Catalog of magnetic field PSD in planetary plasmas; solar cycle tendency

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1. Introduction

This work package is devoted to the analysis of the intermittent turbulence in the planetary plasmas of Venus and the Earth, using data from Cluster and Venus Express data, and also in the vicinity of comets (Halley, Grig-Skjelerupp, 67P/Churyumov-Gerasimenko), Mars and Saturn. PSD are computed for the magnetic field data sets selected for Cluster. At solar maximum (2001-2002) data for the Earth are complemented with some examples from Mars Global Surveyor. At solar minimum (2007-2008) the Cluster data in the Earth plasma are complemented by data from Venus (Venus Express) and Saturn (Cassini-Huygens). This report summarizes activities devoted to the following tasks:

Task 3.1.Planetary data base definition (IASB, INAF, MFGI, OEAW)

- Define and construct planetary plasma databases at solar maximum, D2MAXMSPH (2001-2002, Cluster-OEAW),
- Define and construct planetary plasma databases at solar minimum D4MINMSPH (2007-2008, Cluster, Venus Express – OEAW, IASB)

Task 3.2. Power spectral density and Probability Distribution functions in the planetary plasma (IASB, MFGI, INAF, OEAW)

- Compute PSD on magnetic field and velocity data from selected planetary plasma data bases realize a catalog of PSD for magnetic field fluctuations for each of the databases D2MAXMSPH, D4MINSMSPH (MFGI)

2. Analysis

2.1 Data Processing

First, the magnetic field is transformed into the mean-field-aligned (MFA) coordinate system. The 22 Hz (normal mode) fluxgate magnetometer (FGM) data processed to 4-sec resolution are used for the reasons to remove the spin tone and spin-induced disturbance of the instrumental noise at higher frequencies (above 1 Hz). The background or large-scale magnetic field is averaged over the entire time series. To estimate the time-dependent PSD, the Welch algorithm (Welch, 1967), described in the ISSI scientific report (Eriksson, 1998), is implemented in MATLAB.

1. The total time series of N data points is divided into M shorter intervals of L data points each. Note that since we use FFT (Fast Fourier Transform) without zero-padding, the data points must satisfy the condition $\log_2(L) = \text{integer}$.

2. The M intervals overlap by $L/2$ data points (50% overlap), hence there are $P = 2M - 1$ intervals of L data points each.

3. The mean value of each of the P intervals is subtracted without detrending (after agreement in the IWF STORM team).

4. Each of the P intervals is multiplied by a Hanning-window function.

5. The DFT (Discrete Fourier Transform) of the windowed time series is calculated for each of the P intervals using the MATLAB FFT algorithm. The FFT normalization in MATLAB is

$$X(k) = \sum x(n) e^{-2\pi i(k-1)\frac{n-1}{L}}, \qquad 1 \leq \text{k} \geq L \qquad (1)$$

$$x(n) = \frac{1}{L} \sum X(k) e^{2\pi i(k-1)\frac{n-1}{L}}, \qquad 1 \leq n \geq L \qquad (2)$$

6. The PSD estimate is calculated and corrected for the windowing (PSD estimate is divided by the mean square value of the window function). Note that due to the normalization of Parseval's relation, the PSD estimate is divided by the number of data points L in MATLAB.

7. Finally, to get a PSD estimate with better variance, the average over the P intervals is calculated.

This procedure is used to compute the PSD estimate for all planetary plasmas in the following.

2.2 PSD data format

Each PSD record is stored into an ASCII file, containing one header, describing the format of the data. In the first column the frequency range in Hz is given. The second column gives the total perpendicular PSD estimate determined from the sum of the two PSD estimates calculated from the two perpendicular mean-field-aligned components. The third column gives the parallel PSD estimate determined from the parallel mean-field-aligned component. Both PSD estimates are given in nT^2/Hz. The fourth and fifth columns give the error of the total perpendicular and the parallel PSD estimates respectively. These errors are determined by the standard deviation of each data point from the PSD estimates which are used to get a PSD estimate with better variance (see 7.). Finally these errors are corrected by multiplication with the factor 1.2/P, which is suggested by Welch (1967) for 50 % overlapping time intervals.

3. Description of catalogs

3.1 There are four catalogs of D 3.1:

- **Catalog 1: D2MAXMSP:** This includes time interval lists and PSD plots for solar maximum (2001-2002) of Earth magnetosheath.

- **Catalog 2: D4MINMSP:** This includes time interval lists, PSD plots for solar minimum (2007-2008) of the Earth magnetosheath and time interval lists and PSD plots for solar minimum (2006-2008) of Venus magnetosheath.

- **Catalog 3: Planets and comet:** This includes time interval lists and PSD plots from the data obtained at different planets like Saturn (2005), Mars (1998) and comet P/Halley (1986).

- **Catalog 4: Earth magnetosphere:** This includes time interval list and PSD plots from the data obtained in different regions of the Earth magnetosphere like LLBL/cups (2001 -2003), Lobe (2002) and Plasma sheet (2002).

Selection procedure and criteria (Earth Magnetosheath)

The magnetosheath intervals detection by Cluster was implemented for the periods Feb-April 2001 and January – April 2002, corresponding to solar maximum activity; and January-April 2007 and January – April 2008, corresponding to solar minimum activity. The selection procedure is based on the simultaneous scanning of the following parameters: spacecraft position, magnetic field magnitude, ion velocity, ion temperature and omni-directional ion energy flux. We used the flux-gate magnetometer (FGM) and the ion spectrometer (CIS) measurements. The parameters are downloaded from Cluster Active Archive (CAA). The minimal length of an interval is 35 minutes.

We apply the following thresholds for magnetosheath intervals selection: spacecraft position – $X_{GSE} > 0$, magnetic field $0 < B < 70$ nT, ion velocity $0 < V_{GSE} < 450$ Km/s, ion temperature $T_i >$ (0.01, 0.5) MK and ion energy flux $F_E > (1*10^7/5*10^7)$ keV cm^{-2} s^{-1} sr^{-1} keV^{-1} for energy range 0.1-12 keV. In order to exclude magnetosheath mixing with ion foreshock in the data selection procedure we reject intervals in which the highest energy channels (16 – 30 keV) exceeds certain threshold - $F_E > (1*10^6/3*10^6)$ keV cm^{-2} s^{-1} keV^{-1}. The thresholds assume different values due to a monthly variability in the parameters. It is worth noting that the selection criteria work only when data from all parameters are simultaneously available. Encountered gaps and instrumental errors detected from the instruments are described in instrument caveat files.

3.2 Earth

Data set is provided by Cluster fluxgate magnetometer (Balogh et al., 2001) (spacecraft 1), averaged over 4-second spin, in the season February to April, year 2001 - 2002 for the regions of magnetosheath and LLBL/Cusp; in the season February to April, year 2007-2008 for the regions of magnetosheath; and August to September, year 2001 or 2002 for plasma sheet and lobe. Cluster formed a nearly regular tetrahedron at the size in the range between 100 and 1000 km, suitable for detailed wave analysis.

3.2.1 Magnetosheath

The complete interval list is given in Appendix A1. Time interval is set to 35 minutes, a typical time length needed to resolve turbulent mirror mode structures in the Earth magnetosheath.

3.2.2 LLBL/cusps

Interval list is obtained from Echim et al. (2007), Balan et al. (2006), Bogdanova et al. (2005) and Nykyri et al. (2011) and is given in Appendix A2. Time interval is set to 35 minutes to keep the spectral estimate consistent with the Earth magnetosheath spectra.

Table: Magnetosheath selection based on Cluster measurements (used instruments and parameters and the respective samplings).

Instrument	Quantity	Sampling rate	Parameter
AUX	Spacecraft position	60 s	$\mathbf{X}_{GSE}$, R_E
FGM	Magnetic field	0.045 s, 0.015 s	$\lvert\mathbf{B}_{GSE}\rvert$, nT
CIS-HIA	Ion velocity	4 s	$\lvert\mathbf{V}_{GSE}\rvert$, km/s
CIS-HIA	Ion temperature	4 s	T_i, MK
CIS-HIA	Particle energy flux	4 s	$\mathbf{F_E}$, keV cm^{-2} s^{-1} sr^{-1} keV^{-1}

3.2.3 Lobe

Interval list is provided by the ECLAT FP7-project (running at the Space Research Institute, Graz) which already identified time intervals for different plasma domains in the Earth magnetotail using Cluster data and list of intervals is given in Appendix A3. Time interval is set to 35 minutes.

3.2.4 Plasma sheet

Interval list is provided again by FP7 ECLAT project and is given in Appendix A4. Time interval is set to 35 minutes.

3.3 Venus

Venus Express fluxgate magnetometer data (1-Hz data) are used (Zhang et al., (2008)). Data are provided directly by the magnetometer PI at the Space Research Institute, Graz and list of intervals are given in Appendix A5. Only 10-minute intervals are available because of multiple boundary crossings along the spacecraft orbit. Data are taken from the year 2006 for the reason of high quality in data calibration.

3.4 Saturn

Cassini 1-Hz fluxgate magnetometer data (Dougherty et al., 2004) are available in the Planetary Data System (PDS). Interval list is obtained from the Cassini trajectory plotting tool (provided by the Department of Physics at the University of Iowa) to maintain that the spacecraft is outside the magnetosphere and is list of intervals used in the present study is given in Appendix A6. On some days in January, February, and October 2005, Cassini crosses the Saturn magnetopause at the stand-off distance between 22 Rs and 27 Rs (Achilleos et al., 2008). Time interval is set to 35 minutes. After these periods, no magnetosheath data are available due to the spacecraft maneuver.

3.5 Mars

Mars Global Surveyor magnetic field data are obtained from Magnetometer/Electron Reflec-tometer (MAG/ER) investigation (Acuña et al., 1992; Acuña et al., 1998), available in PDS. Spacecraft orbits during the aerobraking phase (September 1997 - November 1998) have a good coverage in magnetosheath (Espley et al., 2004); Apoapsis decreases from about 54000 km altitude down to about 450 km (cf. Mars planetary radius is about 3400 km). The dayside ionopause/magnetopause is located at about 1.3 planetary radii from the center (i.e., about 1000 km altitude from the surface); the bow shock distance is about 1.7 planetary radii (about 2000 km altitude). The observation period around the end of the first part of aerobraking phase (day 147-199, 1998; or May 27 - July 18, 1998) is most suitable for D3.2 for two reasons: (1) The observation time is closest to the solar maximum in 2000; (2) Magnetic field data are available along the spacecraft trajectories, not only in the magnetosheath but also in the planetary magnetosphere and in the solar wind, necessary for unambiguous identification of magnetosheath. Mars Global Surveyor 3-second averaged fluxgate magnetometer data (Acuña et al., 1992) are used from the Planetary Data System (PDS). Interval list is obtained from Luhmann (2002) (Appendix A8) and the time interval is set to 25 minutes. Mars Global Surveyor measures the Mars atmosphere in situ in nearly circular polar orbits with very low altitudes (380 km from the surface). No Mars magnetosheath data are available after the mapping phase (after 1999).

3.6 Comet P/Halley

8-second data from Giotto magnetometer (Neubauer et al., 1987) are used (data available in PDS). Interval list is obtained from Glassmeier (1987) (Appendix A7) and time interval is set to 35 minutes during its Halley flyby trajectory.

4. Deliverable: Solar cycle tendencies

4.1 D2MAXMSP

The current catalog has the list of time intervals (Appendix A1.1) and PSD plots (Appendix B1) for the solar maximum (2001-2002) of Earth magnetosheath region. Here the superposed power spectral density for solar maximum is shown in Fig. 4.1 for the sake of convenient and better visualization. The complete list of intervals and PSD plots are given in the appendix that is available on-line at http://www.storm-fp7.eu

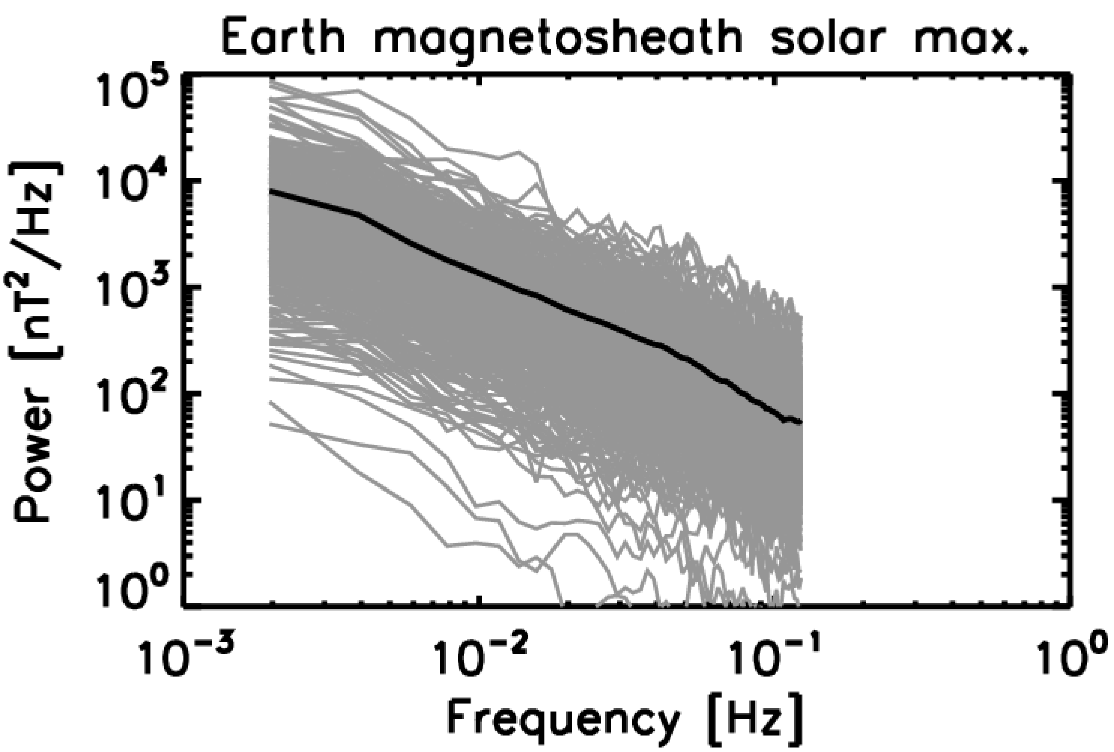

Figure 4.1: Superposed power spectral density for 381 events in Earth magnetosheath for solar maximum (2001-2002). The spectral slope is approximately -1, which is flatter than -5/3. The complete time interval list which is used for the superposed PSD is given in the Appendix B1.

4.2 D4MINMSP

This catalog includes the complete list of time intervals (Appendix A 2.1) and PSD plots (Appendix B 2.1) in Earth magnetosheath for solar minimum (2007-2008). For having better physical insight and comparison with other planets the complete time interval list (Appendix A 2.2) and PSD plots (Appendix B2.2) for solar minimum (2006-2009) in the Venus magnetosheath are also included in this catalog. Here for the sake of completeness the superposed power spectral density in the Earth magnetosheath and Venus magnetosheath are shown in Fig. 4.2.1 and Fig. 4.2.2:

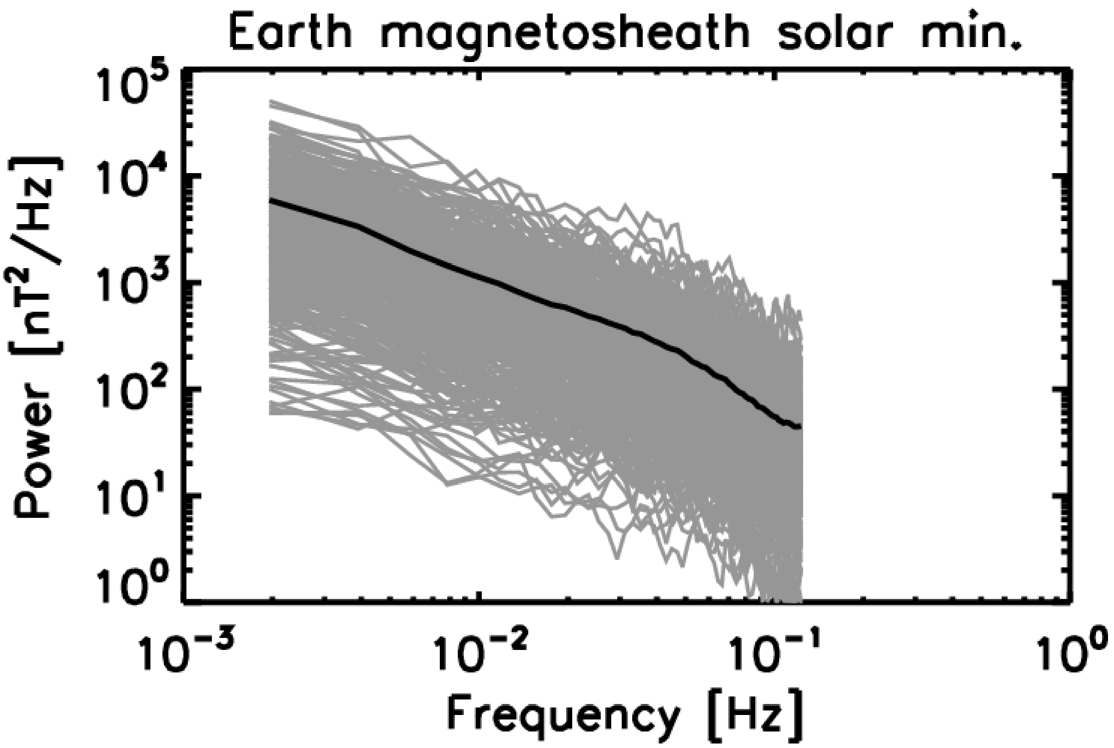

Figure 4.2.1: Superposed power spectral density for 337 events in the Earth magnetosheath for solar minimum (2007-2008). The spectral slope is approximately -1, which is flatter than -5/3. The complete time interval list which is used for the superposed PSD is given in the Appendix A2.1.

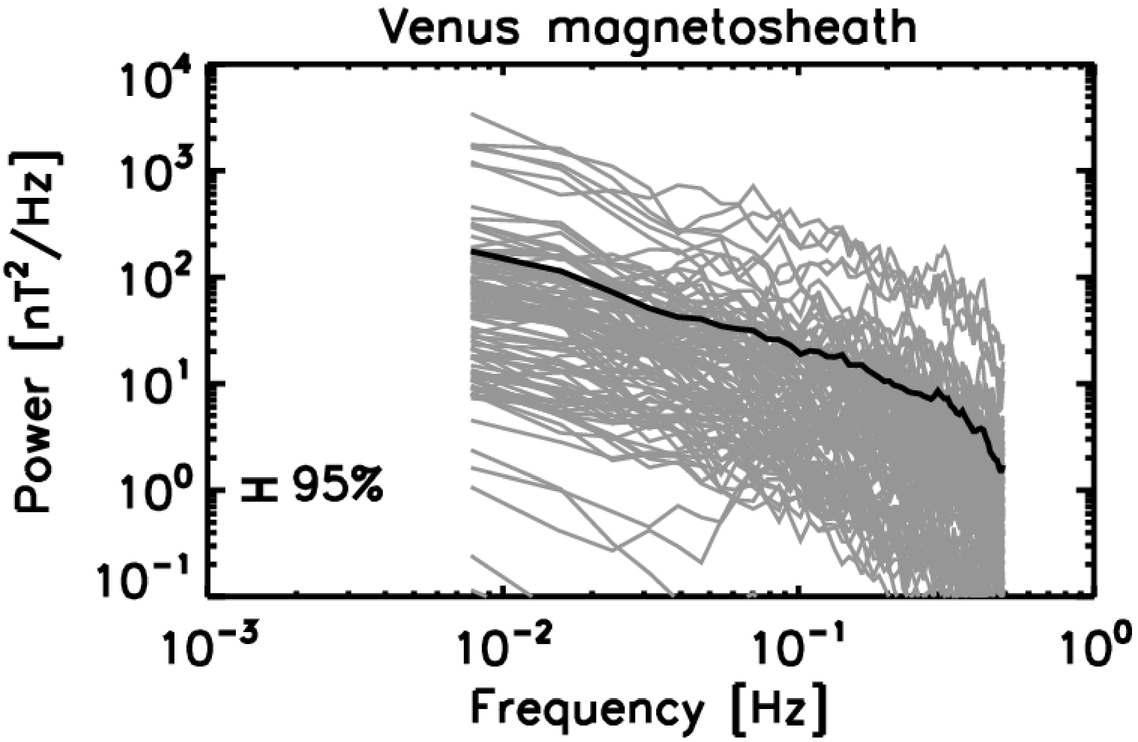

Figure 4.2.2: Superposed power spectral density for 106 events in the Venus magnetosheath for solar minimum (2006-2008). The spectral slope is approximately -1, which is flatter than -5/3. The complete time interval list which is used for the superposed PSD is given in the Appendix A2.2.

4.3 Planets and comet

The present catalog consists of the time interval lists (A 2.3, A 2.4 and A 2.5) of different planets and comet respectively. The superposed power spectral density plots are shown in Fig. 4.3.1, Fig. 4.3.2 and Fig 4.3.3:

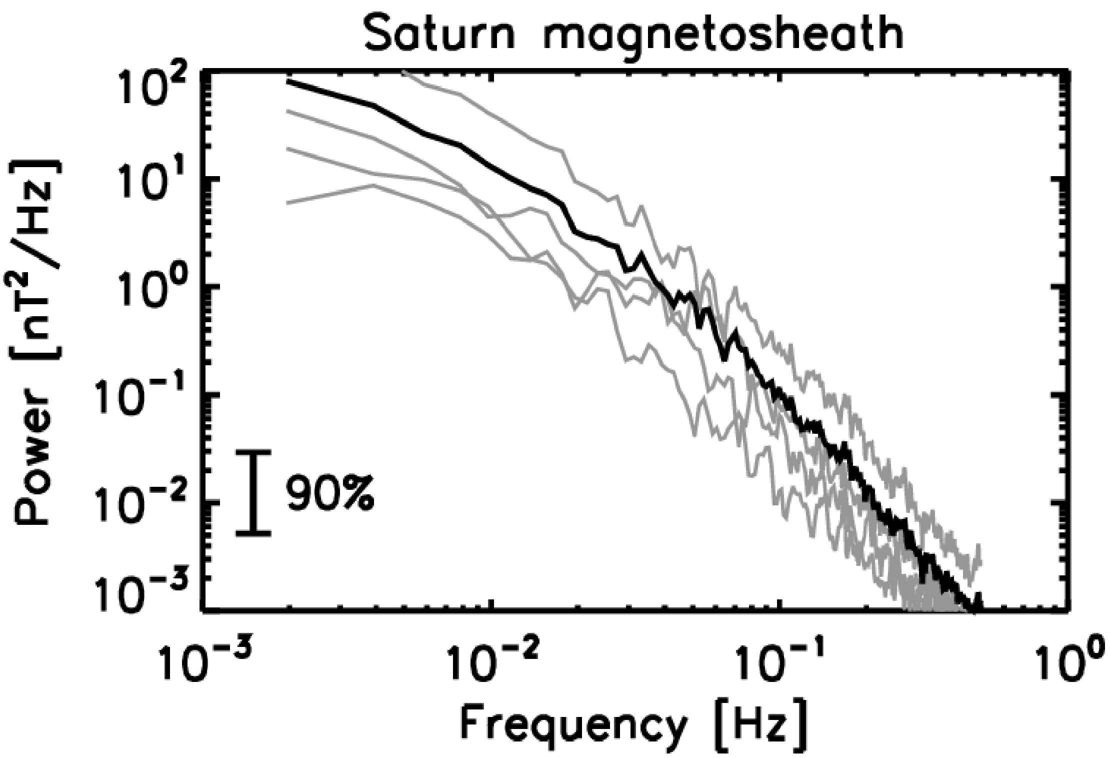

Figure 4.3.1: Superposed powers spectral density for 4 events in the Saturn magnetosheath.

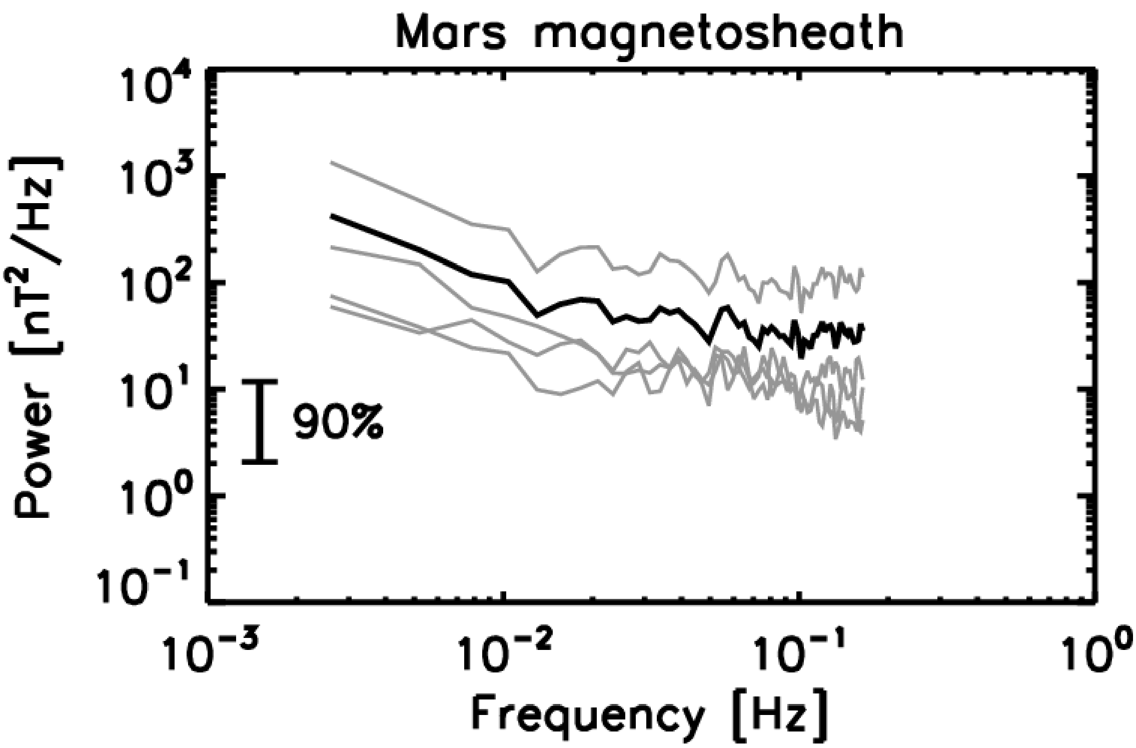

Figure 4.3.2: Superposed powers spectral density for 4-events in the Mars magnetosheath.

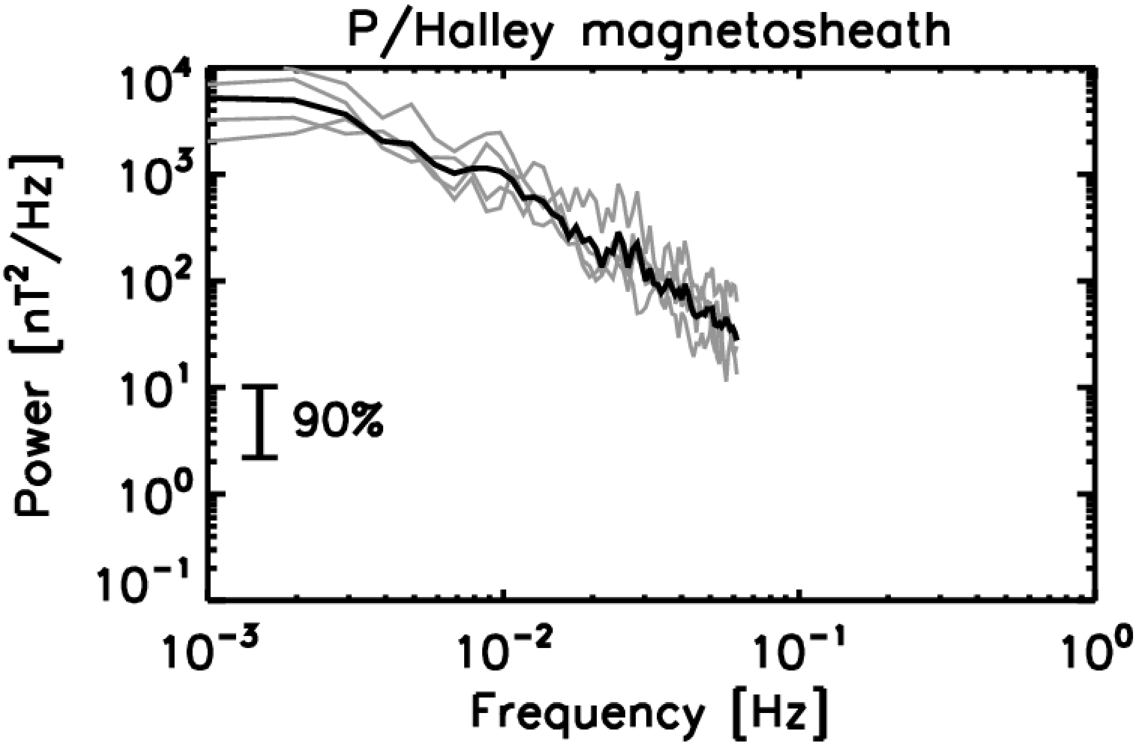

Figure 4.3.3: Superposed powers spectral density for 5 events in the magnetosheath of the Comet P/Halley.

4.4 Earth magnetosphere

This catalog has the time interval lists (A 1.2, A 1.3 and A1.4) and PSD plots from the data obtained in different regions of the Earth magnetosphere like LLBL/cups (2001 – 2003), Lobe (2002) and Plasma sheet (2002) respectively. To have a real flavour and comparison of the variation in the tendency of powers spectral density in the different regions (as mentioned above) of the Earth magnetosphere all the PSD plots in these magnetosphere regions are plotted in a single figure which is illustrated in Fig. 4.4:

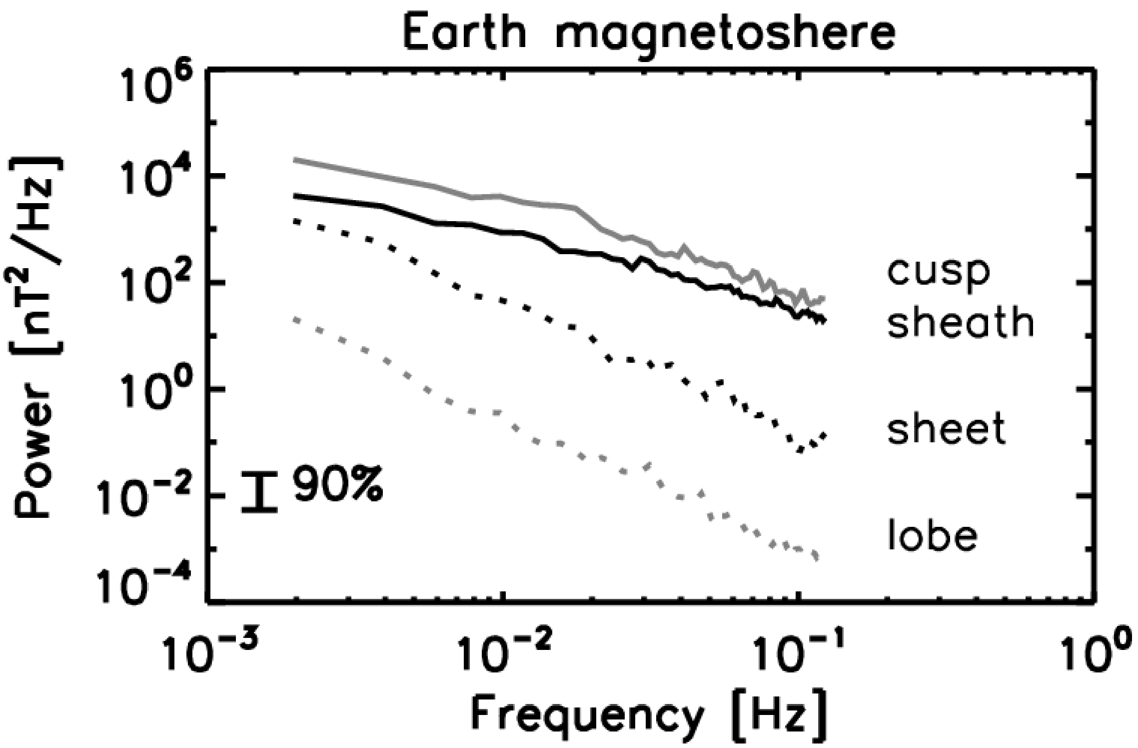

Figure 4.4: The powers spectral density of 5 events in the Earth magnetosphere.

All the data and catalogs reported in this document are stored on the website of the project as an ftp repository at ftp://ftp-ae.oma.be and are password protected. The password is available by request from the project coordinator (marius.echim@oma.be).

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Block Diagram of Catalog D3.1