Characteristics of Jupiter's Magnetospheric Turbulence Observed by Galileo

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In collisionless plasmas, turbulence is thought to play an important role in mass transport and energy dissipation. Magnetic fluctuations in the Jovian magnetosphere are essentially in a turbulent state. Previous studies discussed the effect of turbulence on heating the expanding plasma from Io and the relationship with the electric potential drop which accelerates electrons and leads to strong Jovian aurora. Previous analyses of the Jovian magnetosphere disturbances have focused mainly on their power spectra and the corresponding slopes in the low frequency range of 10^{-4}–10^{-2} Hz, which is limited by low time resolution ($\Delta t \sim 24$ sec.).

Here we extend those studies to cover a wider range of scales by combining both low and high-time resolution data of Galileo magnetometer (MAG). We use particles data from the plasma instrument (PLS) and empirical models including energetic particle contributions to estimate the local plasma parameters.

We obtain 11 power spectra of magnetic field in the frequency range of 10^{-4}–1 Hz, which covers both MagnetoHydroDynamics (MHD) and ion kinetic scales. The frequencies of the evidenced spectral breaks are found to be relatively well correlated with the characteristic scales of heavy ion. The spectral indices below and above the spectral breaks are found to be broad and cover the ranges of 0.6–1.9 and 1.7–2.5, respectively. An analysis of higher order statistics shows an intermittent feature of the turbulence, found to be more prominent in the plasma sheet than in the lobe. Furthermore, a statistical survey of the power of the fluctuations using low-time resolution data suggests a radially varying dawn-dusk asymmetry: the total power is larger in the duskside (dawnside) at distances <50 R_J (>80 R_J), which would reflect flow shear and global magnetospheric activity.

Reference:

Tao, C., F. Sahraoui, D. Fontaine, J.de Patoul, T. Chust, S. Kasahara, and A. Retinò (2015), Properties of Jupiter's magnetospheric turbulence observed by the Galileo spacecraft. J. Geophys. Res. Space Physics, 120, 2477–2493, doi: 10.1002/2014JA020749.

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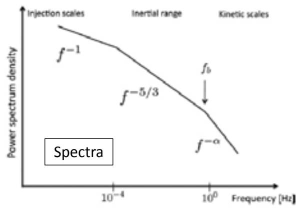
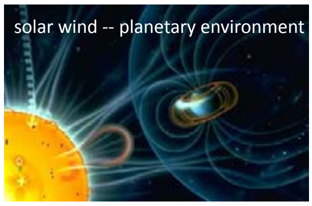
1. Intro. Turbulence and Space Plasma

*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]

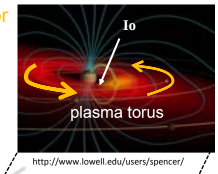


http://www.daystarfilters.com/Sun_Day/SunEarth.shtml

1. Intro.: Jovian magnetosphere

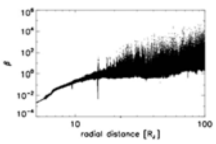
Rotation-dominant, energetic particle accelerator

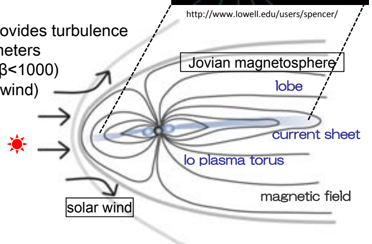
- Fast rotation (9h55m)
- Strong magnetic field (momentum x20,000 Earth's)
- Plasma source at Io locating inner magnetosphere
  → Sulfur ion, Oxygen ion, …, Proton
  → Plasma rotate in the vast magnetosphere region



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)





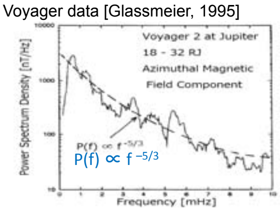
1. Intro.: Jovian magnetosphere

"Turbulence-like field fluctuations" in the Jovian magnetosphere

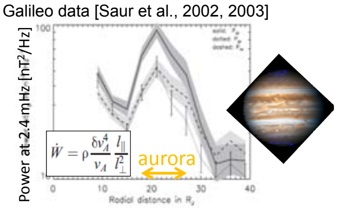
◆less resonant peak → turbulence is dominant feature and a good index of activity
◆spectral index ~ -5/3 [Glassmeier, 1995]
◆small $\delta b/B_0$ & index~2 at the inner magnetosphere (< 26 R_J), [Saur et al., 2002]
cf. solar wind $\delta b/B_0$~1

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 (<30 R_J) 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

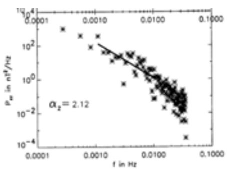
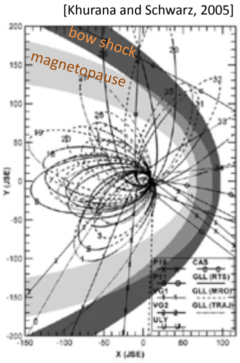


Fig. Spectral power of 1 hour interval at 20 R_J [Saur et al., 2002]

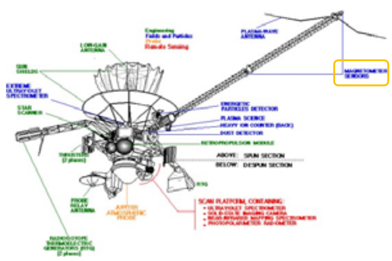
We use high time-resolved magnetometer data observed by Galileo
→ Characterize Jovian magnetospheric turbulence feature and its relation with magnetospheric dynamics

2. Data set : Galileo

[Khurana and Schwarz, 2005]

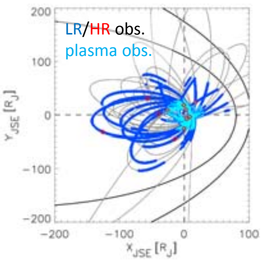


Jovian magnetospheric orbiter
Dec. 1996 - Sep. 2003
covering many radial and local time (LT)

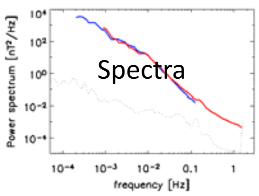


2. Data set : MAG data

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 → June 23,1996 – Nov. 11,2002 Statistic survey



Wavelet analysis
(using Morlet function)



3. Analysis: Plasma parameters

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

-ion inertial length (di) $d_i = \frac{c}{\omega_{pi}}$ $\omega_{pi} = \sqrt{\frac{n_i Z_i^2 e^2}{m_i \varepsilon_0}}$

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

Corresponding characteristic frequencies for di & ρi:
using 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: an empirical model [Bagenal and Delamere, 2011].
Energetic particle profile based on EPD observation [e.g., Mauk et al., 2004] is added.

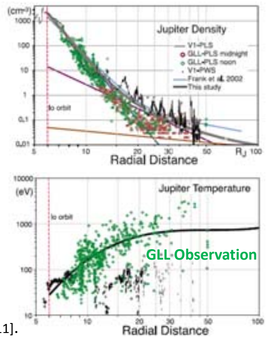


Fig. Observed and modeled radial profiles of density (upper) and temperature (lower) radial profiles [Bagenal and Delamere, 2011]

4. Spectrum: over view (HR+LR)

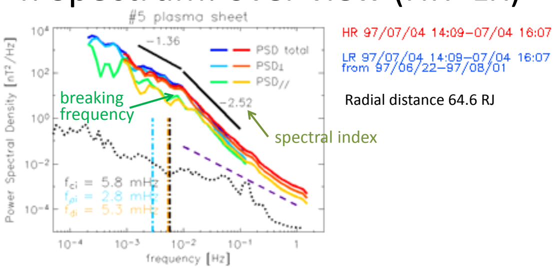


Fig. An example of spectrum from HR and LR data

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

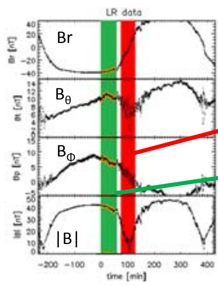
-Spectral index is 1.3 (2.4) at lower (higher) frequency range

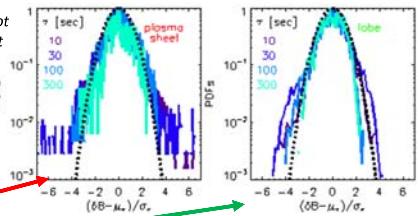
-$B_{//}$ ($B_{\perp}$) is dominant at lower (higher) frequency range

4. Spectrum: intermittency

δB ≡ δB(t+τ)-δB(t)

PDF (probability distribution function) of δB is *Gaussian* or *not*
→dissipation *self-similary* or *not*

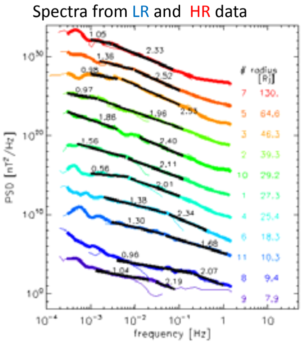




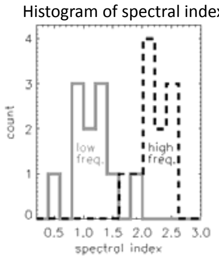
Intermittent feature is
seen in the inertial frequency range of plasma sheet
less in the lobe

4. Spectrum : spectral index

Spectra from LR and HR data



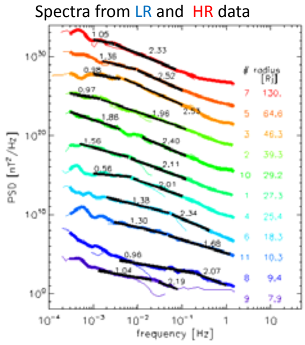
Histogram of spectral index



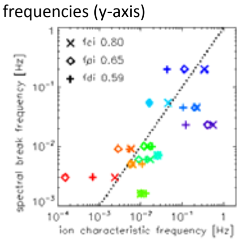
Spectral index 0.5-1.9 for f < fb
1.7-2.5 for f > fb

4. Spectrum: break point

Spectra from LR and HR data



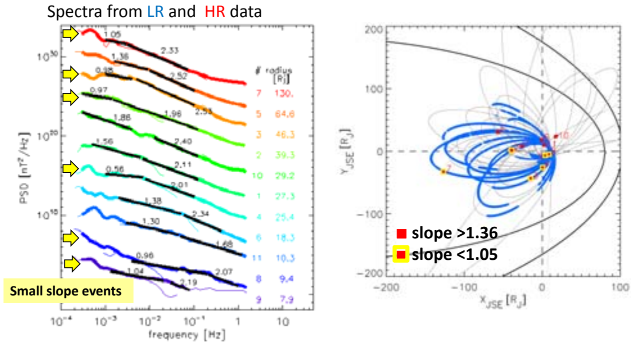
Ion characteristic (x-axis) and break frequencies (y-axis)



Spectral breaking frequency is close to frequency at ion characteristic scales (inertial length and gyro radius, cyclotron freq.)

4. Spectrum: small spectral index

Spectra from LR and HR data

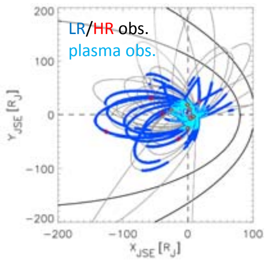


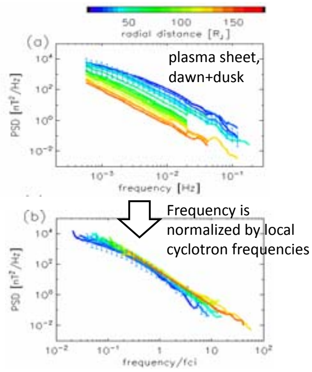
Small slope cases are seen in the dawnside observations

5. Statistical Analysis

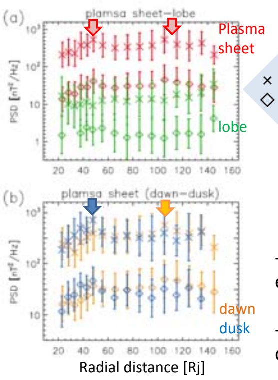
Low resolution (LR) data : Δt~24 sec. → June 23, 1996 – Nov. 11, 2002

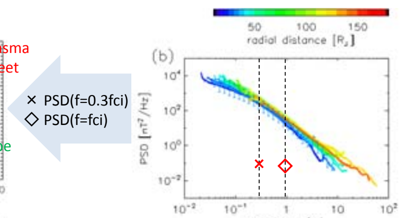
Spectra is averaged over
--plasma sheet & lobe,
--radial distance (5-10 Rj)
--dawn & dusk





5. Statistics: power variation





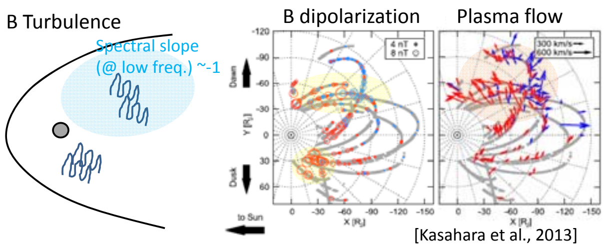
-PSD is large in the plasma sheet with enhancement at ~45 R_J and ~100 R_J.

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

6. Discussion

1. Large total power in the duskside (dawnside) at <50 R_J (>80 R_J)
2. Small spectral index ~-1 at the dawnside: "energy-containing scale"

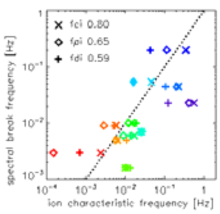
*Reconnection-like magnetic features is observed at these locations, while ion flow and density change is associated with those in the dawnside [Kasahara et al., 2013].
*Large slope variation in the low-frequency range is due to the magnetospheric dynamics, as suggested in the case of Saturn [von Papen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



[Kasahara et al., 2013]

6. Discussion

3. (Intermittency at plasma sheet) > (at lobe)
This dependence is similar as seen in the Earth magnetotail [Weygand et al., 2005]
→ reflecting local structures
(i.e., reconnection and resulting flow).



4. Dependence of the breakpoint frequency on the ion cyclotron frequency, 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 ambiguity in the plasma data, model, and Taylor assumption
 → Expect to plasma measurement by JUICE (future mission 2030-)
 + JUICE/RPWI search coil magnetometer covers electron scale

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. (2015), Properties of Jupiter's magnetospheric turbulence observed by the Galileo spacecraft, J. Geophys. Res. Space Physics, 120, doi:10.1002/2014JA020749.