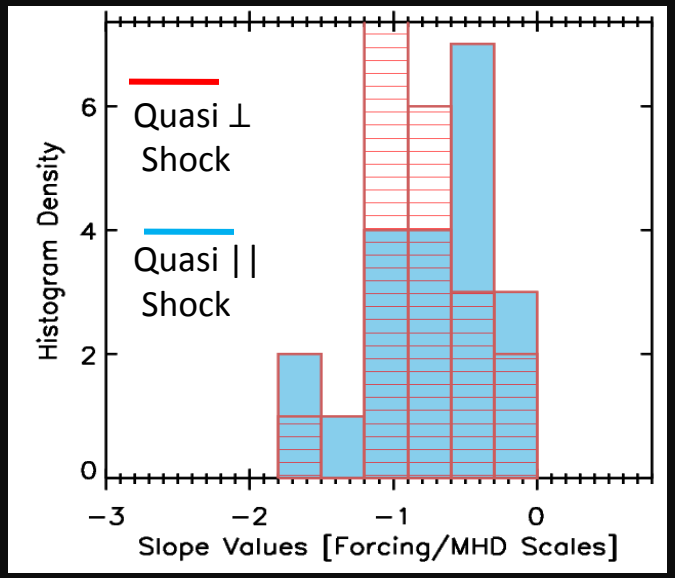
A fundamental difference with the SW:
Absence of the 5/3 Kolmogorov law suggesting the breaking of the universality of the Kolmogorov spectrum



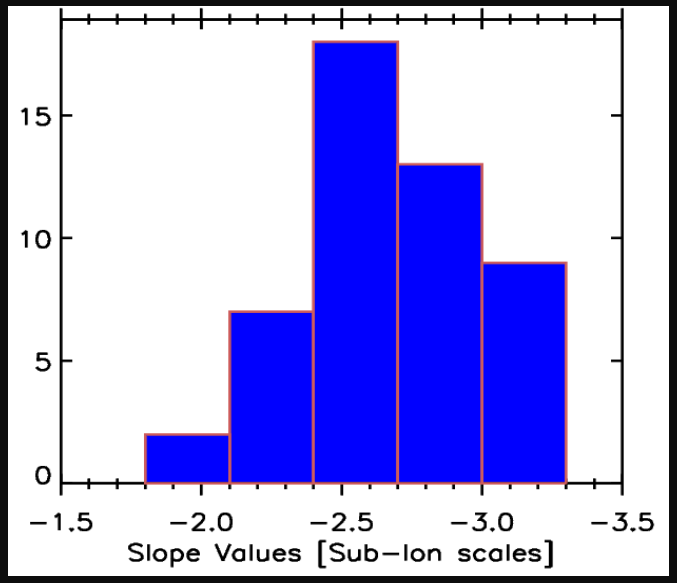


Data Analysis and Results

Statistics on the scaling: 38 magnetosheath crossings (2004-2007)



Energy containing scales

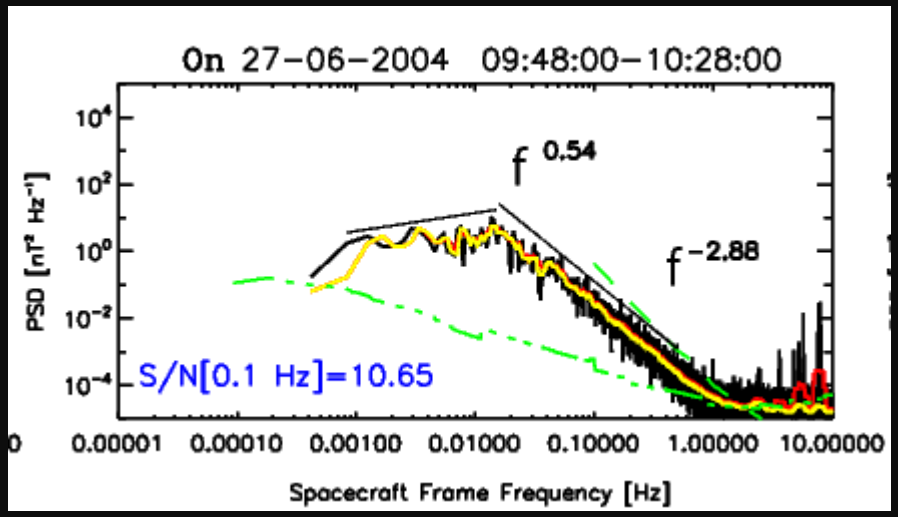


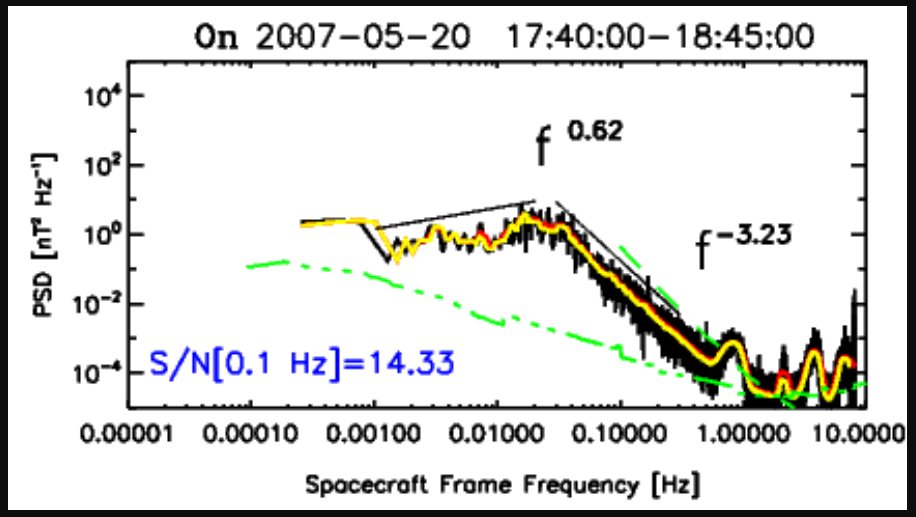
Kinetic scales

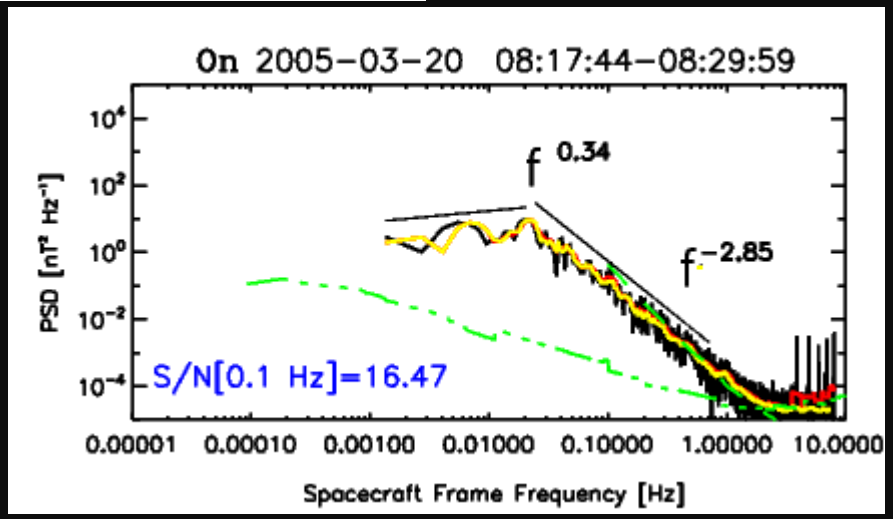
- The presence of two different ranges: The energy containing scale ~ f^{-1} and the kinetic scales ~ $f^{-2.5}$ (Similar to the solar wind)
- The property at the energy containing scales does NOT depend on the structure of the Shock

Data Analysis and Results

Example of magnetic energy spectra in the magnetosheath :





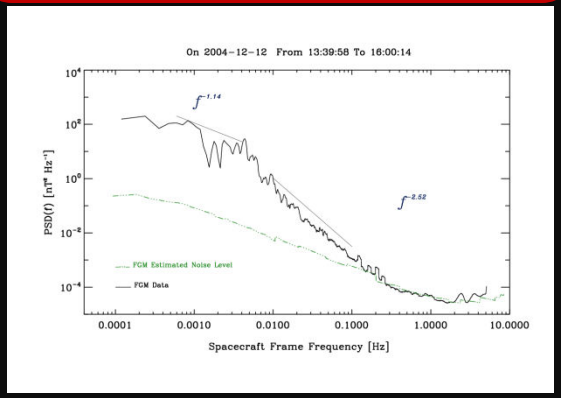


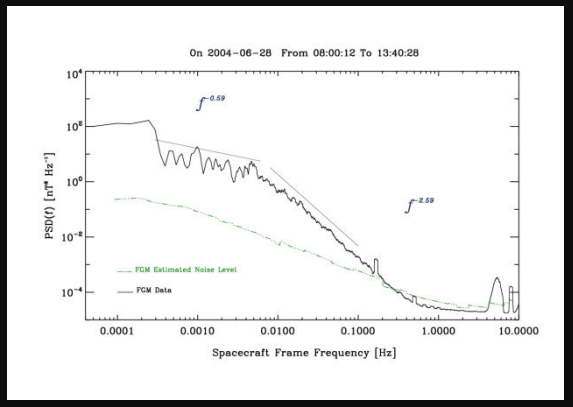
Data Analysis and Results

Higher order statistics: Intermittency *vs.* self-similarity

Parallel Shock
2004/12/12 13:40-16:00

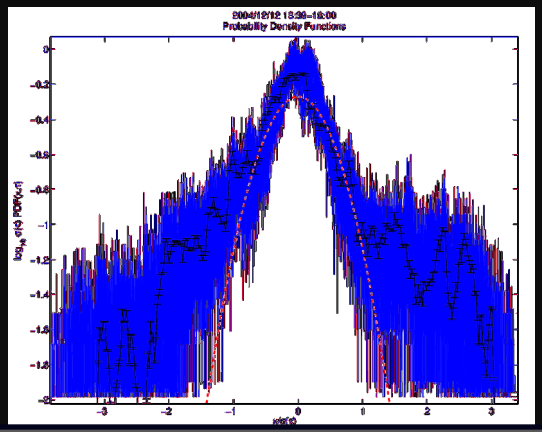
Perpendicular Shock
2004/06/28 08:00-13:40

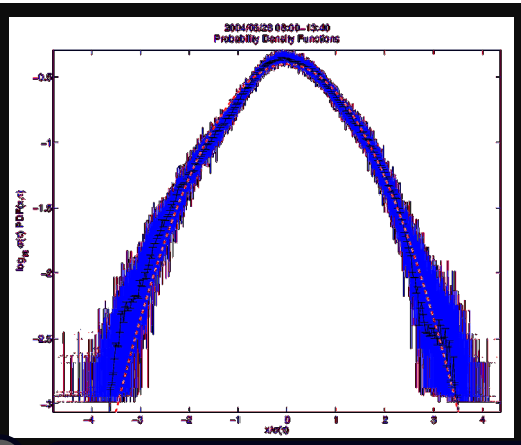




$$\delta B_\tau(t) = B(t+\tau) - B(t)$$

PDFs of the magnetic field increments.



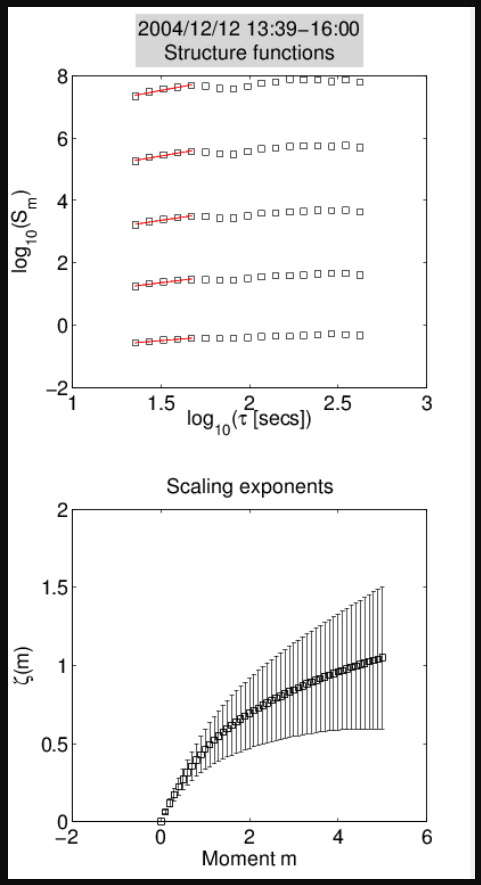


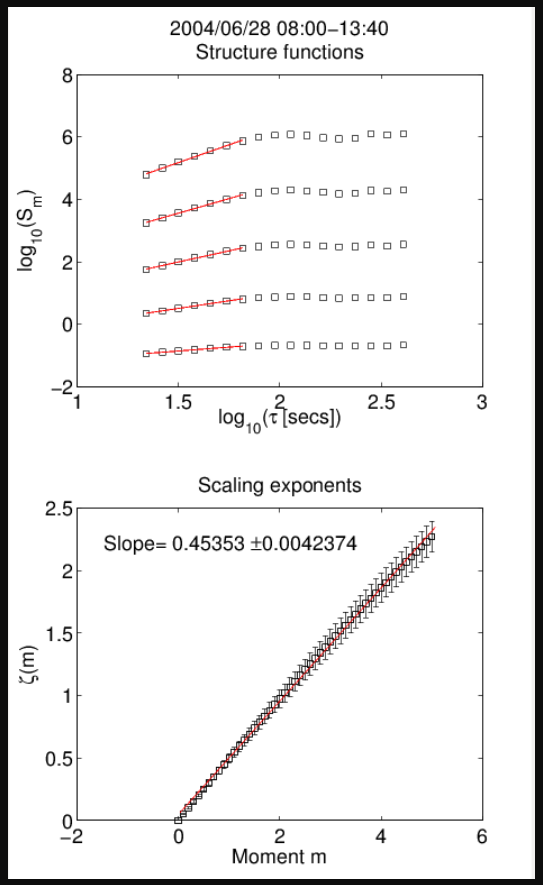
Gaussian PDFs at the large (~f^{-1}) and **presence of tails** at the sub-ion scales ~$f^{-2.5}$

Gaussian PDFs at the large (~f^{-1}) and the sub-ion scales ~$f^{-2.5}$

Data Analysis and Results

Higher order statistics: Structure functions and scalings





$$S_m(\tau) = \langle |\delta B_\tau(t)|^m \rangle$$

Structure Function of the mth order

$$\zeta(m) \; \alpha \; m$$

➢ **Linear dependance:** self similar

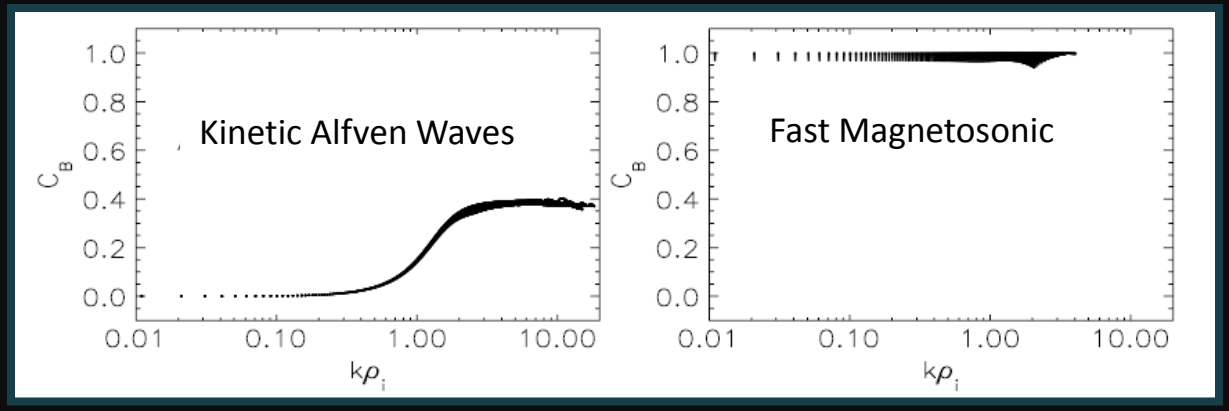
➢ **Non-linear depednance:** Intermittent Signal

✓ ***Intermittent*** **fluctuations at the sub-ion scales** $\sim f^{-2.5}$

✓ ***Self-similar*** **fluctuations at the energy containing scales**

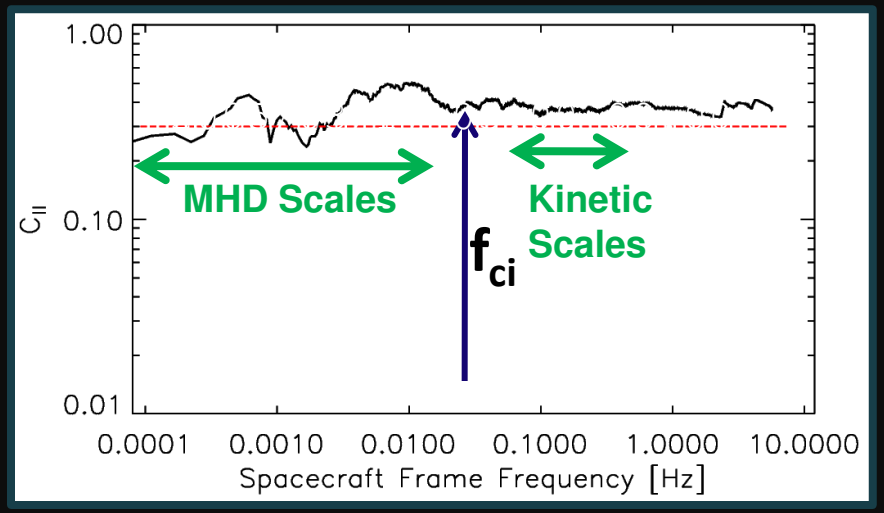
Data Analysis and Results

Wave mode propagation



$$C = \frac{\delta B_{||}^2}{\delta B_{Tot}^2}$$

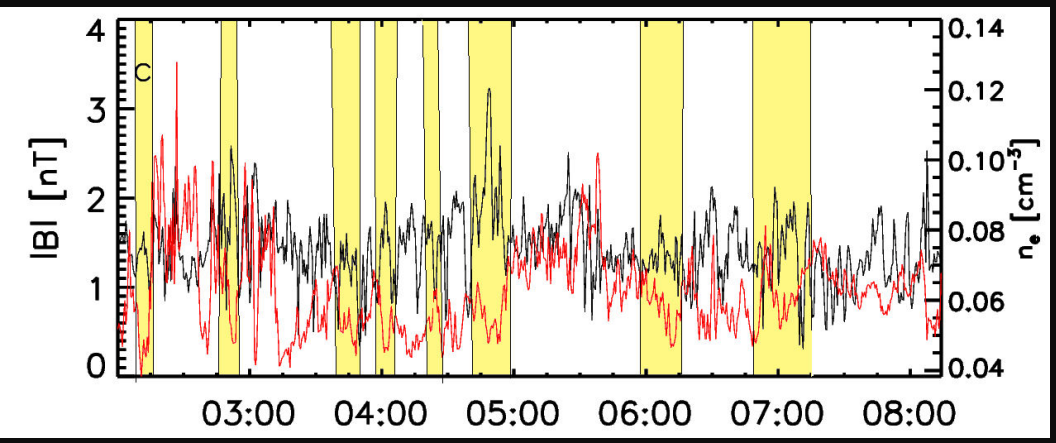
Theoretical magnetic compressibility of the KAW and fast magnetosonic modes *[Sahraoui et al. 2012]*



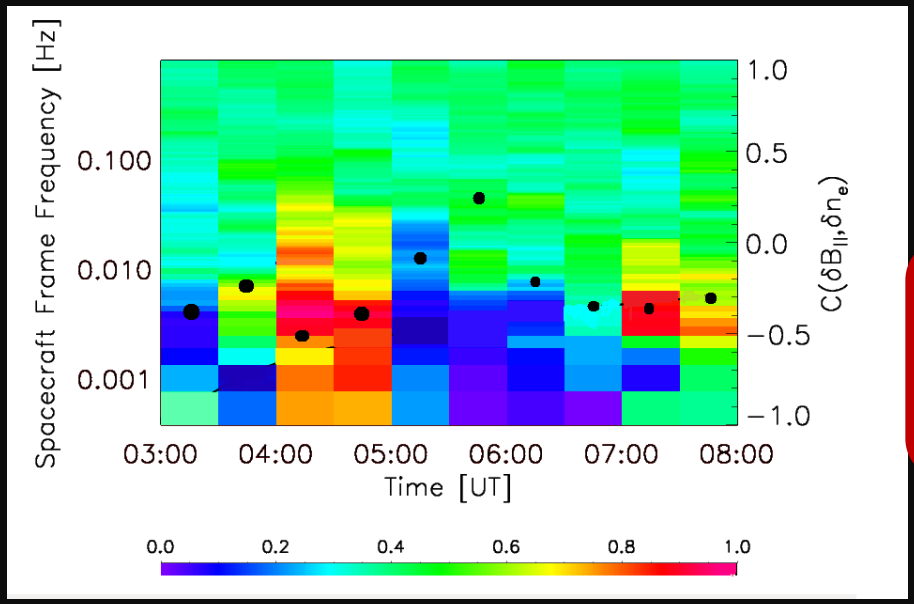
- **Highly compressible** nature of the turbulence at **MHD and kinetic scales.**
- Different from the solar wind case where **KAW Turbulence dominates** *[Kiyani et al., ApJ, 2013]*
- **Slow, or fast modes?**

Data Analysis and Results

Fast or slow modes? δB & n cross-correlation



- The **holes** of the field magnitude coincide with the **bumps** of the electron density.
- The field magnitude exhibits clear dips (holes) in a quasi-periodic way

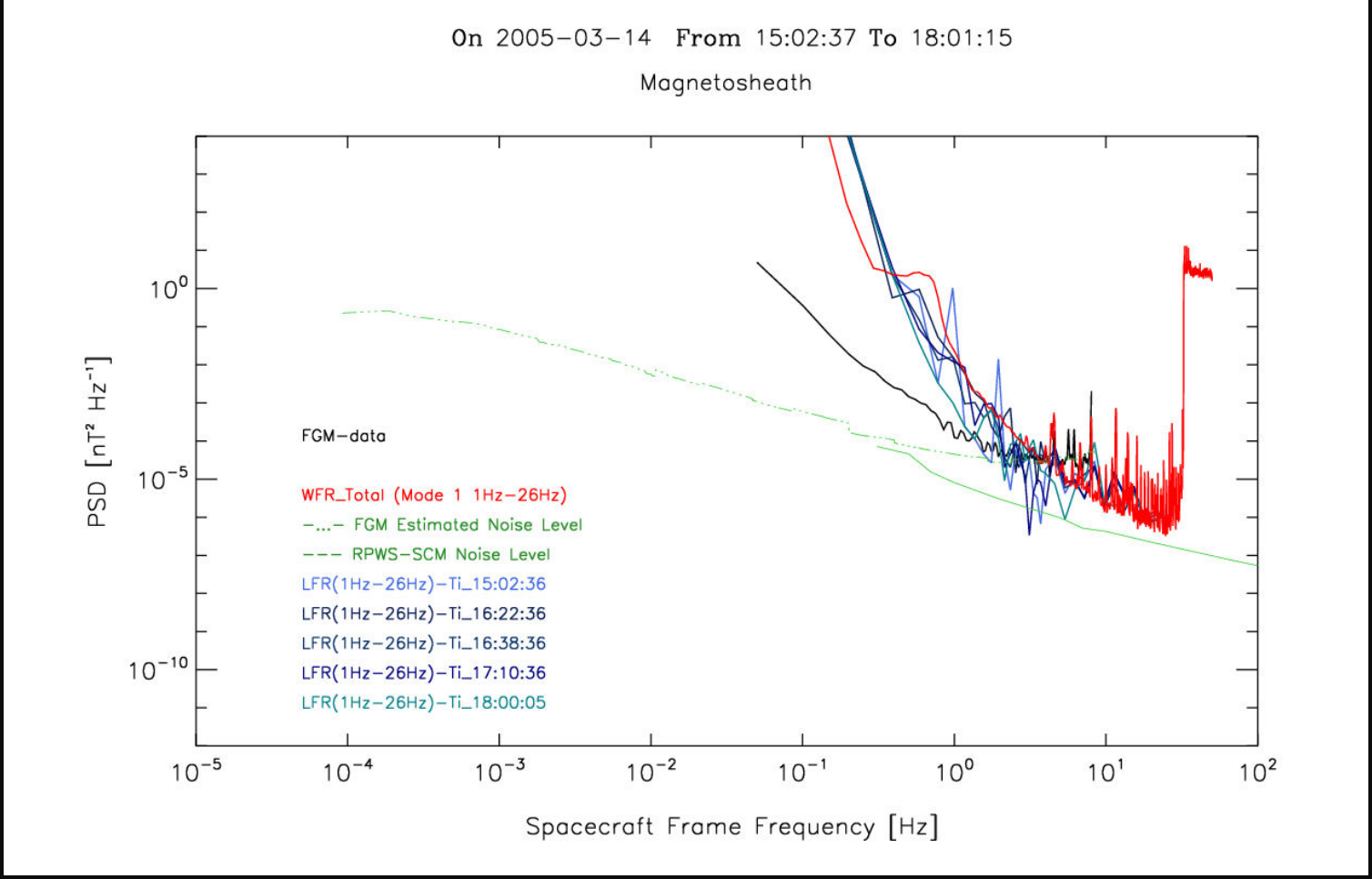


- $< C(\delta B_{||}, \delta n_e) > = -0.26 < 0$

1. Fast modes are ruled out
2. Dominance of **slow (or mirror?) modes**

Data Analysis and Results

Search Coils Data: Re-calibration at Chambon-la-foret



Summary

- **Study of Turbulence in Saturn's magnetosheath using Cassini Data aiming to compare it with the Earth case (different parameters)**

- **Turbulence in the magnetosheath shows the following properties :**
  - Absence of Kolmogorov scaling (different from the sw): a direct transition from the f^{-1} (MHD scales) spectrum to $f^{-2.5}$ (kinetic scales)
  - The f^{-1} range is populated by random-like fluctuations
  - The $f^{-2.5}$ range is populated by intermittent coherent structures
  - Dominance of the slow (or mirror) mode compressible fluctuations at the kinetic scales (different from the solar wind)

- **Current & future work:**
  - Comparisons with the terrestrial magnetosheath
  - Analysing high frequency (electron scale turbulence) using the SCM data
  - Looking at signatures of heating/acceleration of plasma particle