Space Physics
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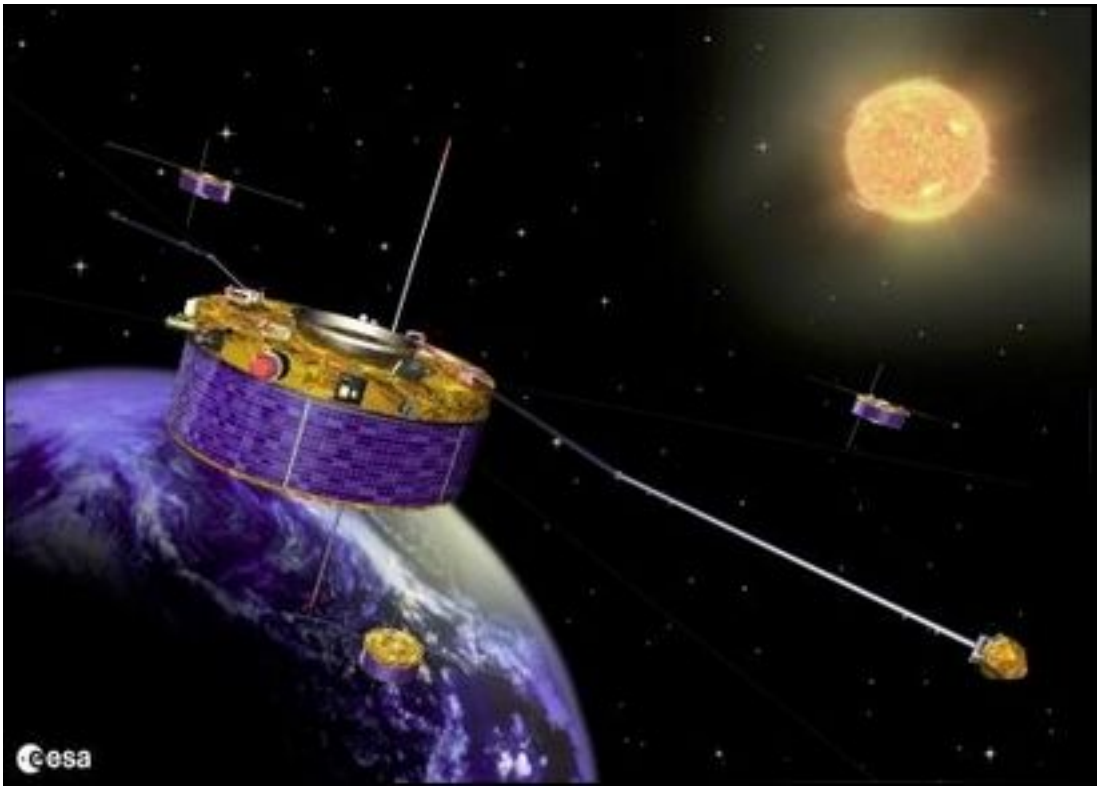
2012-05-13

PRACTICAL 2B
Data analysis



Artist's impression of the four Cluster spacecraft, flying in tetrahedron formation. Picture: ESA

GENERAL INSTRUCTIONS

In this practical you will familiarize yourself with scientific spacecraft data. You will use data both from field and wave instruments and from a particle instrument. Data files and Matlab functions are found on http://www.irf.se/~gabriella/. A short explanation of power spectral densities and hodograms is also found there.

The practical should be summarized in a written report. The report should contain answers to the numbered tasks below, together with a discussion when needed. Put effort into including figures that present your results in a clear way. Try to write as concise as possible.

FIELD MEASUREMENTS

Introduction

In this part of the practical we will analyse waves observed by electric and magnetic field instruments in space. We will look at 50 seconds of data recorded on the 2nd of March 2002, 03:29:10-03:30:00 by the Cluster spacecraft (http://sci.esa.int/cluster).

An overview of the Cluster data can be found at
http://www.cluster.rl.ac.uk/csdsweb-cgi/csdsweb_pick

1. Change date and time to look at the selected event. Where in the magnetosphere are the observations made? Motivate you answer!

Data

The time series data is found in the file E_B.mat, which can be directly loaded into Matlab.The file contains two variables:

EFW_t_gse and **FGM_STAFF_t_gse_RS**

EFW_t_gse contains time (first column) and the two measured components of the electric field (x_{GSE} and y_{GSE}) in mV/m.

FGM_STAFF_t_gse_RS contains time (first column), and three magnetic field components (x_{GSE}, y_{GSE} and z_{GSE}) from the instruments FGM and STAFF. FGM measures the static and low-frequency part of the magnetic field and STAFF measures the wave field. All components have the unit nT.

The start time in both files is: 2002-03-02, 03:29:10.00211 and the coordinate system is GSE (Geocentric Solar Equatorial). Hence, *x* points towards the sun, *z* in the direction of the ecliptic pole (northward) and *y* completes the right-handed system.
The spin period of the spacecraft is 4 seconds.

Time series data

If time series data is available you should always start by looking at this before processing.

2. Plot the time series (all components) from the three instruments. Can you identify any waves? What type of waves are we looking at: Electrostatic or electromagnetic? Is there a need to correct the data somehow? If so, why and how do you do that?

3. Estimate the frequency of the waves by looking at the times series only. Describe how you do. What is you result?

4. Compute the fundamental frequencies (electron and proton gyrofrequencies and the electron plasma frequency) in the plasma. The background magnetic field you have in the data. The density can be found from the overview data. However, the ion density is usually underestimated. Therefore, it is a good idea to compare with the high frequency emissions obtained by the WHISPER instrument. In the WHISPER data you can indentify the electron plasma frequency directly, as a thin horizontal line visible most of the time. What density does the WHISPER signal correspond to? Compare the wave frequency with the fundamental frequencies. What are you conclusions?

Spectrograms and power spectral densities
To get a better overview of the frequency content in a signal we compute the power spectral density (PSD). See PSD_Hodogram.pdf, pages 24-25.

5. Compute the PSD of the electric and magnetic wave fields for the entire time period. If you want you can use the Matlab-function **PSDvsFREQ()**. Compare with your results obtained in 2 and 3.
Also, investigate the how the error changes when you sum over fewer records. If you want you can use the errorbar() function to visualize this. Which are your conclusions?

6. Look at (=make PSDs for) two different frequency ranges: 0-225 Hz and 0-2 Hz. You should aim at good statistics so the frequency resolution should be different in the two plots. The frequency resolution is given by $\Delta f=1/N\Delta t$, where Δt is the time between two samples and N is the record length used in the Fourier transform. For each of the plots: provide all the information about the PSD you present: The length of the record, the shift between records and the total number of records used.

7. Plot spectrograms (=PSD versus time and frequency) of both the electric and magnetic fields. You can do this by using the Matlab function **means()** and ignoring the wave vector output. Try different resolutions in time and frequency. In your report include both spectrograms with high frequency resolution and spectrograms with high time resolution. Which ones do best describe the waves you observed? Provide all the parameters describing your spectrograms (record lengths, shifts, total number of spectra, etc.)

The magnetic field coordinate system and the third electric field component
To analyse the waves further we need to transform the observations to a coordinate system determined by the local background magnetic field, $\mathbf{B_0}$.That is, we want to have one of the components along the background field and the other two in the plane perpendicular to $\mathbf{B_0}$. For the magnetic wave field with three components this is straightforward. The function **OBsystem()** does that. You can use it to do the transformation, but make sure you understand how it works first. The observed electric field has only two components and can, therefore, not be transformed directly. (Why?) Fortunately, we can compute the third component if we assume $\mathbf{E}\cdot\mathbf{B_0}=0$. This is often, but not always, a good assumption. The function **thirdE()** computes the third component of the electric field, using this assumption.

8. Now we can produce a so-called hodogram (see PSD_Hodogram.pdf, p 26), which shows how the wave field vector moves in the plane perpendicular to $\mathbf{B_0}$. If the field vector moves in the same direction as a positive ion would gyrate then the wave is left-hand polarized. If the vector rotates in the opposite direction the wave is right-hand polarized. Plot the magnetic field vector in this plane and determine the polarization of the waves. Sometimes it is easier to see the rotation if you normalize the length of the vectors to 1. Do the same with the electric field wave vector.

9 (OPTIONAL) It can be shown that in this case the energy propagates almost anti-parallel to the magnetic field (Stenberg et al., 2005). We can use Means' method to compute the wave vector for the waves. The function **means()** gives the components of the wave vector vkx, vky, vkz. But the method is cannot distinguish between **+k** and **–k**, and in this case we have to switch the direction of the output.
Make two spectrogram type plots: θ versus time and frequency and ϕ versus time and frequency, where θ is the angle between the background magnetic field and the wave vector and ϕ is the angle in the plane perpendicular to $\mathbf{B_0}$. What do you see?

References

Means, J. D., Use of the Three-Dimensional Covariance Matrix in Analyzing the Polarization Properties of Plane Waves, *J. Geophys. Res., 77*, 5551-5559, 1972.

Stenberg, G., Observations of waves in space plasmas, chapter 4, 2002

Stenberg, G., et al., Electron-scale sheets of whistlers close to the magnetopause, Ann*. Geophys., 23,* 3715-3725, 2005.

PARTICLE MEASUREMENTS

Introduction

In the second part of the exercise we will look at particle data from the SWIM instrument onboard the Chandrayaan-1 (http://www.isro.gov.in/chandrayaan/htmls/-home.htm) spacecraft. Chandrayaan-1 orbits the moon at an altitude of 100 km. The position of the spacecraft at different times is shown in the files orbit_1069.png and orbit_1070.png, which also show the position of the moon with respect to Earth.

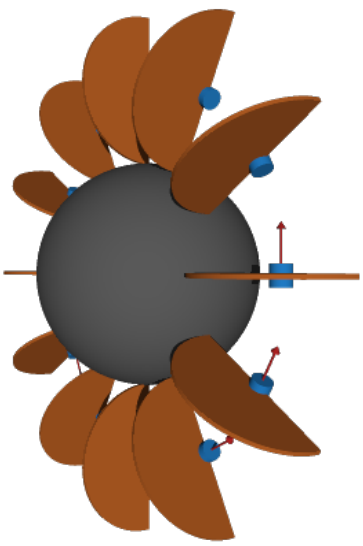


***Figure 1**: The SWIM field of view at different times.*

The SWIM instrument measures in a plane and the orientation of the instrument is such that one of the angular bins points towards the moon (nadir) and another angular bin looks in the zenith direction. All other angular bins look in the plane containing these two directions. Hence, as the spacecraft moves around the moon, the viewing direction of the instrument with respect to sun/solar wind will change (see Figure 1).

Data

The data files orb_1069_swim.csv and orb_1070_swim.csv contains data from two consecutive orbits. The files contain a number of rows. Each row contains the time and the number of counts for each of the 16 energy levels. The data can be read into Matlab with the built-in **textscan()** function.

Spectrograms

1. Plot spectrograms, that is, the number of counts versus time and energy, for the two orbits. The different energy levels you find in a comment line in the data files. Once every orbit SWIM looks at the solar wind. Identify when this happens in the two orbits.

2. Protons are the main ions in the solar wind, but can you identify any other components? Motivate you answer!

Solar wind velocity and temperature

3. Make energy spectra, this is, plot observed counts versus energy for a selected time interval around the solar wind observation.

4. Determine the solar wind proton velocity and temperature by first transforming the data from energy to velocity space and then fitting a Maxwellian distribution. What temperatures and velocities do you get? Are there differences between the orbits? If so, why?

5. How do you determine the velocity of other components in the solar wind? What results do you get?

6. Compare your results with the observations made by one of the spacecrafts ACE or WIND:
http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_SWEPAM.html or
ftp://space.mit.edu/pub/plasma/wind/kp_files/
Note that the ACE/WIND measurements are made far upstream of the spacecraft so you have to compensate for this when you compare.

APPENDIX

Matlab functions for wave analysis

Files:
OBsystem.m
thirdE.m
means.m
PSDvsFREQ.m

<u>THIRDE/OBSYSTEM</u>
[e3]=**thirdE**(b3,e2)
[vOB]=**OBsystem**(v,B0)

Comment: z along a given vector B, y along bxr, with r=(0,0,1)

Examples:
```
[e3comp]=thirdE(FGM4,E4);
E4OB=OBsystem(e3comp,FGM4_LF);
B4OB=OBsystem(FGM4,FGM4_LF);

ex=E4OB(:,2).';
ey=E4OB(:,3).';
ez=E4OB(:,4).';
```

bx=B4OB(:,2).';
by=B4OB(:,3).';
bz=B4OB(:,4).';

<u>PSD VERSUS FREQ</u>
[vpsd,vpsddev,vpsdx,vpsdxdev,vpsdy,vpsdydev,vpsdz,vpsdzdev,vfreqs]=
PSDvsFREQ(bx,by,bz,FSAMP,NK,Kstart,Kshift,N,NG,GW)

Input and output:
INPUT
bx, by, bz: three field components
FSAMP: sampling frequency

NG, N, GW: fft-parameters
NG=length of record
GW=length of centered Gaussian window
NG/N=number of frequency bins to average over;

NK, Kstart, Kshift: Time-parameters
NK=total number of time bins,
Kstart=index where to start computation
Kshift=number of points to shift between computations;

OUTPUT
vpsd, vpsddev: Total power spectral density, standard deviation
vpsdx, vpsdxdev: power spectral density in x-component, standard deviation
vpsdy,vpsdz, vpsdydev, vpsdzdev: same for y- and z-components

Example:
[psdE,psddevE,psdEx,psdExdev,psdEy,psdEydev,psdEz,psdEzdev,Efreqs]=
PSDvsFREQ(ex,ey,ex,25,11,1,512,2048,2048,512);

<u>MEANS</u>
[vpsd,vpsdz,vpsddev,vkx,vky,vkz,vkxs,vkys,vkzs,vttags,vfreqs]=
means(bx, by, bz, FSAMP, NK, Kstart, Kshift, N, NG, GW, ntshift, ntaver);

Input and output:
INPUT
bx, by, bz: three wave B-field components

If the wave vectors should make sense the input components should be in OB-system (magnetic field oriented). The function **OBsystem()** can be used.

FSAMP: sampling frequency [samples/sec]

NG, N, GW: fft-parameters
NG=length of record
GW=length of centered Gaussian window
NG/N=number of frequency bins to average over;

ntshift, ntsvar: time-averaging parameters
ntaver=number of fft-records to average over
ntshift=number of points to shift for each new record;

NK, Kstart, Kshift: global time-parameters
NK=total number of time bins,
Kstart=index where to start computation
Kshift=number of points to shift for each new time bin;

OUTPUT
vpsd,vpsdz,vpsddev: Total power spectral density, PSD in the bz-component, standard deviation in total PSD computation
vkx,vky,vkz,vkxs,vkys,vkzs: The wave vector components and their standard deviations.

Examples:
[tfpsdB, tfpsdEB,tfpsdBdev,vkx,vky,vkz,vkxs,vkys,vkzs,Bttags,tffreqsB]=**means**(bx, by, bz, 25, 112, 1, 512, 1024, 1024, 256, 256, 5);