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International Workshop and School on Solar system plasma turbulence, intermittency and multifractals

Characteristics of Jupiter's magnetospheric turbulence observed by Galileo

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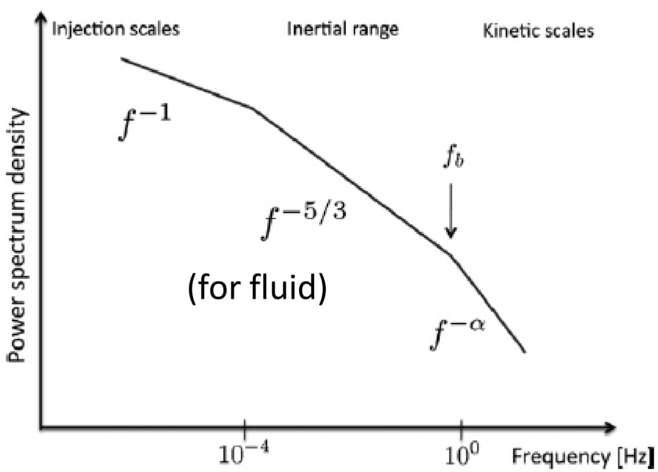
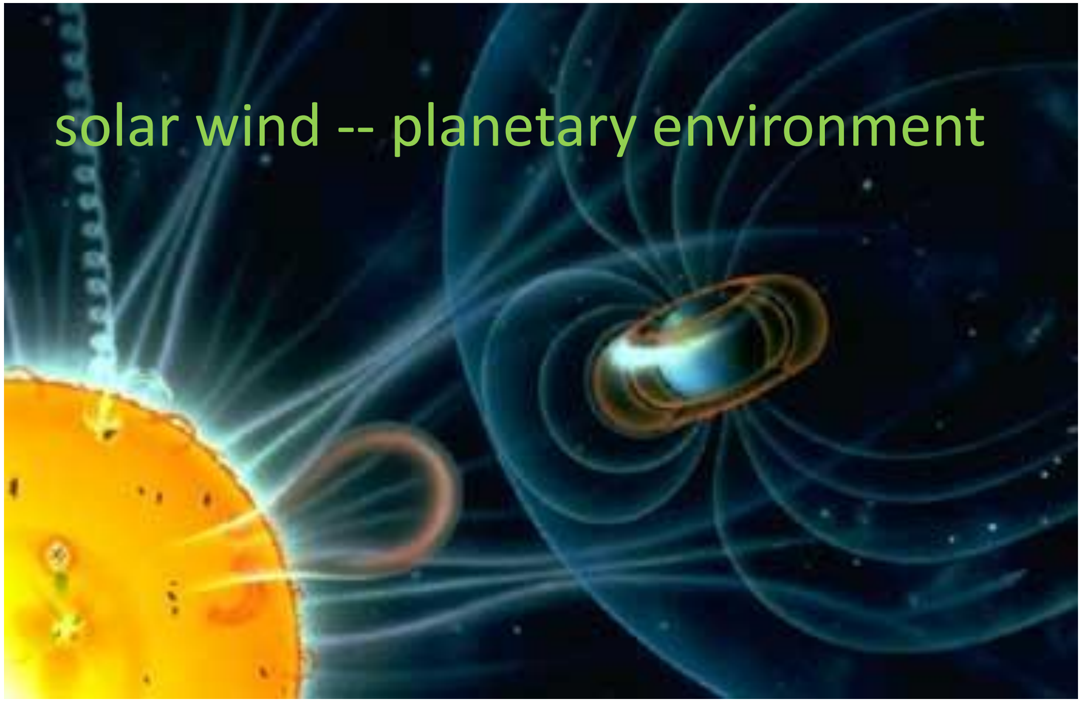
1. Intro. Turbulence and Space Plasma

*Turbulence is a ubiquitous phenomenon seen both in fluid and plasma
*Turbulence couples multi-scales

*Space plasma in various regions provides various parameters



[Bourouaine et al., 2012]



http://www.daystarfilters.com/Sun_Day/SunEarth.shtml

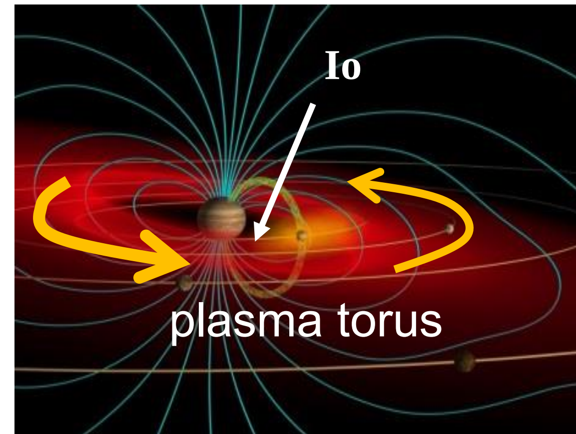
1. Intro.: Jovian magnetosphere

Rotation-dominant, energetic particle accelerator

- Fast rotation (9h55m)
- Strong magnetic field (momentum x20,000 Earth's)
- Plasma source at Io locating inner magnetosphere

→ Sulfur ion, Oxygen ion, …, Proton

→ Plasma rotate in the vast magnetosphere region

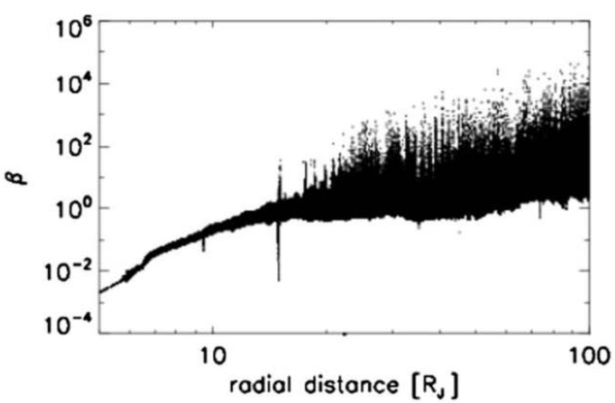


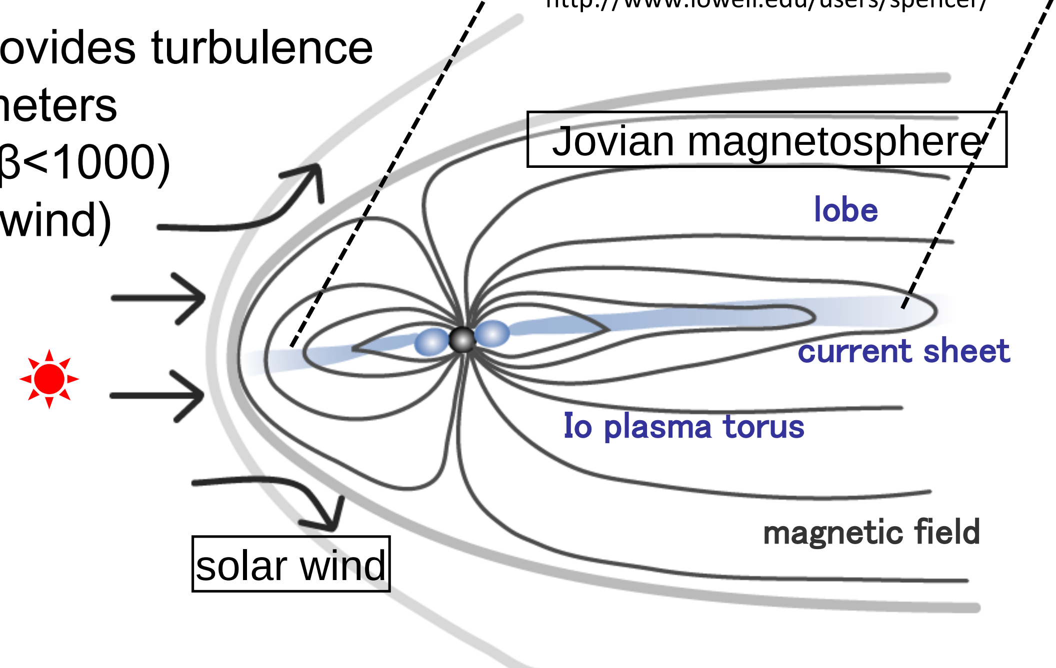
http://www.lowell.edu/users/spencer/

- Planetary magnetosphere would provides turbulence under unique environment with parameters

(e.g., Jupiter magnetosphere 0.01<β<1000)

+ dawn-dusk asymmetry (rot. + solar wind)





1. Intro.: Jovian magnetosphere

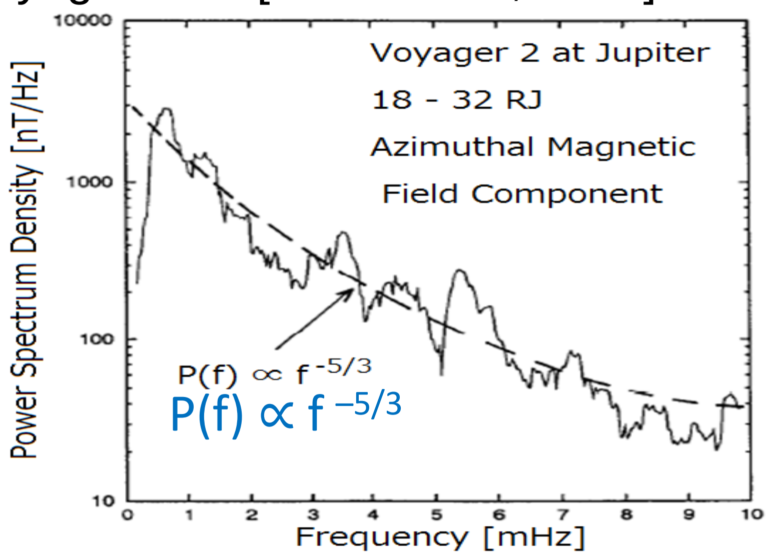
"Turbulence-like field fluctuations" in the Jovian magnetosphere

- ◆less resonant peak → turbulence is dominant feature and a good index of activity
- ◆spectral index ~ -5/3 [Glassmeier, 1995]
- ◆small $\delta b/B_0$ & index~2 at the inner magnetosphere (< 26 R_J), [Saur et al., 2002] cf. solar wind $\delta b/B_0$~1

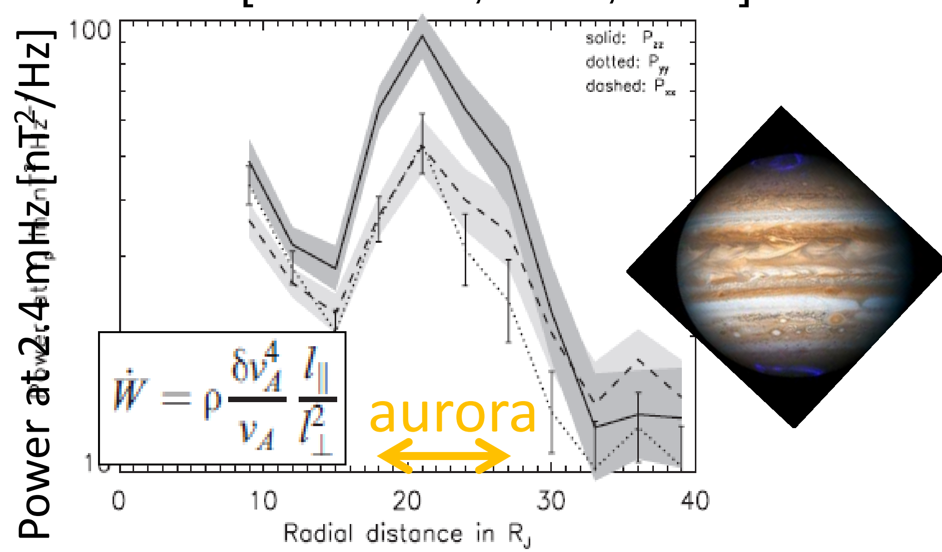
Effect of turbulence on

- ◆heating the expanding plasma from Io [Saur et al., 2004]
- ◆electric potential drop which accelerates electrons & create Jovian aurora [Saur et al., 2003]

Voyager data [Glassmeier, 1995]



Galileo data [Saur et al., 2002, 2003]



1. Intro.: Motivation of this study

Previous works used low time-resolution data in the limited radial distance and time.

Questions:
(1) Spectral feature, existence of break point?
(2) How turbulence feature varies in global various region?
(3) Relation between turbulence characteristics and magnetospheric phenomena?
(4) Comparison among different planetary magnetospheres

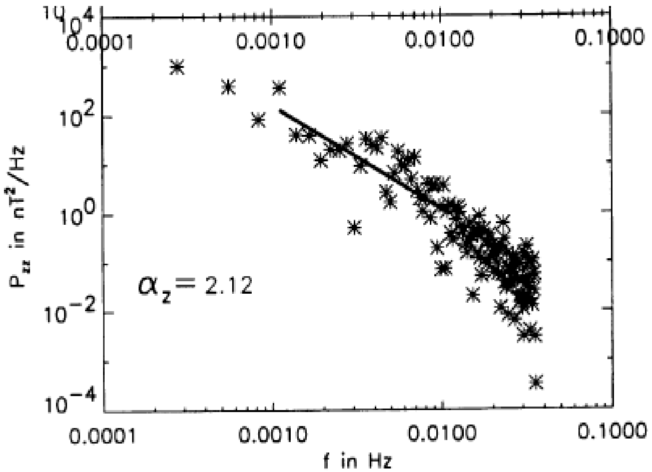
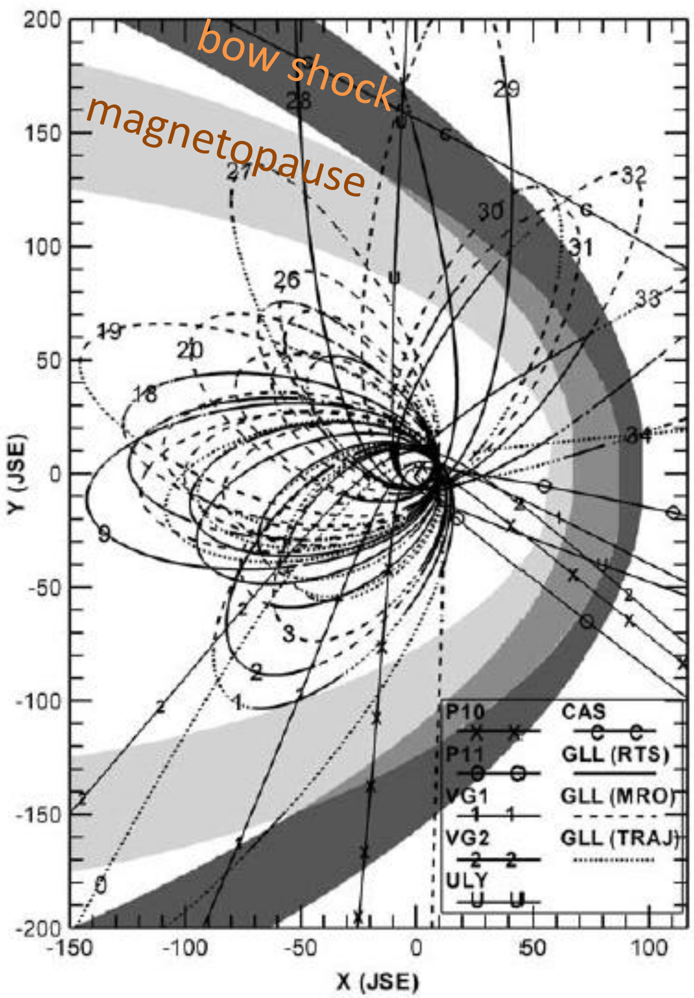


Fig. Spectral power of 1 hour interval at 20 R_J [Saur et al., 2002]

We use high time-resolved magnetometer data observed by Galileo
→ Characterize Jovian magnetospheric turbulence feature and its relation with magnetospheric dynamics

2. Data set : Galileo

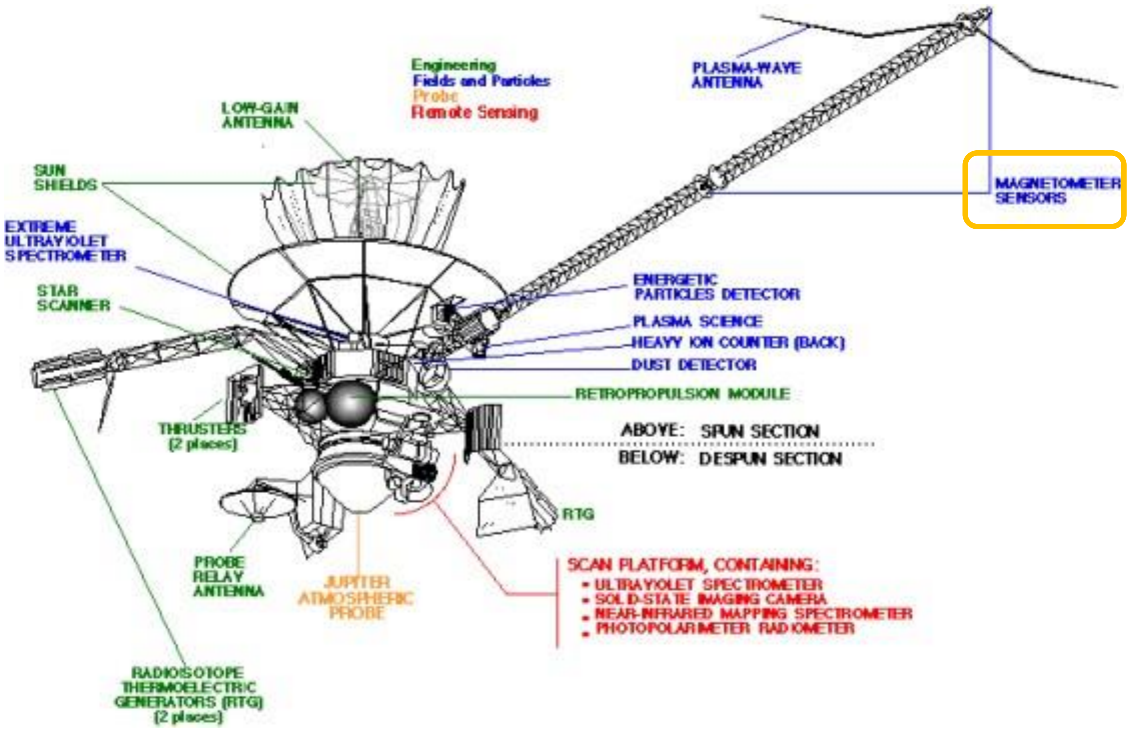
[Khurana and Schwarz, 2005]



Jovian magnetospheric orbiter

Dec. 1996 - Sep. 2003

covering many radial and local time (LT)



2. Data set : MAG data

<u>Galileo in the magnetosphere</u>

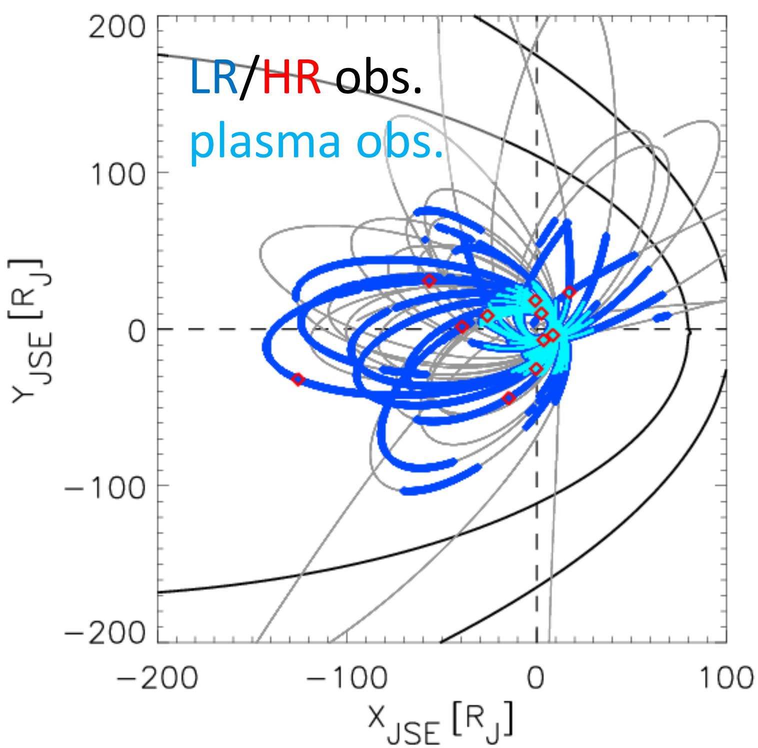
MAG: flux gate magnetometer [e.g., Kivelson et al., 1992]

High resolution (**HR**) data :

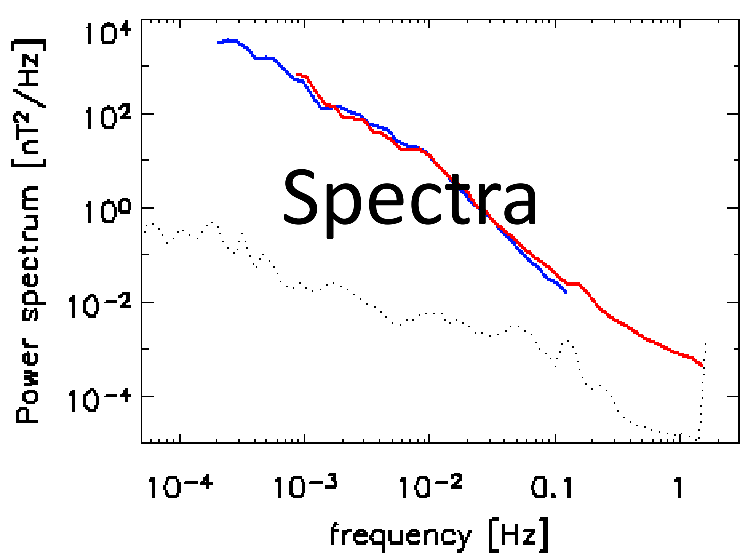
moon flyby: 24 events (not used in this study)

magnetosphere: 23 → 11 events (above noise level) Δt~0.33 sec., 35-280 min.

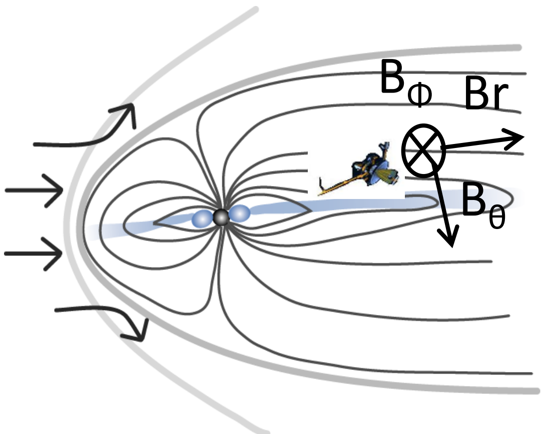
Low resolution (**LR**) data : Δt~24 sec. →<u>June 23, 1996 – Nov. 11, 2002</u>



Wavelet analysis
(using Morlet function)

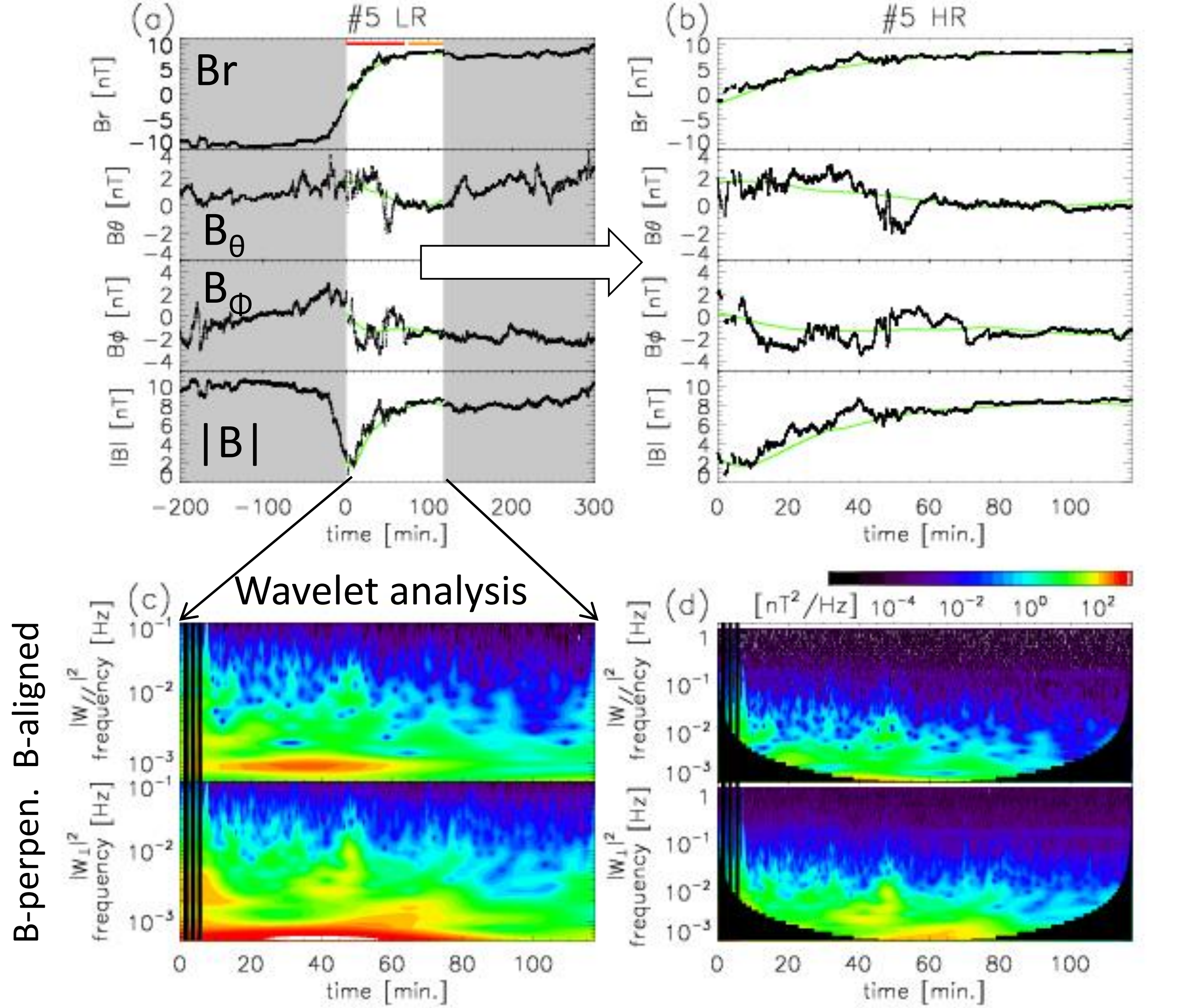


3. Analysis: Spectrum (ex.1997/07/04 14:09)



Low resolution data

High resolution data



4. Spectrum: over view (HR+LR)

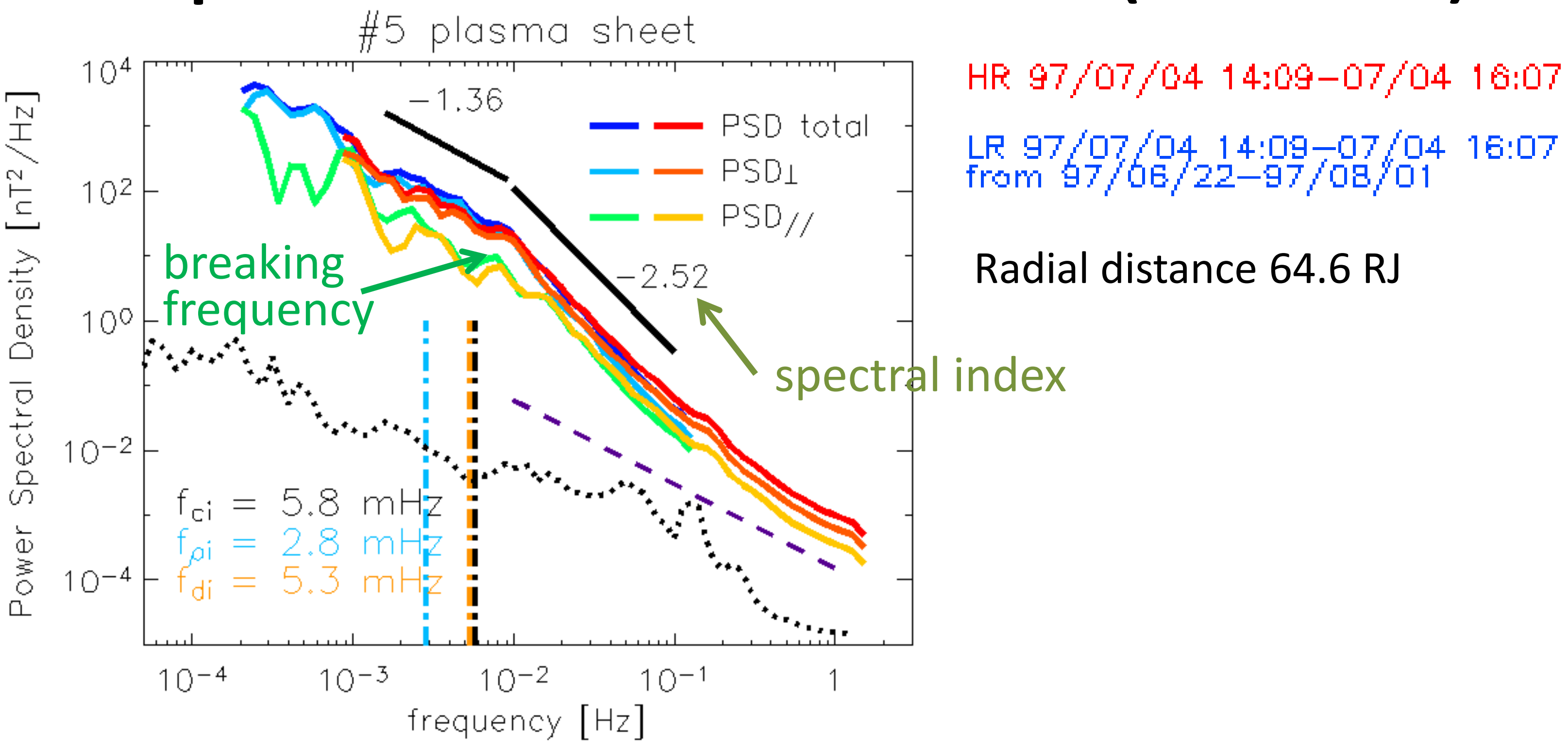


Fig. An example of spectrum from HR and LR data

-Spectral break is seen at ~0.01 Hz in both LR and HR data

-Spectral index is 1.3 (2.4) at lower (higher) frequency range

-$B_{//}$ ($B_{\perp}$) is dominant at lower (higher) frequency range

3. Analysis: Plasma parameters

Characteristic plasma parameters

-ion cyclotron frequency (fci) $\Omega_i = \frac{q_i B}{m_i}$

-ion inertial length (di) $d_i = \frac{c}{\omega_{pi}}$ $\omega_{pi} = \sqrt{\frac{n_i Z_i^2 e^2}{m_i \epsilon_0}}$

-ion gyro-radius (ρi) $\rho_i = \frac{v_{Ti}}{\Omega_i}$ $v_{Ti} = \sqrt{\frac{2k_B T_i}{m_i}}$

-plasma beta (βi) $\beta_i = \frac{p_{plasma}}{p_{magnetic}} = \frac{n_i k_B T_i}{(B^2/2\mu_0)}$

→ From ion inertia length and ion gyro-radius, corresponding characteristic frequencies are obtained as follows by Taylor Assumption:

-ion inertial length (fdi) $f_{di} = \frac{v_{ave}}{2\pi d_i}$

-ion gyro-radius (fρi) $f_{\rho i} = \frac{v_{ave}}{2\pi \rho_i}$

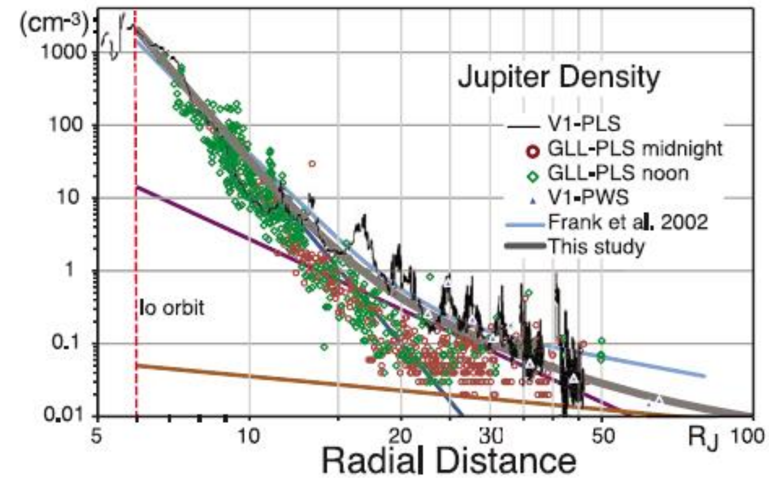
Magnetic field : directly observed value

Ion density and temperature :

-If data exists: PLS [Frank et al., 1992] observation

-If not: refer to an empirical model [Bagenal and Delamere, 2011]

Energetic particle profile based on EPD observation [e.g., Mauk et al., 2004] is added.



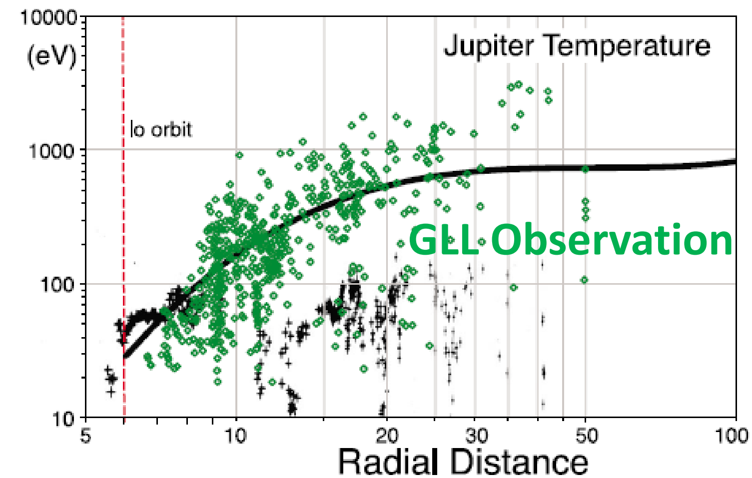
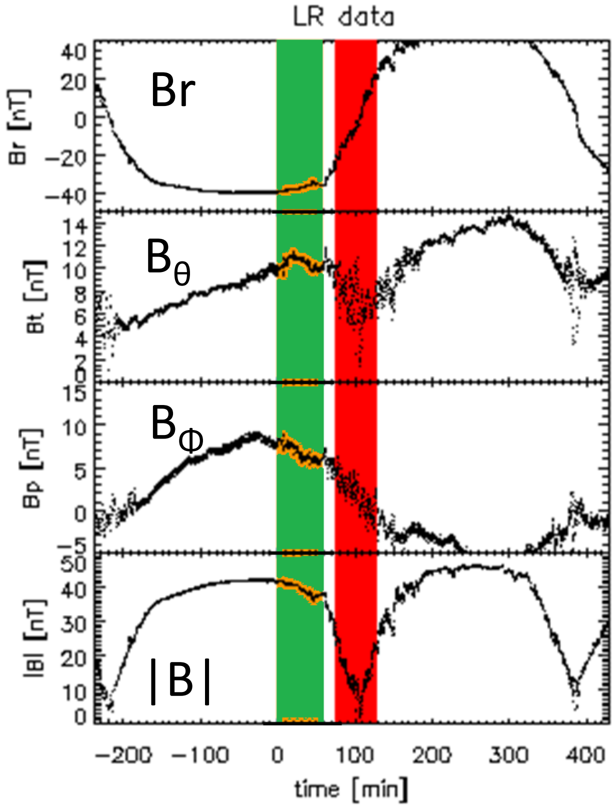


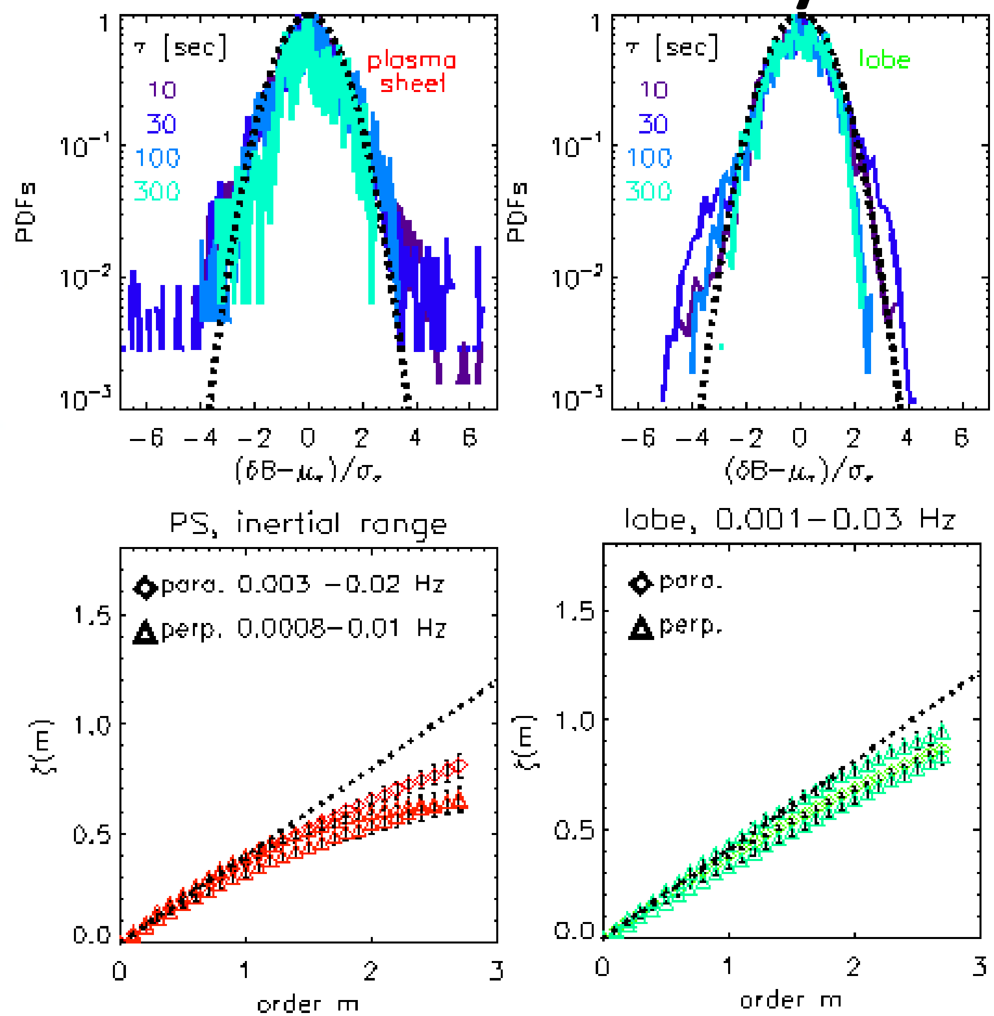
Fig. Observed and modeled radial profiles of density (upper) and temperature (lower) radial profiles [Bagenal and Delamere, 2011]

4. Spectrum: intermittency

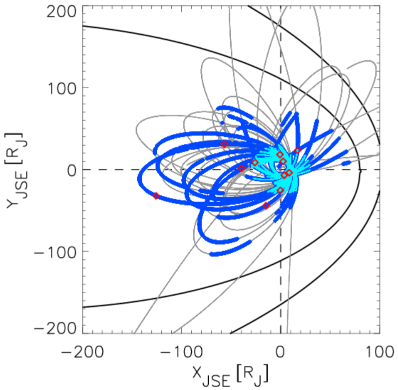
Intermittency →dissipation self-similary or not

$\delta B \equiv \delta B(t+\tau)-\delta B(t)$
$S_m(\tau)=<\delta B(t,\tau)^m> \propto \tau^{\xi(m)}$
m: order $S_m(\tau)$: structure function





Intermittent feature is
seen in the inertial frequency range of current sheet
less in the lobe



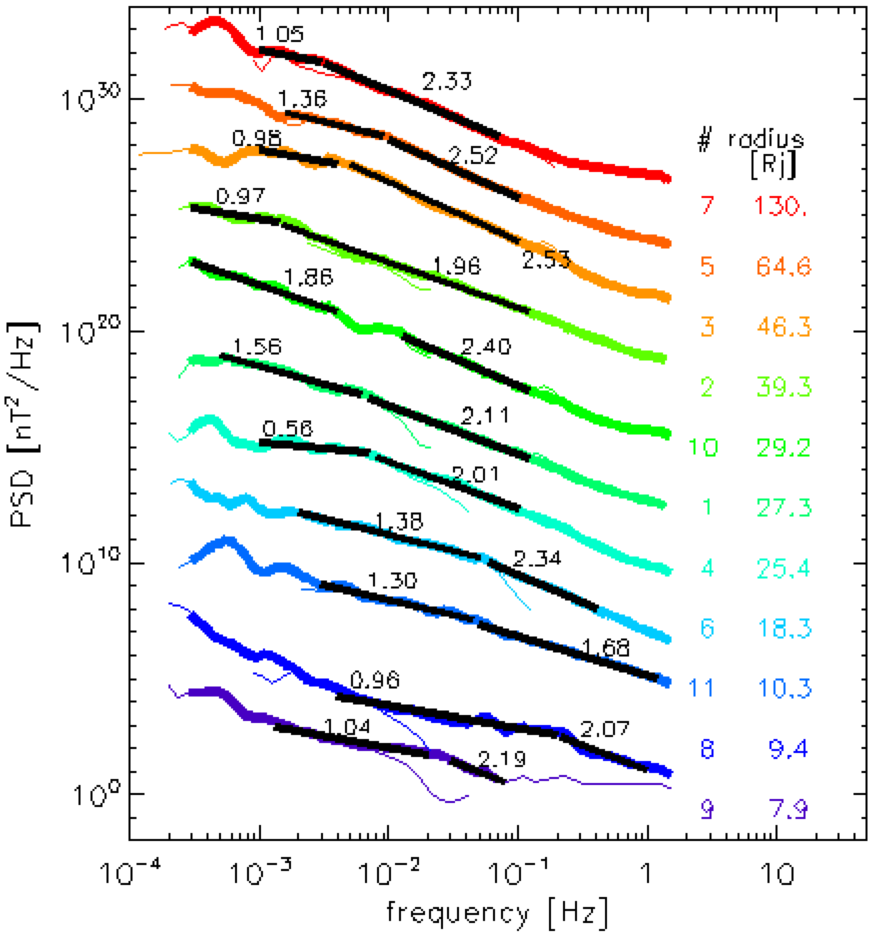
HR events

-11 events (of 23) with power well above the “minimum” level

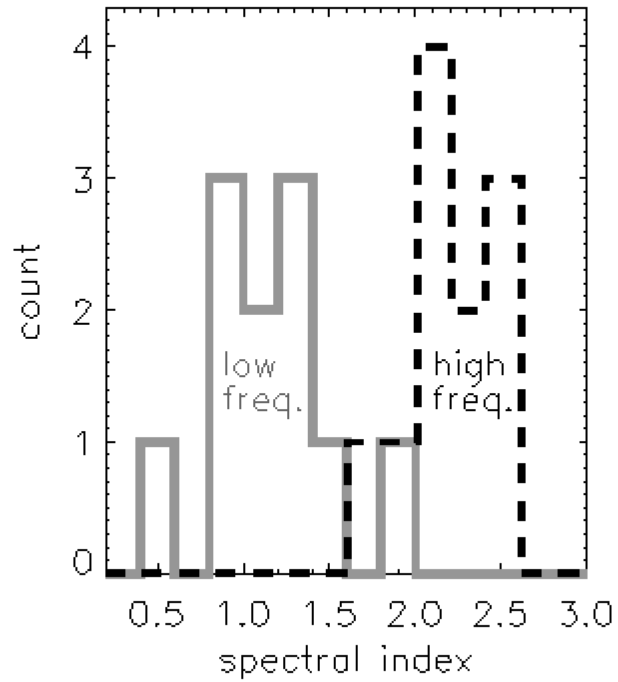
#	Start time	Galileo $(x,y,z)_{JSE}$ [RJ]	R [RJ]	LT [h]	β	index 1	index 2
1	1996/06/30 02:00	(-25.9, 8.57, 0.186)	27.3	22.7	2.43	1.78	2.11
2	1996/09/11 02:38	(-39.2, 1.5, -0.22)	39.3	23.8	1.72	0.59	1.89
3	1997/03/30 18:49	(-14.7, -43.9, -0.037)	46.3	4.7	3.41	0.98	2.53
4	1997/05/06 13:00	(-0.2, -25.3, -0.38)	25.3	5.9	1.17	0.71	1.94
5	1997/08/23 14:07	(-125.8, -31.9, -0.52)	129.8	0.9	3.22	1.05	2.33
6	1997/07/04 14:09	(-56.6, 30.9, -0.12)	64.5	22.0	1.43	1.50	2.48
7	1997/07/28 13:50	(-0.7, 18.2, -0.04)	18.2	18.1	1.08	1.38	2.26
8	1999/05/03 15:59	(8.5, -3.8, -0.02)	9.3	10.4	0.15	0.96	2.07
9	1999/07/01 23:52	(3.6, -6.9, 0.00)	7.8	7.8	0.10	1.04	2.19
10	2002/11/03 15:27	(17.2, 23.5, -0.29)	29.2	15.5	2.41	1.96	2.40
11	2002/11/04 21:48	(2.4, 9.9, -0.12)	10.2	17.0	0.26	1.30	1.68

4. Spectrum : spectral index

Spectra from LR and HR data



Histogram of spectral index

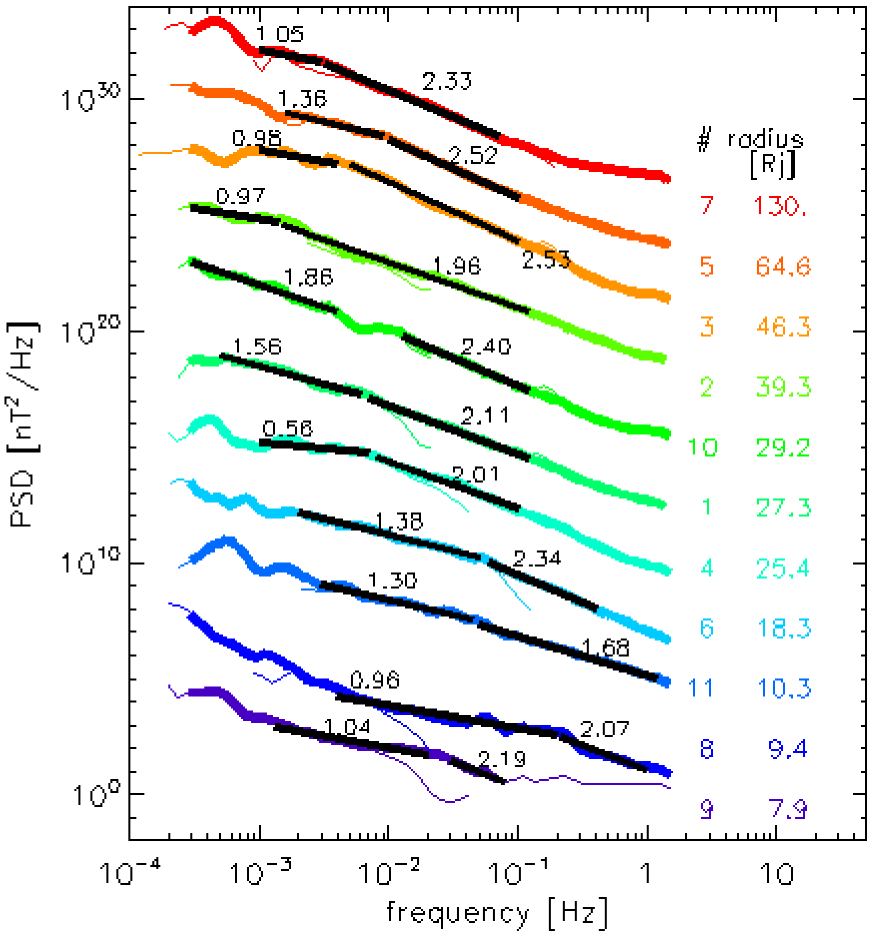


Spectral index 0.5-1.9 for f < fb

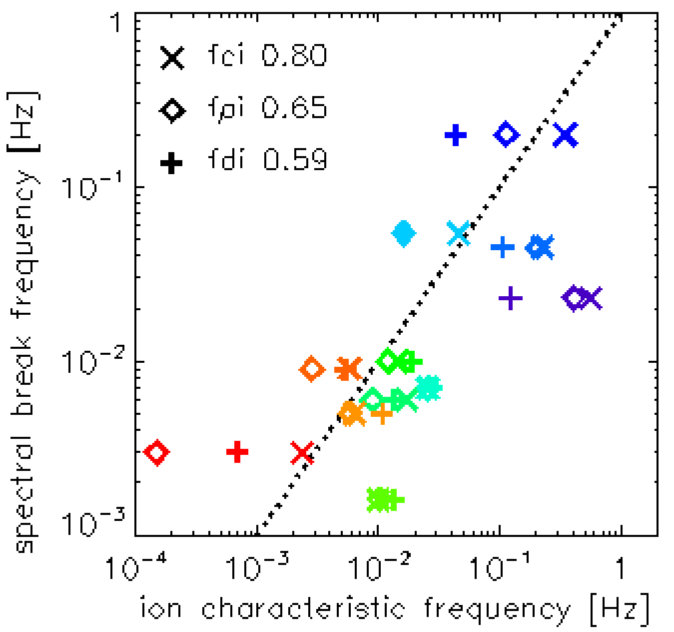
1.7-2.5 for f > fb

4. Spectrum: break point

Spectra from LR and HR data



Ion characteristic (x-axis) and break frequencies (y-axis)

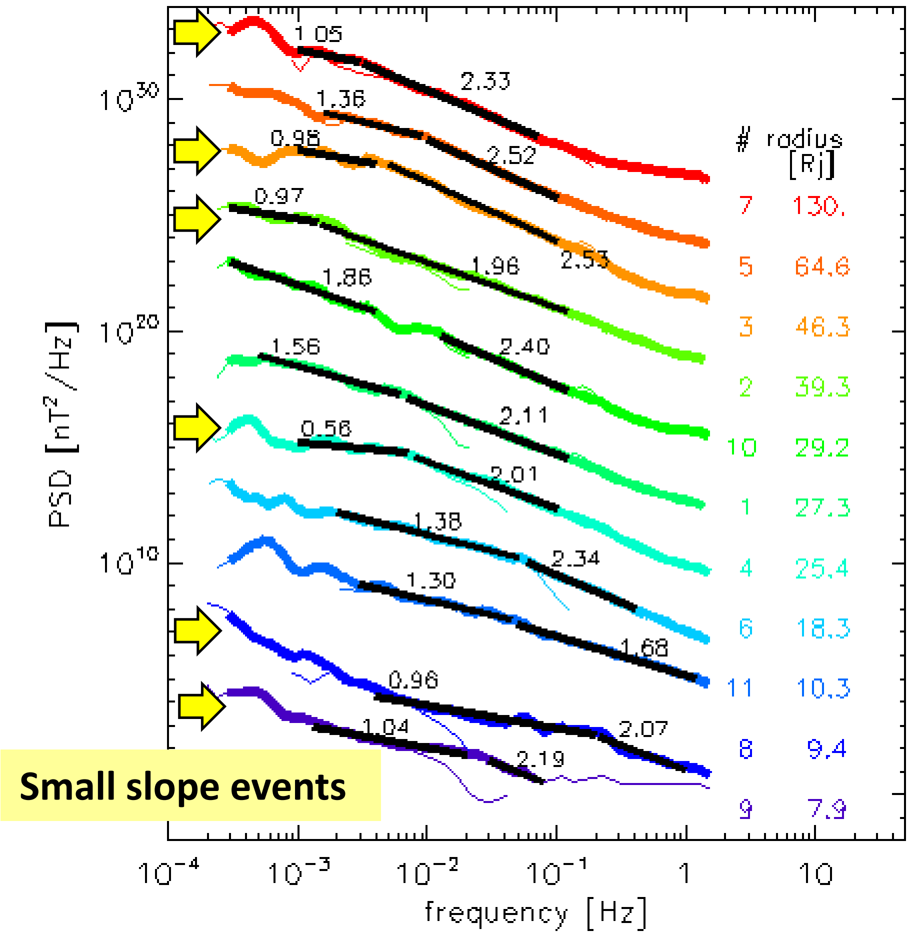


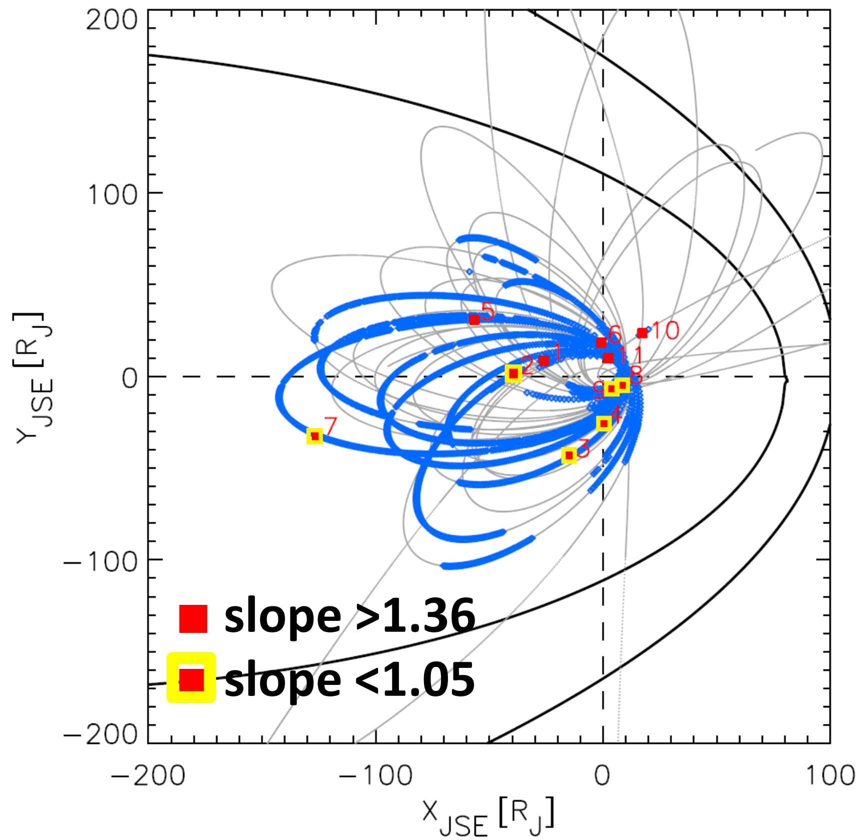
Spectral breaking frequency is

-close to frequency at ion inertial length and gyro radius

4. Spectrum: small spectral index

Spectra from LR and HR data





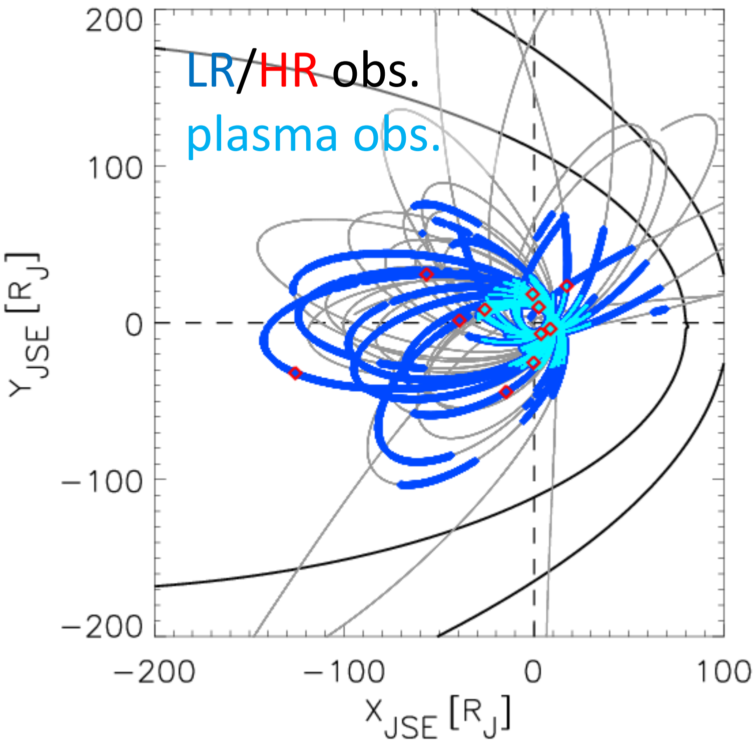
Small slope cases are seen in the dawnside observations

5. Statistical analysis

<u>Galileo in the magnetosphere</u>

Low resolution (**LR**) data : Δt~24 sec. →June 23, 1996 – Nov. 11, 2002

*Separate current sheet & lobe (automatically)



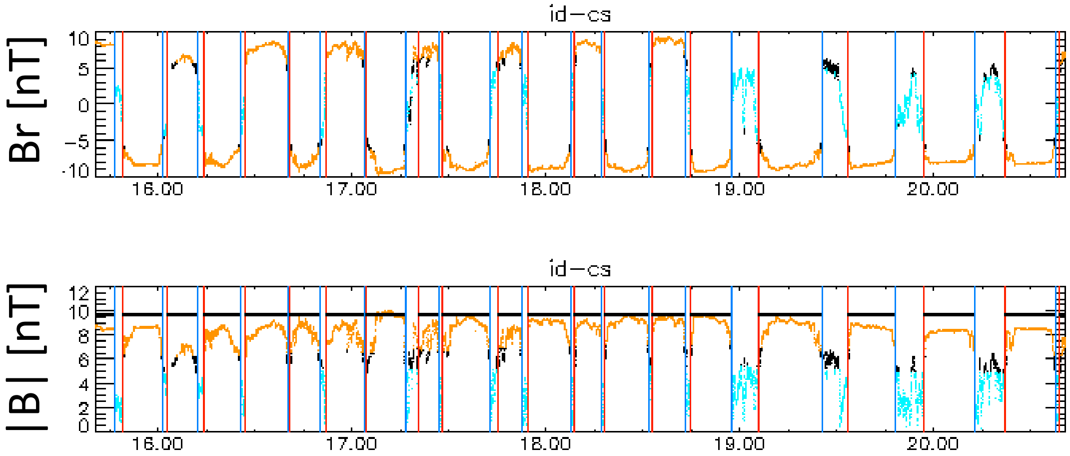
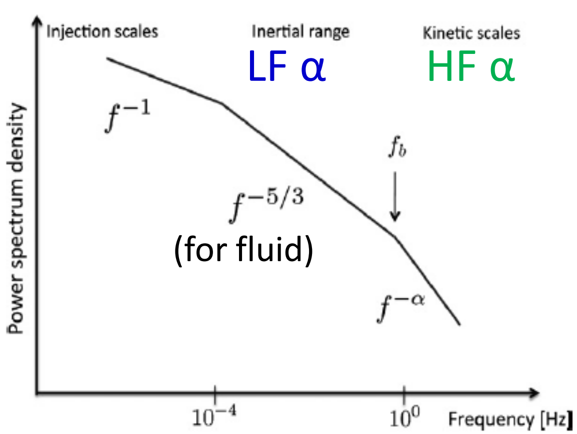


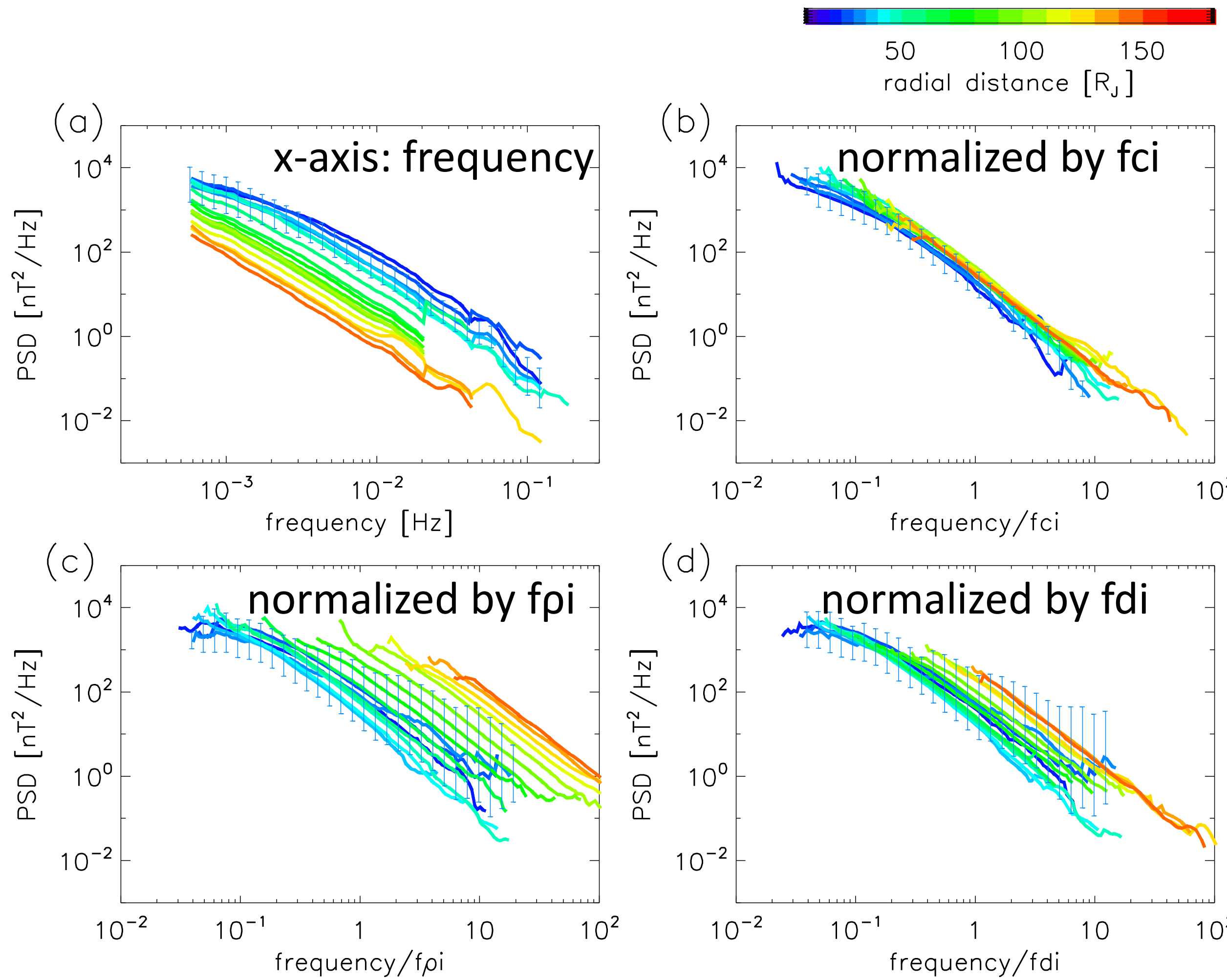
Fig. An example of CS/lobe separation

5. Statistics: Radial dependence

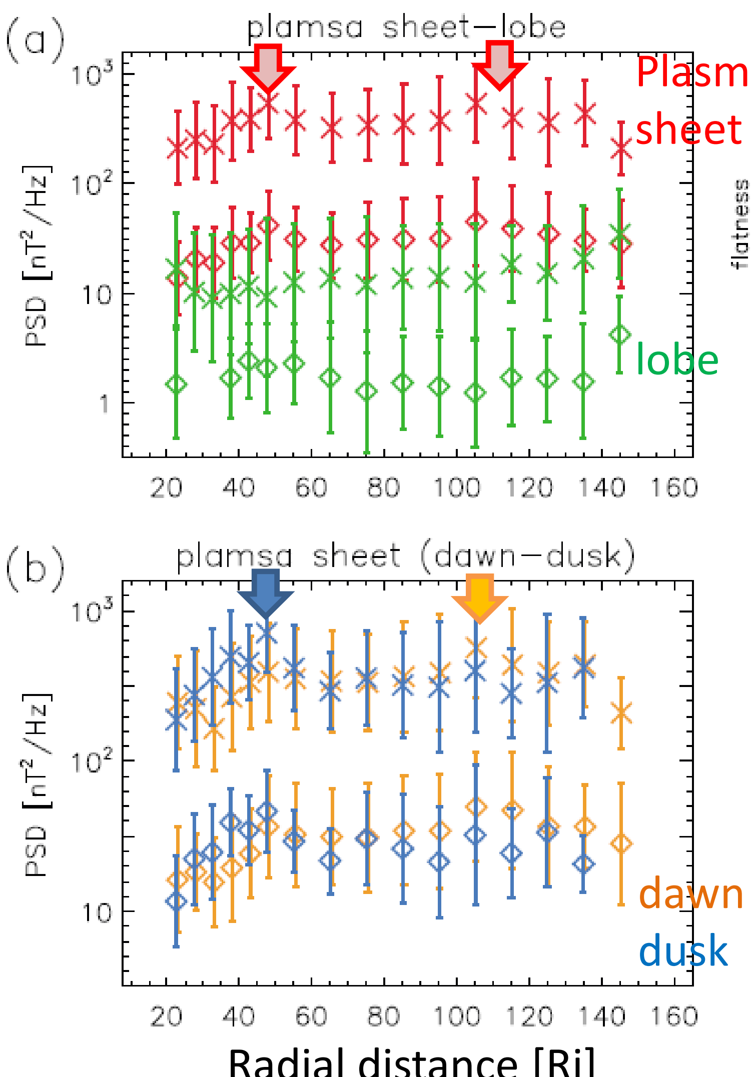
-Most concentration of PSD by normalization with fci.

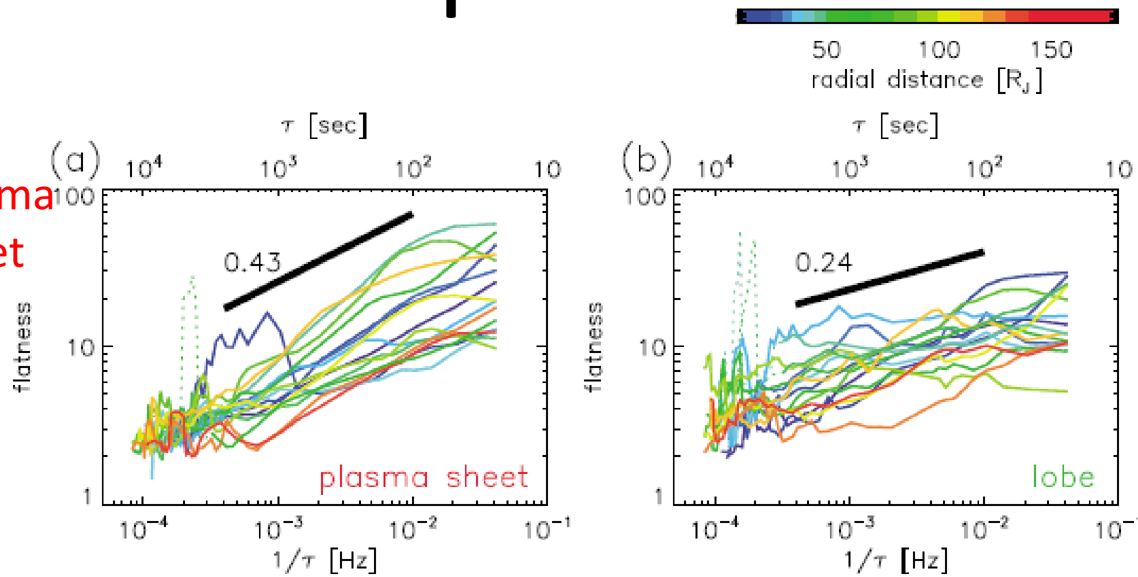


[Bourouaine et al., 2012]



5. Statistics: Radial dependence 2



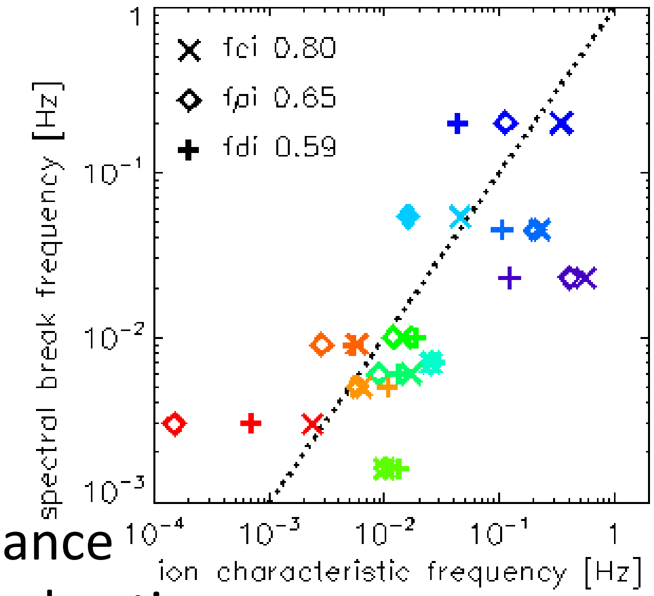


-Large deviation of flatness from Gaussian (=3) for plasma sheet case than lobe.

-PSD is large in the plasma sheet with enhancement at ~50 R_J and ~100 R_J.

-PSD enhancements at ~50 R_J is seen in the duskside and ~100 R_J in the dawnside.

6. Discussion



1. Dependence of the breakpoint frequency on the ion gyrofrequency, than ion scales (cf. Ion inertial scale for solar wind)

→ Possible role of ion cyclotron waves and resonance in the dissipation of magnetic energy into particle heating

*There is also an ambiguity in the plasma data, model, and Taylor assumption
→ Expect to JUICE (future mission 2030-)

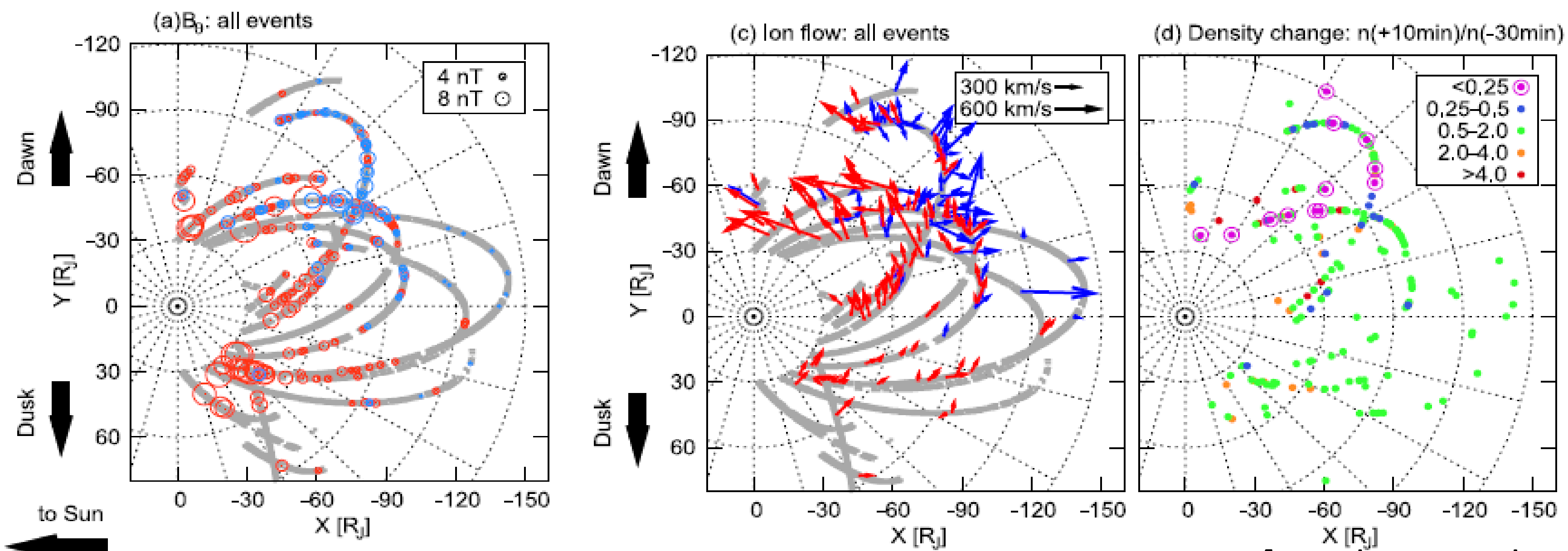
2. (Intermittency at current sheet) > (Intermittency at lobe)

This regional dependence is similar as seen in the Earth magnetotail [Weygand et al., 2005]
→ reflecting local structures (i.e., reconnection and resulting flow).

6. Discussion

3. Large total power in the duskside (dawnside) at <50 R_J (>80 R_J)
4. Small spectral index at the dawnside is close to -1 in the “energy-containing scale”

*Reconnection-like magnetic features is observed at these locations, while ion flow and density change is associated with those in the dawnside [Kasahara et al., 2013].
*Large slope variation in the low-frequency range is due to the magnetospheric dynamics, as suggested in the case of Saturn [von Papen et al., 2014].



[Kasahara et al., 2013]

7. Summary and Conclusions

We analyze Galileo/MAG high and low resolution data using a wavelet method.

(1) Spectral feature, existence of break point?

★ We confirmed (at least) two spectral index.

-- The spectral index is 0.5-1.9 for lower and 1.7-2.5 for higher range of break point.

-- Spectrum break is close to frequency at ion gyrofrequency and ion scales.

(2) How turbulence feature varies in global various region?

★ The turbulence power and intermittency is strong in the plasma sheet than lobe.

★ The power enhances at ~50 R_J at the duskside and ~100 R_J at the dawnside.

(3) Relation between turbulence characteristics and magnetospheric phenomena?

★ Dawn-dusk asymmetries of PSD radial profile and slope at “energy-containing scales” would be related with magnetospheric reconnection and ion flow features.

statistical distribution so far. → event study?

(4) Comparison among different planetary magnetospheres

★ Dominance of intermittency in the plasma sheet is the same with Earth.

★ Spectral feature is due to plasma parameter. Detail → accurate obs. by JUICE etc.

Tao et al., Properties of Jupiter’s magnetospheric turbulence observed by the Galileo spacecraft, J. Geophys. Res. Space Physics, 2015