EGU General Assembly 2020

UiO : Department of Physics
University of Oslo

Vienna | Austria | 3–8 May 2020

ST2.1 Open Session on the Magnetosphere
D2948 | EGU2020-21014

Evolution of Turbulence in the Kelvin-Helmholtz Instability mediated by the Magnetopause and its Boundary Layer

Francesca Di Mare, Luca Sorriso-Valvo, Alessandro Retino', Francesco Malara, and Hiroshi Hasegawa

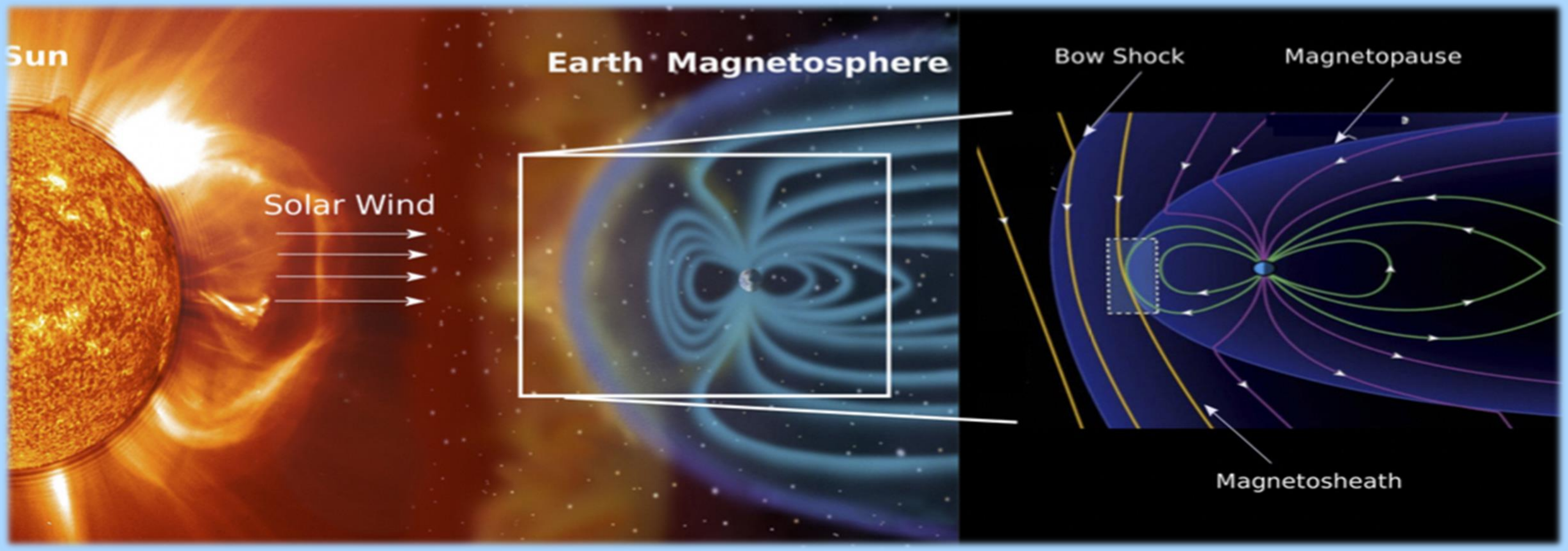
Speaker: Francesca Di Mare
Department of Physics, University of Oslo
f.d.mare@fys.uio.no

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

Turbulence at the interface between the solar wind and the magnetosphere

Space plasmas display fluctuations and nonlinear behaviour at a broad range of scales, being in most cases in a turbulent state.

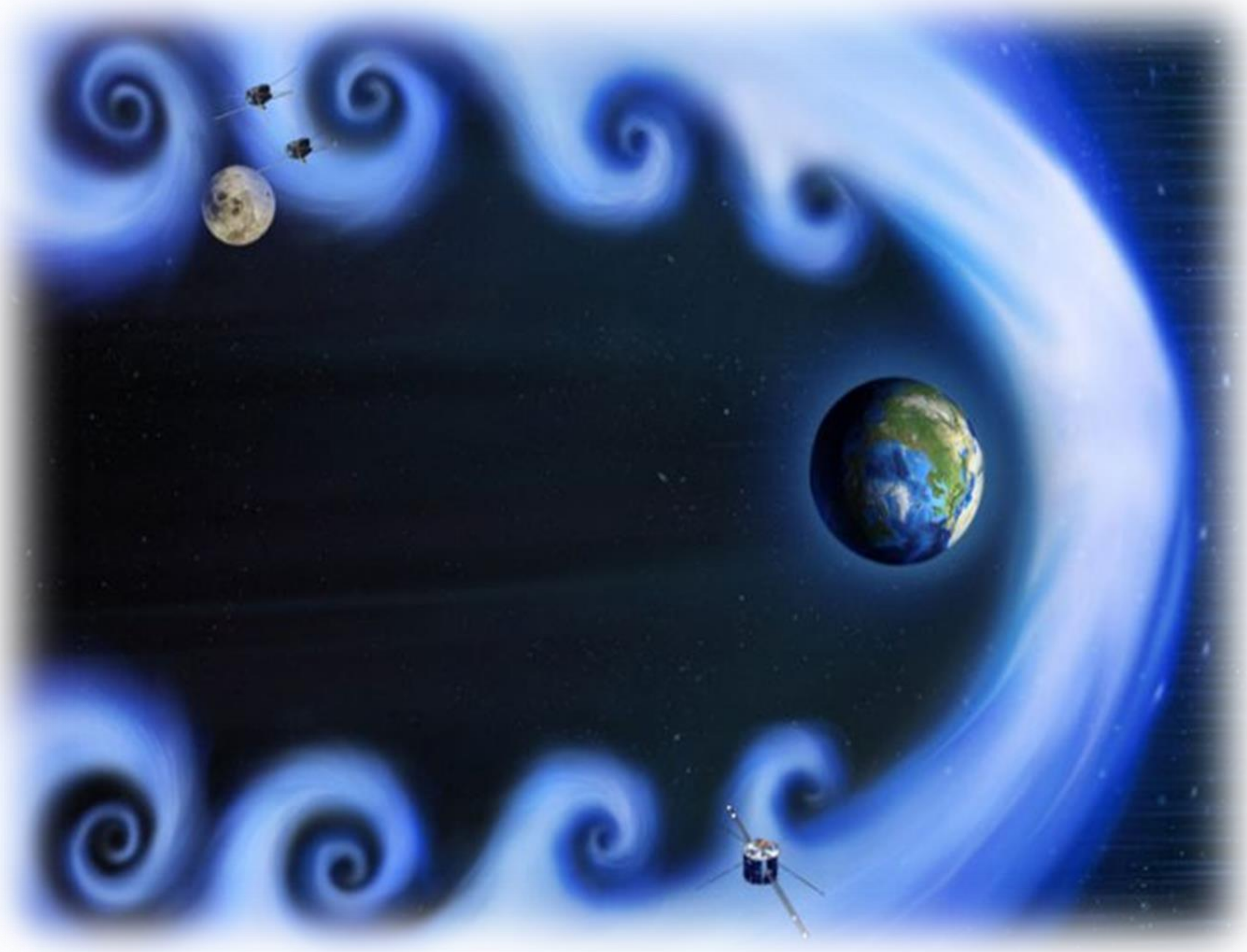


©SOHO/LASCO/EIT NASA, ESA) ©J. Burch

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

Transport Mechanism: Kelvin Helmholtz Instability



©Quanqi Shi

The Kelvin–Helmholtz Instability can drive waves at the magnetopause.

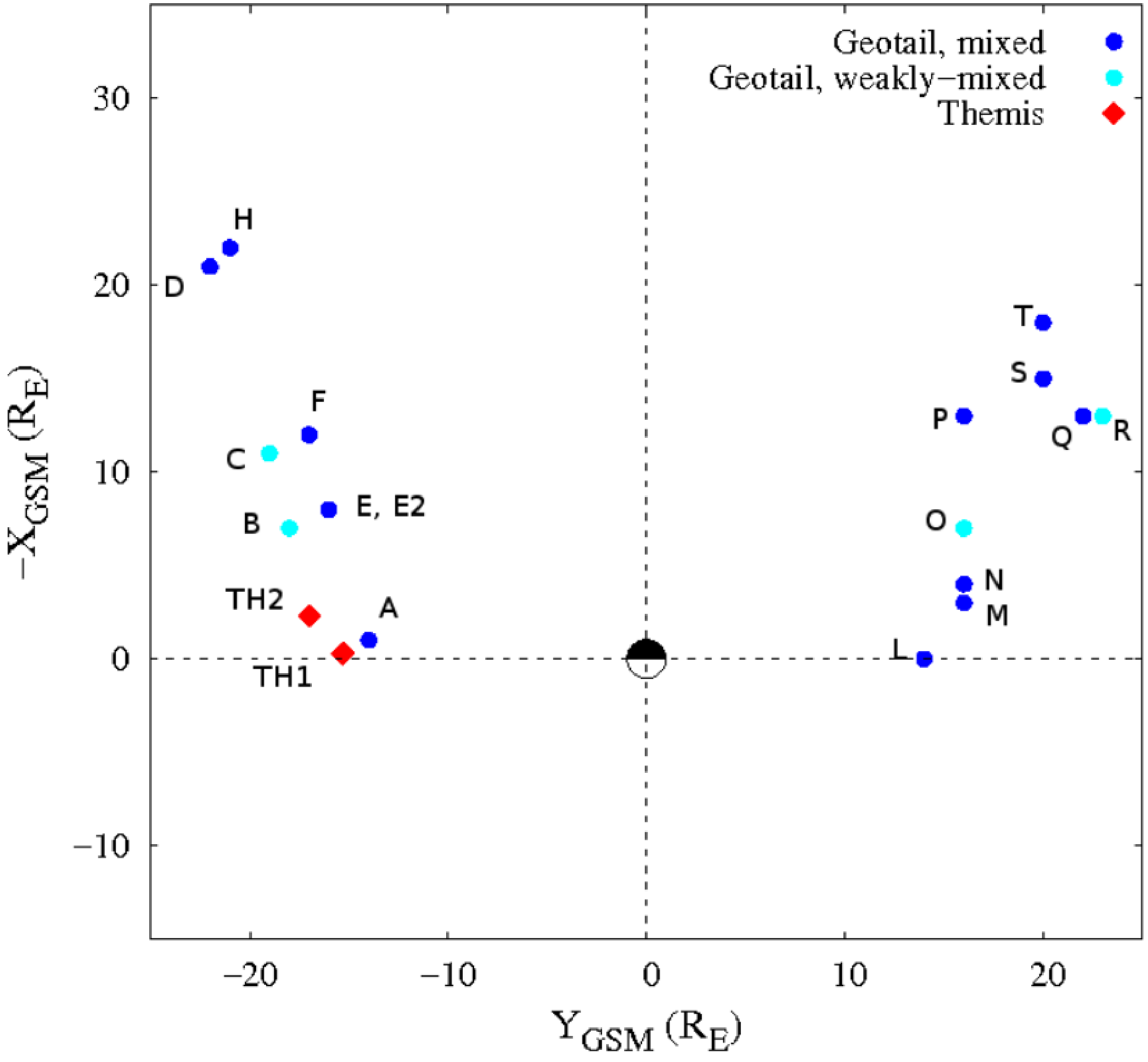
When the waves reach a turbulent state, plasma and energy are transported from the dense magnetosheath into the more rarified magnetosphere.

These waves can grow to form rolled-up vortices and facilitate transfer of plasma into the magnetosphere.

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

Dataset Overview



17 events of the **Geotail** spatial observations from 1995 to 2003 (Hasegawa *et al*. 2006, Fujimoto *et al.* 1998, 2000, 2003, Stenuit *et al*. 2002):

- Magnetic fiel data by FGM instrument at high resolution (16 s);
- LEP (Low Energy Particles Experiment) ion moment data (12 s) to get data of density and plasma velocity.

2 events of **THEMIS** during November 2008 (Lin *et al.* 2014):

- Magnetic fiel data by FGM instrument at high resolution (128 s);
- Density and plasma velocity by MOM (on-board moments) instrument (3 s).

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

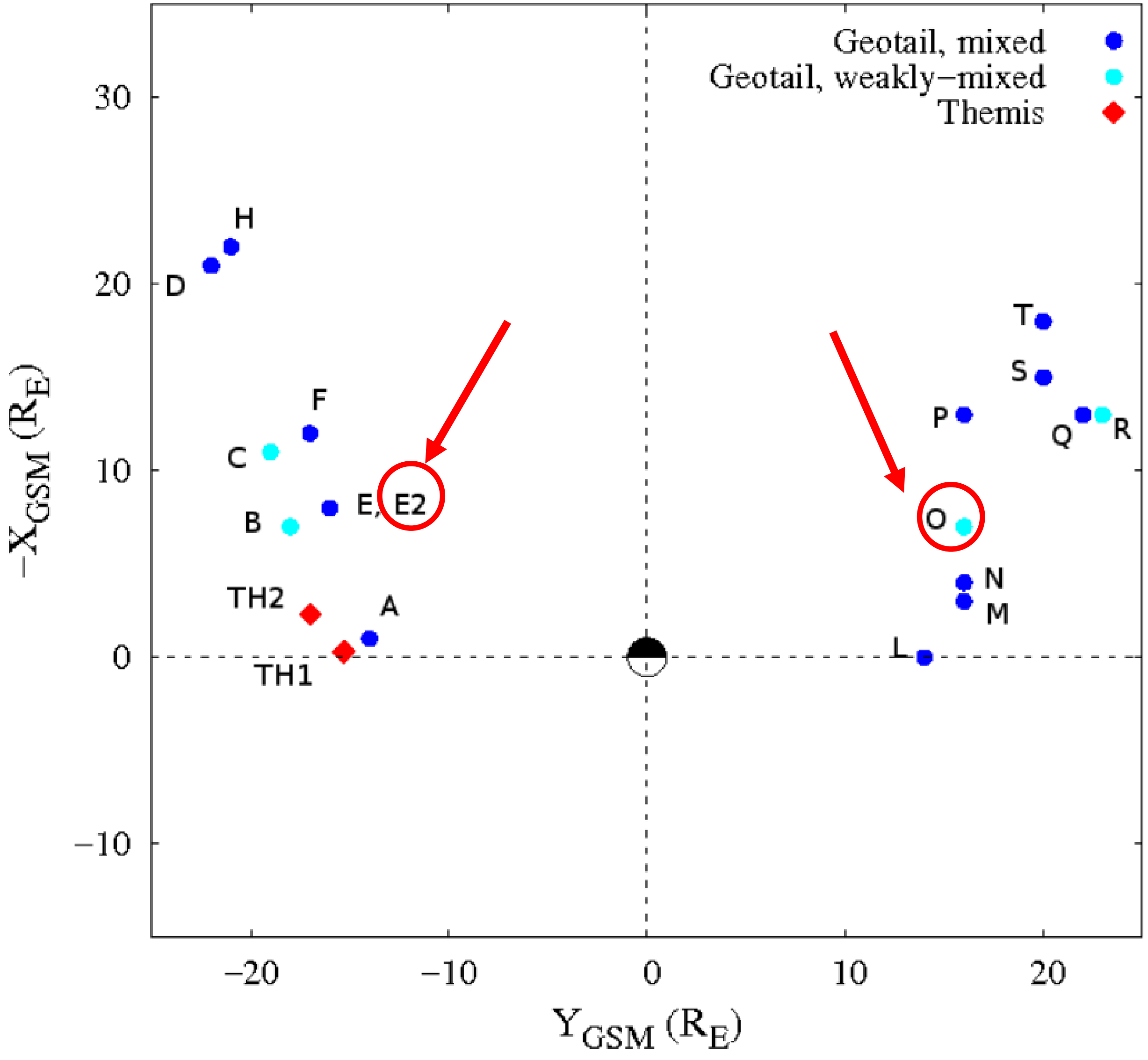
Event List of rolled-up vortices detected by Geotail over nine years from 1995 to 2003, adapted from Hasegawa et al. 2006. The last two events were detected by THEMIS probe C, adapted by Lin et al. 2014.

Event	Interval	GSM Position	IMF Condition	Mixing Status	Period	v_{ms}
GEOTAIL MISSION						
S	1995-03-24 0600-0800	(−15, 20, 4)	ES[1] NBZ[2]	Mixed	2–3	227
O	1997-01-10 2050-2400	(−7, 16, 4)	ND[3] NBZ after N-t[4]	Weakly mixed	2–3	169
P	1997-01-11 0400-0500	(−13, 16, 4)	ES NBZ	Mixed	∼ 3	219
Q	1997-02-12 1430-1600	(−13, 22, 3)	ES NBZ	Mixed	∼ 2	281
T	1998-04-13 0315-0430	(−18, 20, 4)	ES NBZ	Mixed	2–3	312
L	1998-08-01 0530-0730	(0, 14, −3)	ES NBZ	Mixed	∼ 3	92
D	1998-12-27 1800-2100	(−21, −22, −4)	ES NBZ	Mixed	3–4	247
N	1999-02-15 1445-1515	(−4, 16, 2)	NBZ after N-t	Mixed	∼ 2	279
M	1999-07-20 0630-0730	(−3, 16, −2)	ES NBZ	Mixed	2–3	230
E	2000-11-01 1030-1200	(−8, −16, 6)	ES NBZ	Mixed	2-3	298
H	2001-01-25 1330-1630	(−22, −21, 0)	ES NBZ	Mixed	∼ 5	182
B	2001-11-16 1900-2000	(−7, −18, 2)	Extended NBZ (often ND)	Weakly mixed	2–3	183
C	2001-12-07 2000-2130	(−11, −19, −1)	SNBZ[5] after N-t	Weakly mixed	∼ 3	257
E2	2002-03-25 0530-0900	(−12, −17, −2)	ES NBZ	Mixed	2–3	299
F	2002-03-25 1000-1300	(−8, −16, −1)	ES NBZ	Mixed	2–3	299, 347
A	2002-10-15 2100-2300	(−1, −14, 3)	Extended NBZ	Mixed	2–3	332
R	2003-07-17 0330-0500	(−13, 23, −1)	ND NBZ after N-t	Weakly mixed	∼ 2	419
THEMIS MISSION						
TH1	2008-11-06 0850-0920	(−0.3, −15.3, 4.6)	ES NBZ	Mixed	∼ 2	288
TH2	2008-11-18 0720-0730	(−2.3, −17, 3.4)	ES NBZ	Mixed	∼ 3	348

ES[1]: extended strong; *NBZ*[2]: northward IMF; *ND*[3]: non dominant; *N − t*[4]: N-turning; *SNBZ*[5]: strong NBZ; Mixed/Weakly mixed means that a significant/small amount of magnetosheath ions was identified, i.e., n>/</1/cm^3, in the BL.

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo



Two different samples are here shown:

- E2 event in the «mixed status», in which a significant amount of cool magnetosheath-like ions was present on the magnetospheric side of the magnetopause, where the density, evaluated using the full phase space distribution, is $n > 1/cm^3$;
- O event, in the «weakly-mixed status», when magnetosheath-like ions were found on magnetospheric side, with density lower than $n < 1/cm^3$;

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

Data Analysis – Time series analysis techniques - Diagnostic for intermittent turbulence

In order to characterize the properties of the magnetic field fluctuations, any event was analyzed using the standard diagnostics for intermittent turbulence.

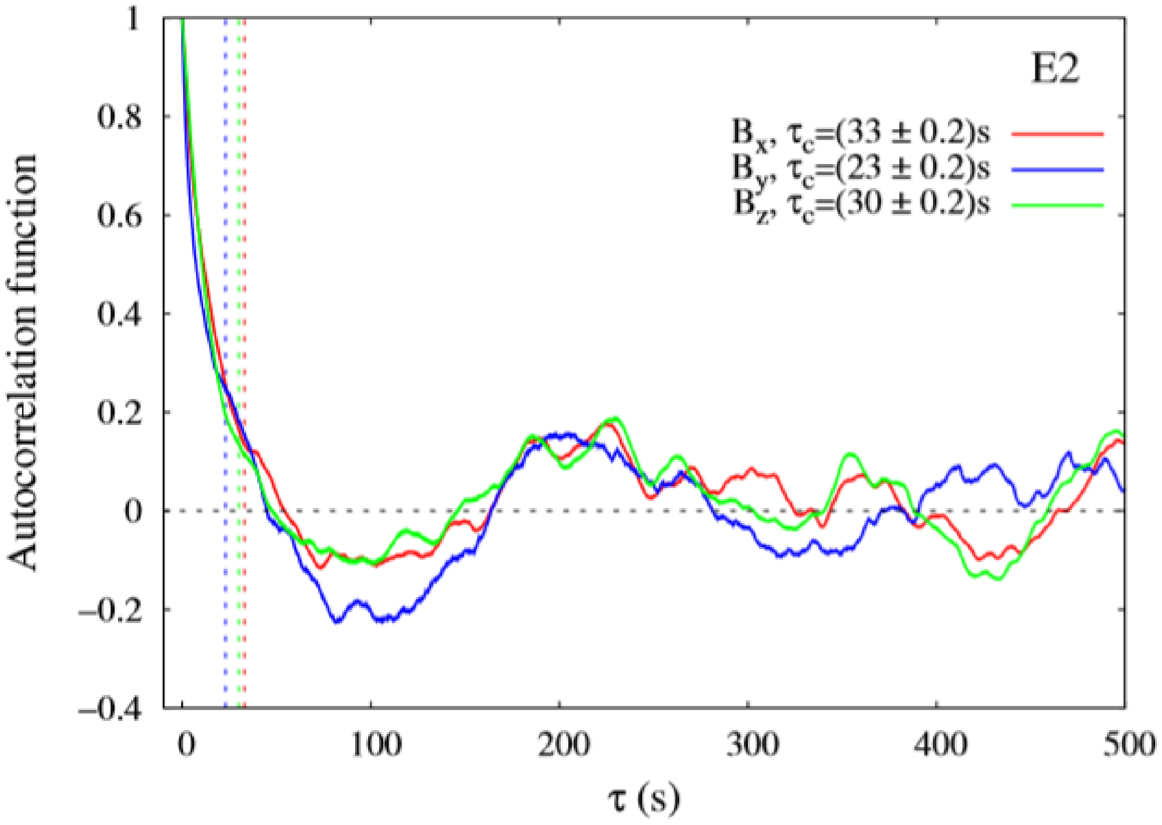
The following tools and parameters have been obtained:

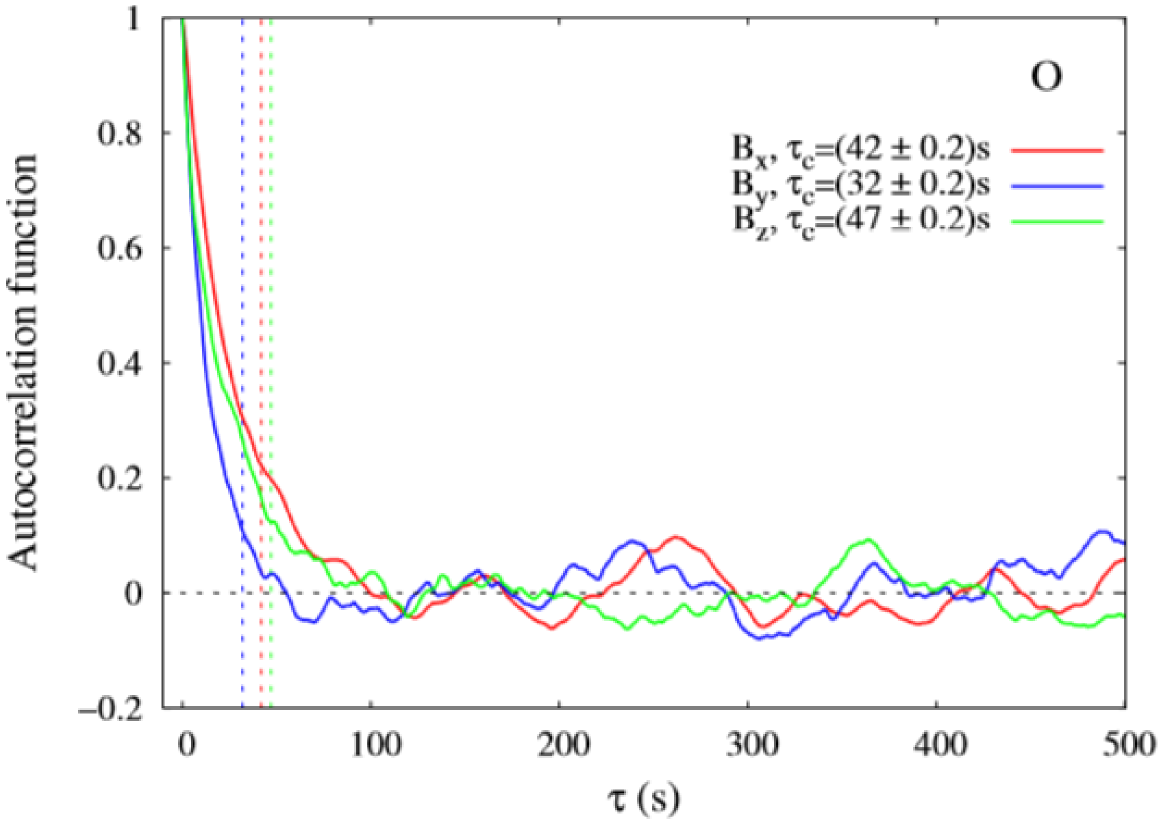
- The Autocorrelation function, which gives useful information about the correlation scale of the field;
- The Power Spectral Density (PSD) of the magnetic energy to understand how the energy cascade happens and which scales are involved;
- the Probability Distribution Functions (PDFs) of the scale-dependent increments, whose deviation from Gaussian will qualitatively illustrate the presence of intermittency;
- The Kurtosis with its scaling exponent.

Francesca Di Mare
f.d.mare@fys.uio.no

UiO Department of Physics
University of Oslo

The Autocorrelation function





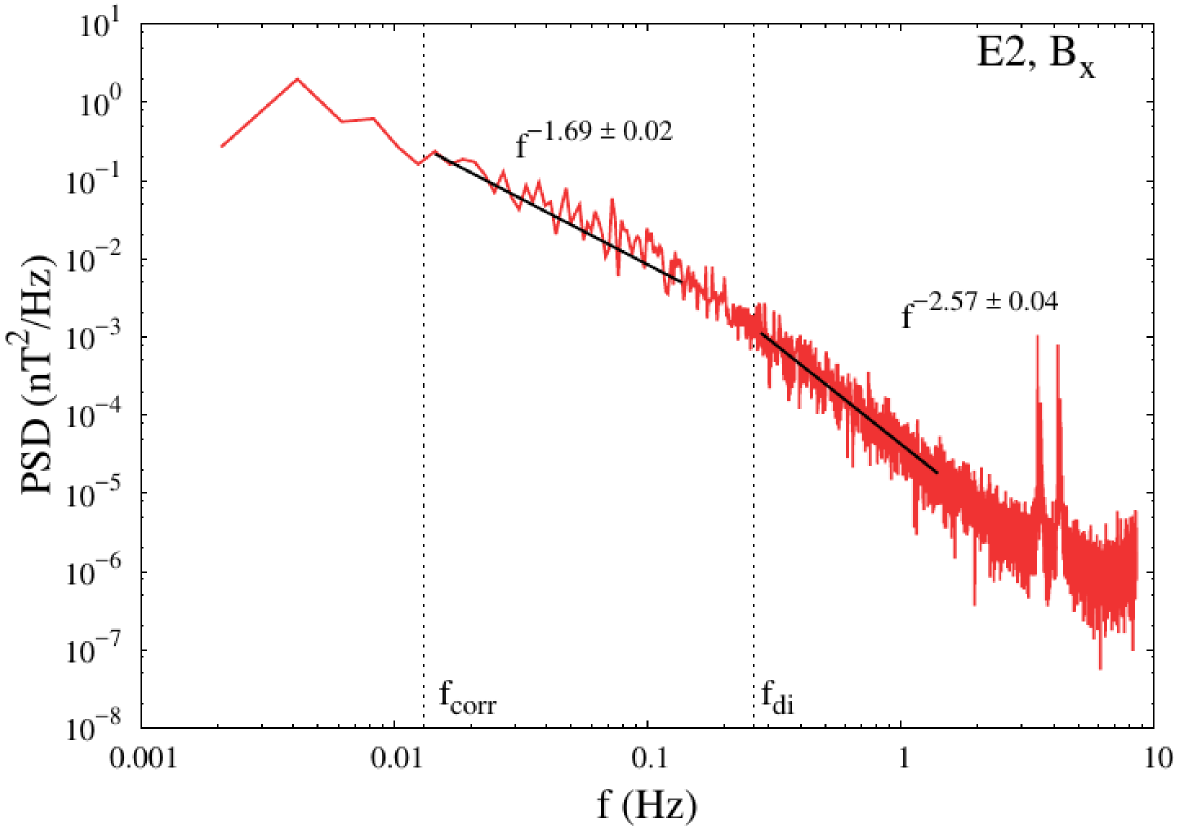
- Roughly parabolic shape near the origin, indicating the field smoothness in the “dissipative” range;
- Slower decay to zero, indicative of the inertial range of turbulence.

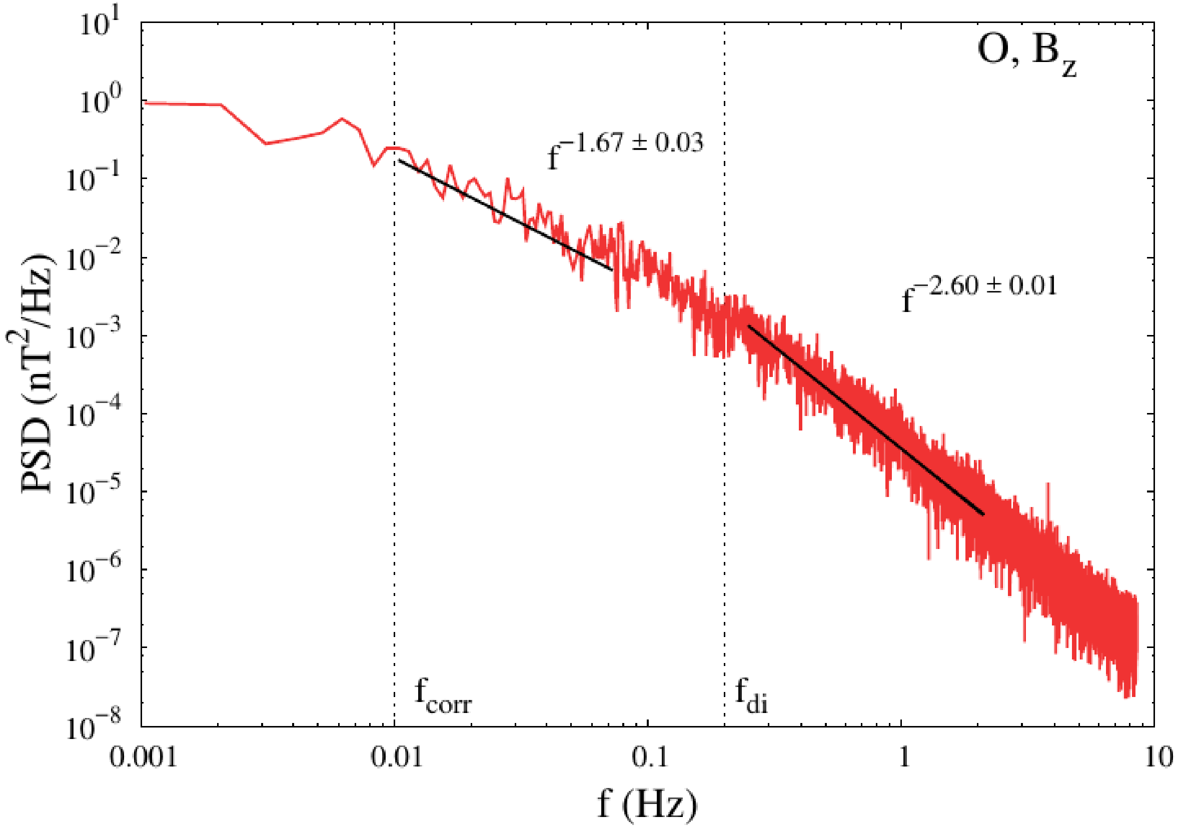
Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

The magnetic energy power spectra

- A Kolmogorov-like spectrum is observed at MHD scales;
- A steeper power law is suggested below ion scales.



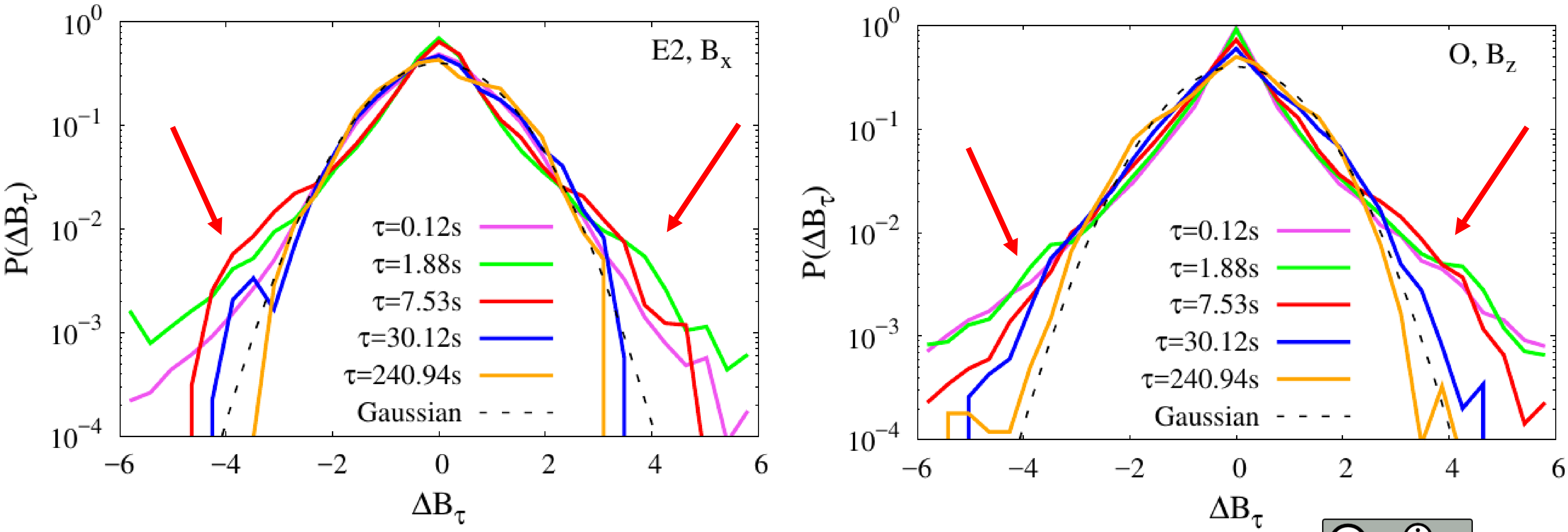


The vertical black dashed lines indicate the frequency f_{di} related to the ion inertial length *di*, and the frequency related to the correlation time f_{corr}.

Francesca Di Mare
f.d.mare@fys.uio.no

The probability distribution functions (PDFs)

- Probability distribution functions of B component normalized increments ΔB;
- PDF is gaussian at large scales, while has strong tails at small scales.

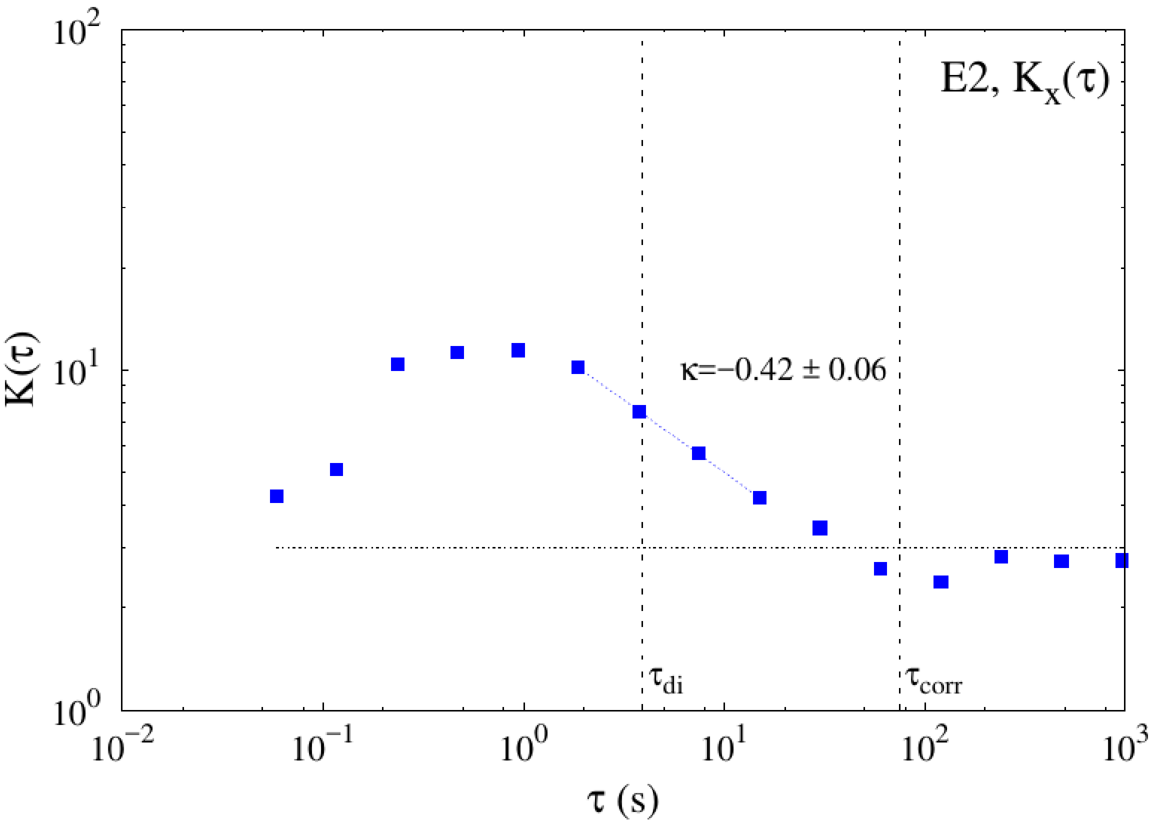


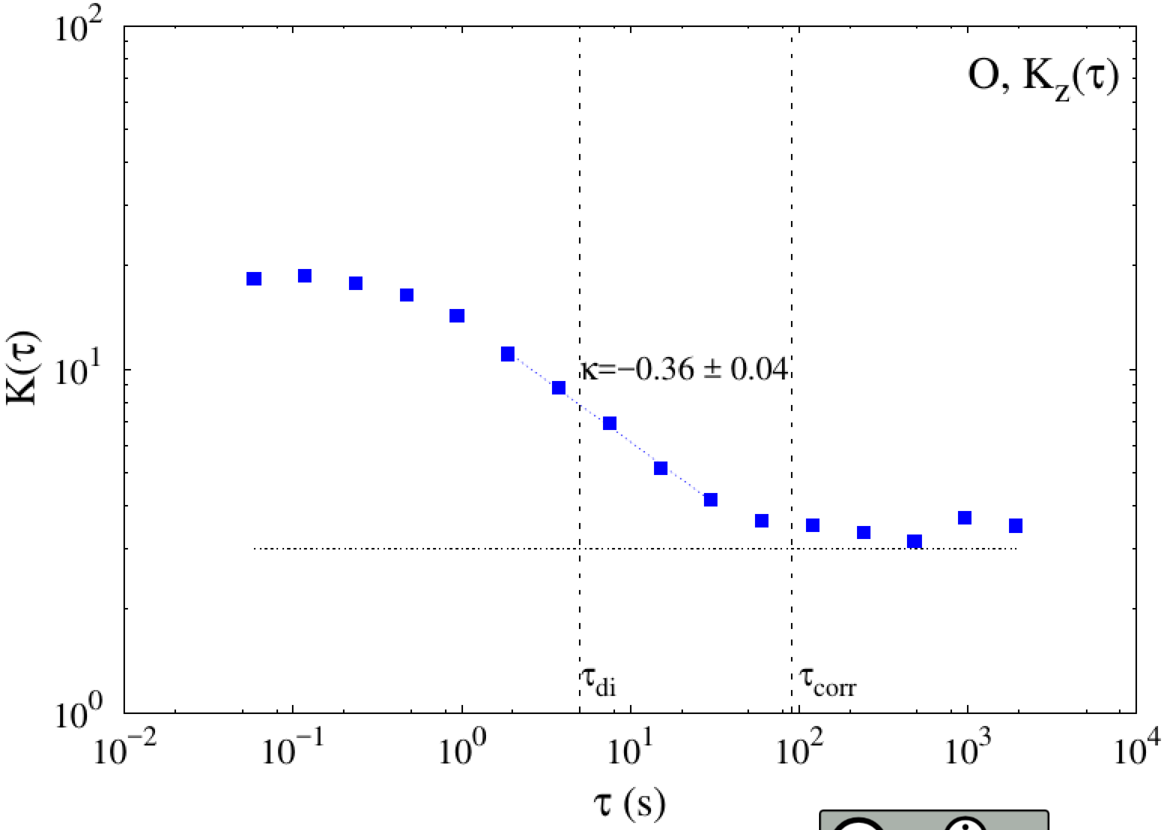
Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

The Kurtosis

- Typically gaussian at large scales;
- Increases towards small scales in the inertial range;
- Saturates at ion scales.



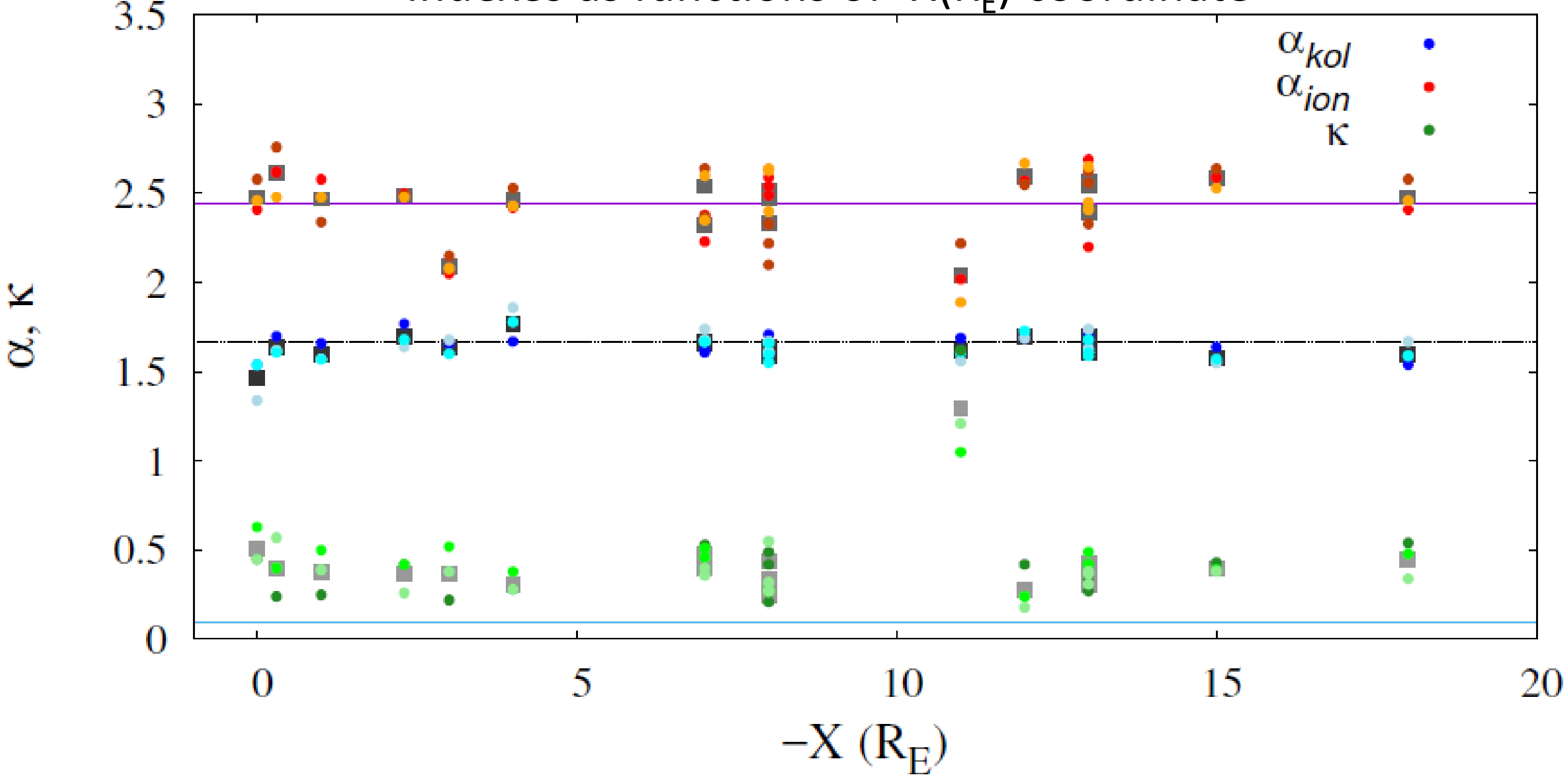


Francesca Di Mare
f.d.mare@fys.uio.no

The variation of the turbulence and intermittency parameters as a function of the spacecraft position along the magnetopause

Analysis of the variation of parameters characterizing turbulence and intermittency, along the magnetopause.

Indexes as functions of -X(R_E) coordinate



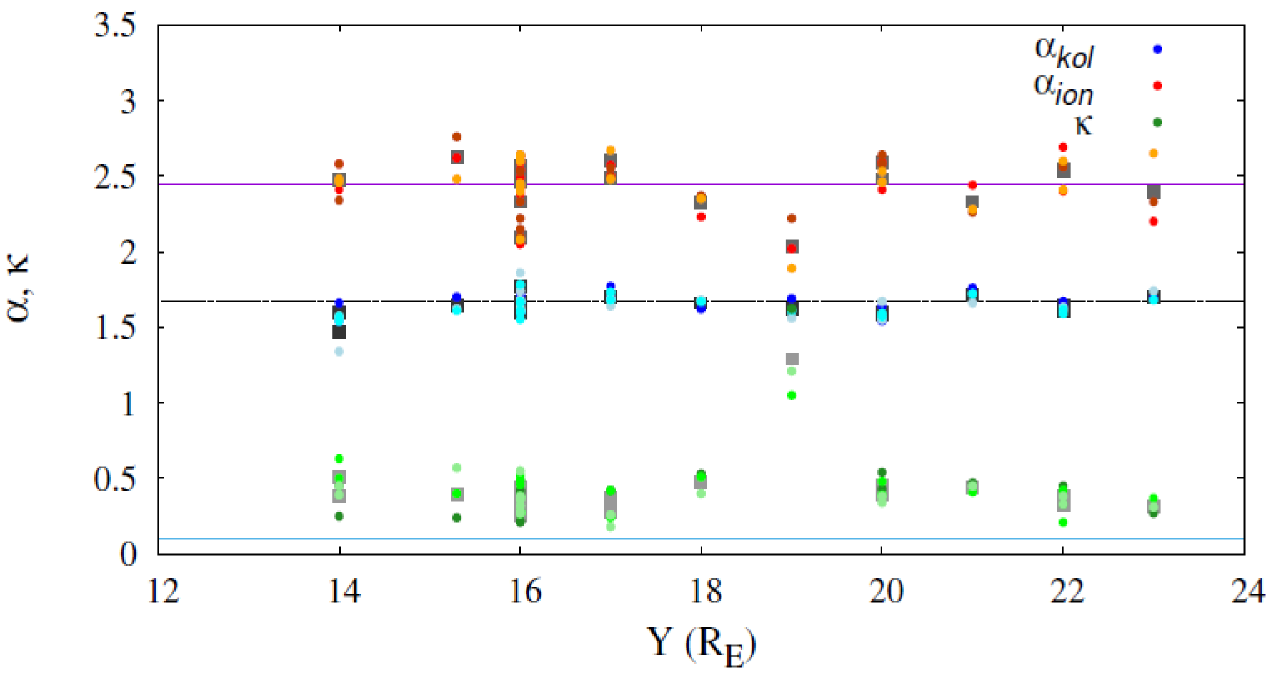
- α_{kolm} spectra indexes at MHD scales (blue dots);
- α_{ion} spectra indexes at ion scales (red dots);
- *k* scaling exponent of the kurtosis (green dots);
- mean value of each sample (grey square)

Francesca Di Mare
f.d.mare@fys.uio.no

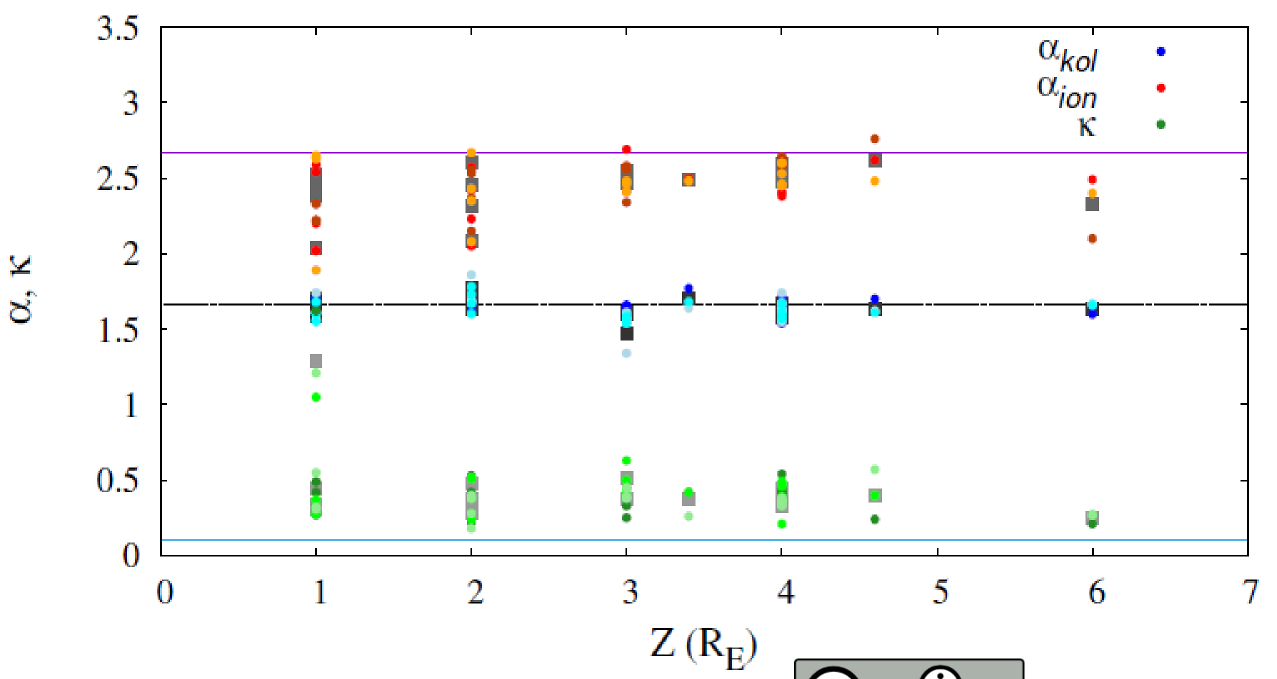
UiO : Department of Physics
University of Oslo

The variation of the turbulence and intermittency parameters as a function of the spacecraft position along the magnetopause

Indexes as functions of $Y(R_E)$ coordinate



Indexes as functions of $Z(R_E)$ coordinate

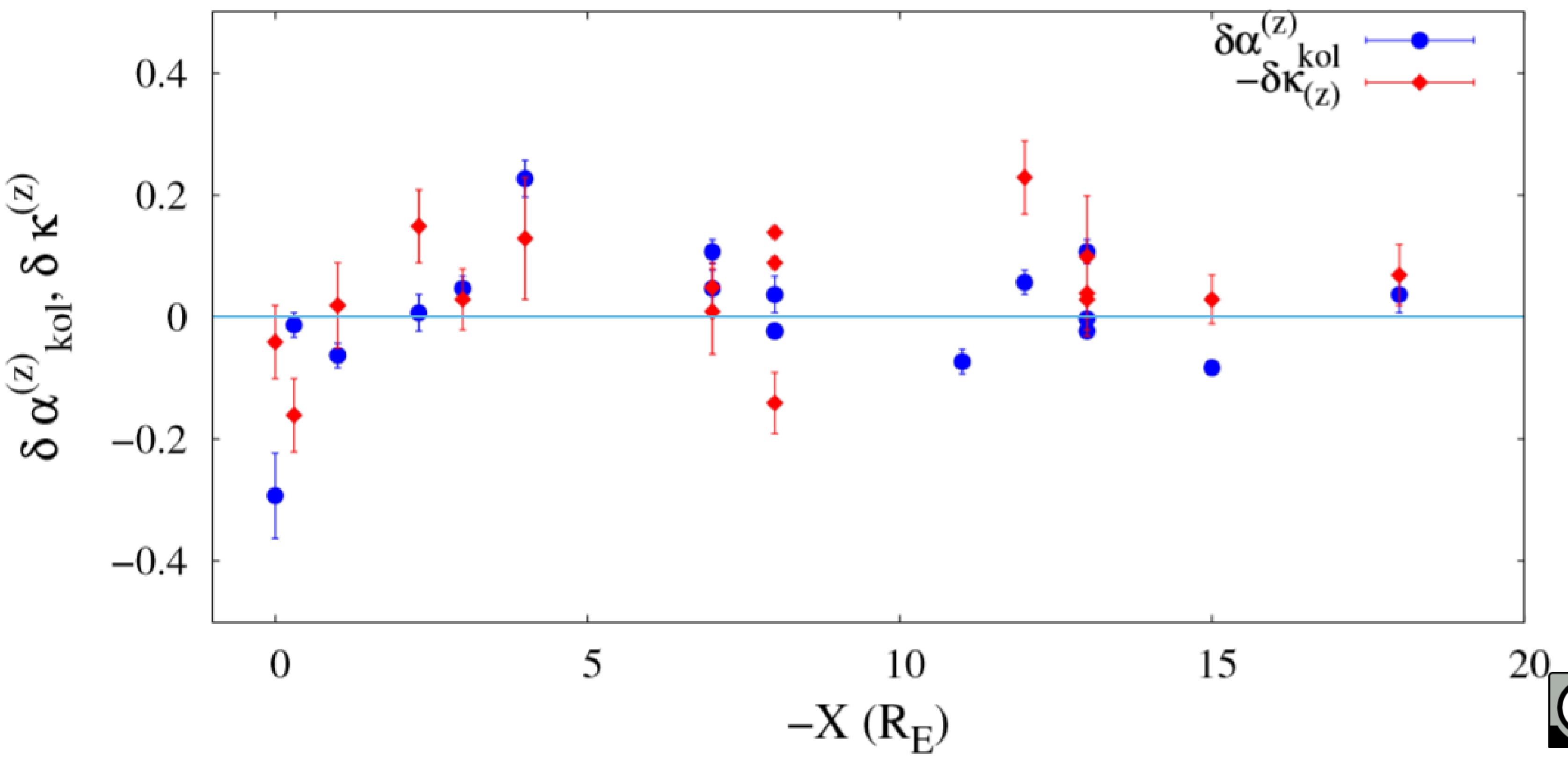


Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

The variation of the turbulence and intermittency parameters as a function of the spacecraft position along the magnetopause

In order to look for correlations between the variations in the turbulence parameters, we directly compare the fluctuations around their means of the inertial range spectral exponent and the kurtosis scaling exponent.
There is a hint of some correlation in the trend of the two indexes.



Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

Kelvin-Helmholtz periodicity

	v_{ms} (km/s)	Fluctuation Period (min)	λ (R_E)
A	332	2-3	7.8
B	183	2-3	4.3
C	257	3	7.3
D	247	3-4	8.1
E	298	2-3	7.0
E2	299	2-3	7.0
FsetA	299	2-3	7.0
FsetB	347	2-3	8.2
H	182	5	8.6
L	92	3	2.6
M	230	2-3	5.4
N	279	2	5.3
O	169	2-3	4.0
P	219	3	6.2
Q	281	2	5.3
R	419	2	7.9
S	227	2-3	5.3
T	312	2-3	7.3

- The periodicity associated with such oscillation can be estimated approximately $\lambda \sim$ 6-7 R_E;
- Amplitude decreasing further away from the dusk-dawn line;
- Possible saturation may be reached after $X \sim -15R_E$
- The average wavelength $\lambda \sim 6.4$ R_E is consistent with that reported in literature for KH instability (Hasegawa *et al.* 2004, 2006, 2009, Fairfield *et al.* 2000, Kivelson and Chen 1995)

Francesca Di Mare
f.d.mare@fys.uio.no

Conclusions 1/2

Properties of plasma turbulence and intermittency along the tail-flank magnetopause and its boundary layer have been studied, when Kelvin–Helmholtz instability was reported (Geotail and THEMIS data, recognized as rolled-up vortices by Fairfield et al. 2000, Hasegawa et al. 2006, Fairfield et al. 2007, Fujimoto et al. 1998, Stenuit et al. 2002, Lin et al. 2014, taken during satellite magnetopause crossings.)

Time-series analysis techniques to the collection of 19 samples has been applied, in order to obtain the autocorrelation function, the power spectrum, the probability distribution functions of the field increments and their kurtosis.

- The autocorrelation functions is standard and display values of the correlation scales τ_{corr} that vary between 13 and 47 s, in agreement with typical values observed in this region.
- In the MHD range of scales, the spectrum is well represented by a power law with exponent~ -1.69, not far from the Kolmogorov value $-5/3$. Below the typical proton scales, the spectrum is instead compatible with a steeper power law with exponent in the range between -1.89 and -2.76. The inertial range breaks around the frequency associated with the ion inertial scale fdi, where kinetic plasma effects start being non-negligible.
- Probability distribution functions are characterized by high tails and the deviation from Gaussian increases towards smaller scales. This behavior suggests the presence of structures.
- The Kurtosis showed the presence of a power-law consistent with the spectral inertial range, and the anomalous scaling exponent κ gave a quantitative estimate of the intermittency.

Francesca Di Mare
f.d.mare@fys.uio.no

UiO : Department of Physics
University of Oslo

Conclusions 2/2

In light of the results obtained, the behaviour of several parameters have been investigated, as a function of the progressive departure along the Geocentric Solar Magnetosphere coordinates, which roughly represent the direction in which we expect the KHI vortices to evolve towards fully developed turbulence.

- A fluctuating behavior of the parameters suggest some possible correlation with KH period, estimated approximately 6.4 RE. Such observed wavelength is consistent with the estimated vortices roll-up wavelength reported in the literature for these events (Hasegawa et al. 2004, 2006, Hasegawa 2009, Fairfield et al. 2000, Kivelson & Chen 1995).

- If the turbulence is pre-existent, it is possible that the KHI modulates its properties along the magnetosheath, as we observed. On the other hand, if we assume that the KHI has been initiated near the magnetospheric nose and develops along the flanks, then the different intervals we study may be sampling the plasma at different stages of evolution of the KH-generated turbulence, after the instability has injected energy in a cascading process as large-scale structures.

For more details about this work please see:

Di Mare, F.; Sorriso-Valvo, L.; Retinò, A.; Malara, F.; Hasegawa, H.;
Evolution of Turbulence in the Kelvin–Helmholtz Instability in the Terrestrial Magnetopause, Atmosphere 2019, 10, 561.
DOI: http://dx.doi.org/10.3390/atmos10090561