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Space Physics
Practical 2
Data Analysis

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June 17th, 2011
Revision 1

SpaceMaster

Field Measurements

This part of the report consists in the analysis of data belonging to waves observed by electric and magnetic field instruments in space. The period of interest is data recorded on March 2nd, 2002 from 03:29:10 to 03:30:00 UT. The instruments used to obtain the date are:

- EFW: Measures the components of the electric field (x_{GSE} and y_{GSE}) in mV/m.
- FGM: Measures the static and the low-frequency part of the magnetic field in nT.
- STAFF: Measures the wave field in nT.

1. *Where in the magnetosphere are the observations made? Motivate you answer!*

The observations were made close to the magnetopause when the spacecraft is moving from inside the magnetosphere to outside of it. Figure 1 shows the location the spacecraft in the time period between 00:00 and 06:00 UT. Reviewing the data on figure 2, it is possible to see that around 03:30, there is a drastic change in the data recorded by the different instruments. There is an increase in the ion speed which now is more stable, also the electric field increases; there are increments in the ion and electron energies and the electric and magnetic frequencies increases too. All these increments lead us to believe that the spacecraft is on a transition zone been this zone and the magnetopause.

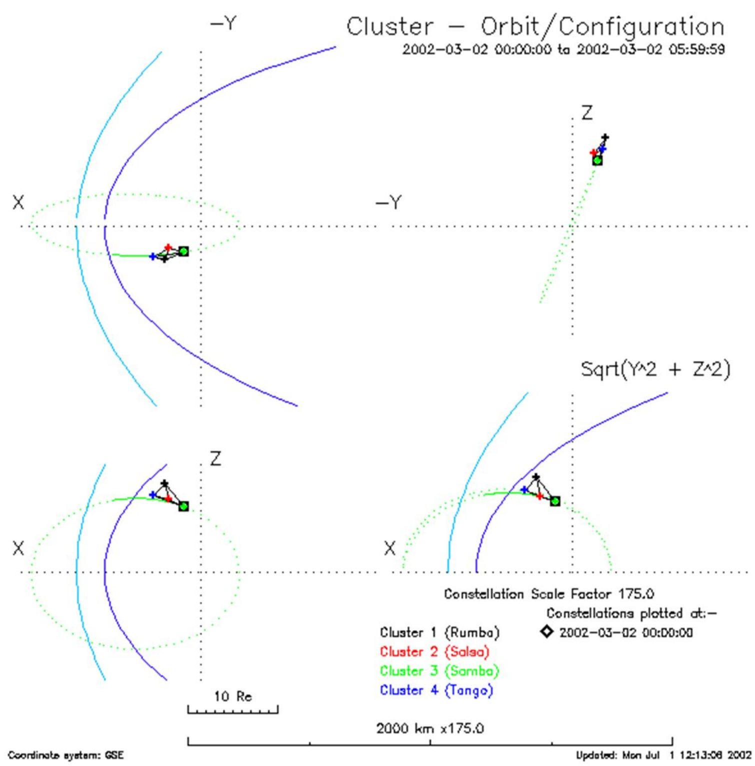

Figure 1 – Orbit location of the Cluster spacecraft

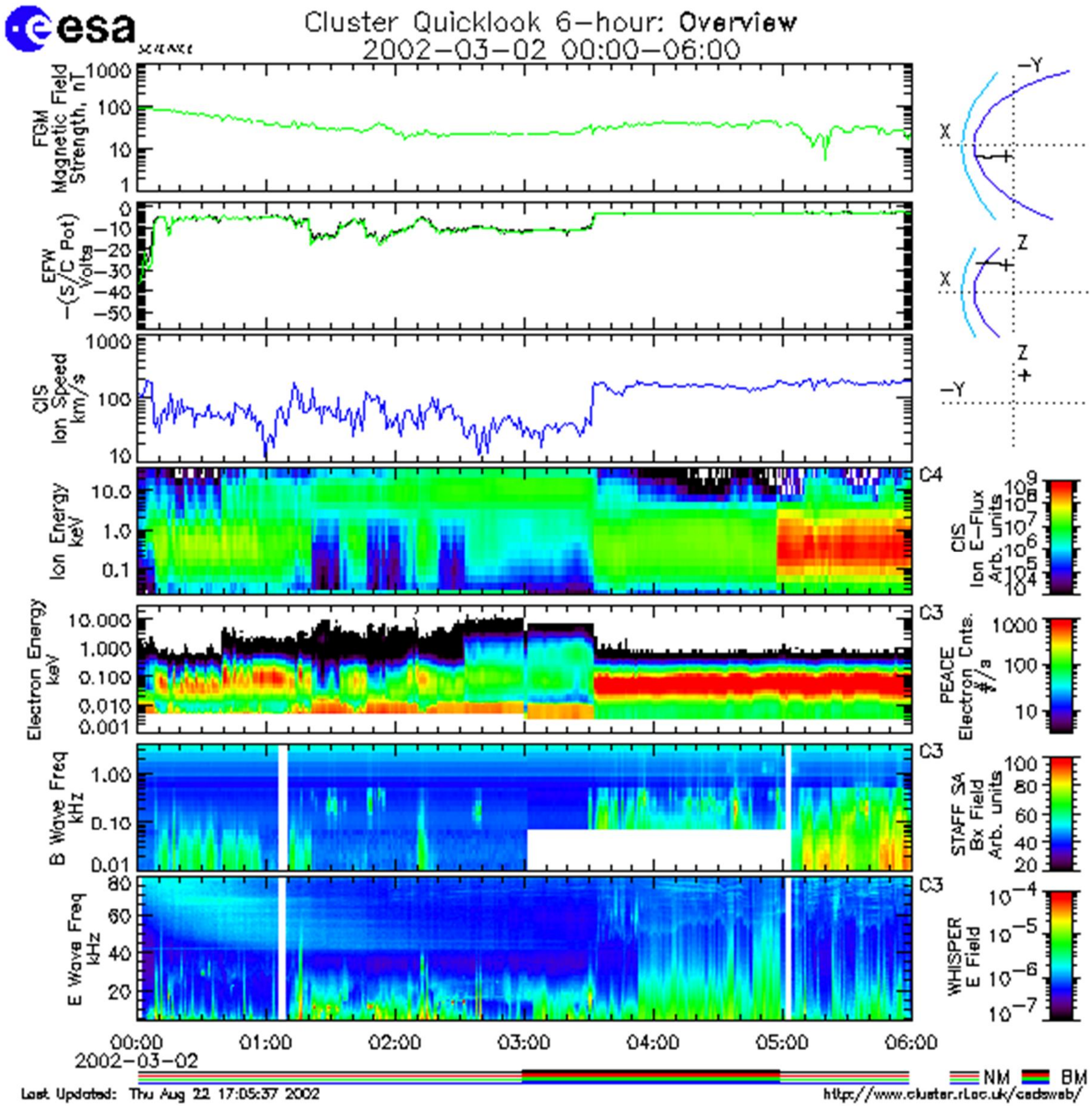

Figure 2 – Electric and magnetic data observed by the Cluster spacecraft

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?*

By looking at the plots we can identify a wave. This was an electromagnetic wave. The electromagnetic wave is the one occurring between the seconds 20 and 30. This wave could be considered an electromagnetic wave because there are fluctuations in both the electric and magnetic fields (figures 3 and 5). There is fluctuations between seconds 55 and 60 which could be either an electrostatic

wave or an interference cause by other instruments on the spacecraft. To judge correctly looking at the time series only is not enough. We can recognize the interference by looking at the spectrogram of the electric field which is discussed later.
There are usually two expected effects that cause an unphysical signature on instruments measurements. These effects are common on double probe measurement on a spinning spacecraft. One of these effects is caused by the rotation of the spacecraft that causes an oscillation component of half the period of rotation of the spacecraft. The second effect is caused by the unbalance reception of sunlight on the two probes given that both probes are not receiving the same photon flux at the same time. The unphysical signature in the given data is evident because of the persistent oscillation with a constant frequency thru the measurements.
Since these oscillations are not occurring naturally, we need to remove the frequency component. In order to do this and given that the frequency is known by means of signal processing we can remove the harmonics occurring at this frequency therefore having corrected data. Another method could be despunning (3) which consists on removing the effects caused by the spinning of the spacecraft however in order to use this method a good and accurate model of the spacecraft rotation and mass distribution of the spacecraft is required. We can also see a dc shift in the x-component of E. This can be corrected by taking the mean value and then subtracting from the X-component of the electric field.

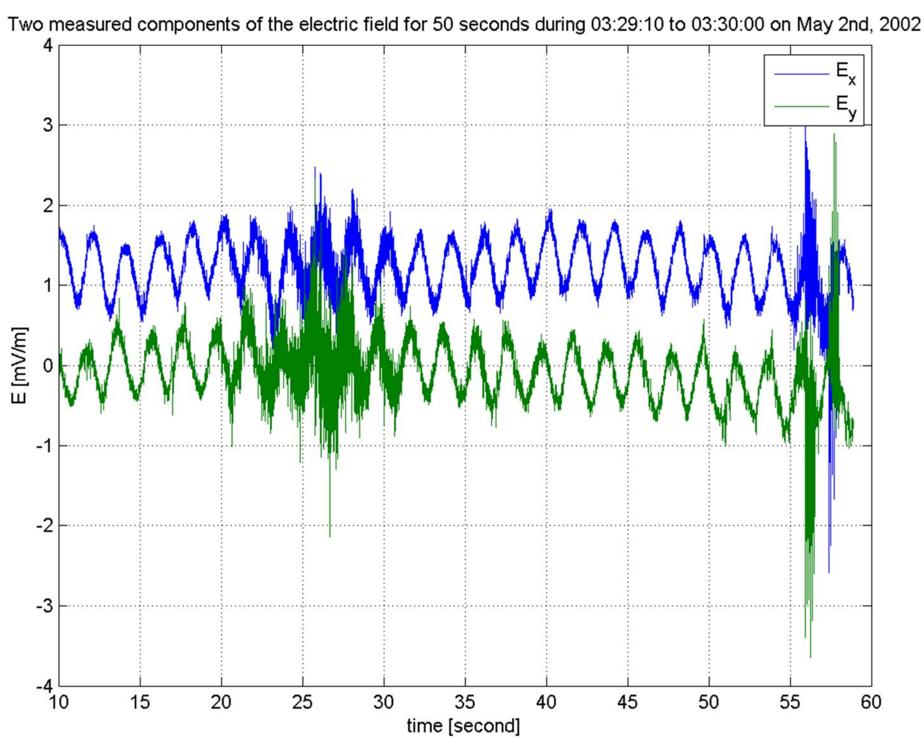

Figure 3 – Electric field measured by the EFW

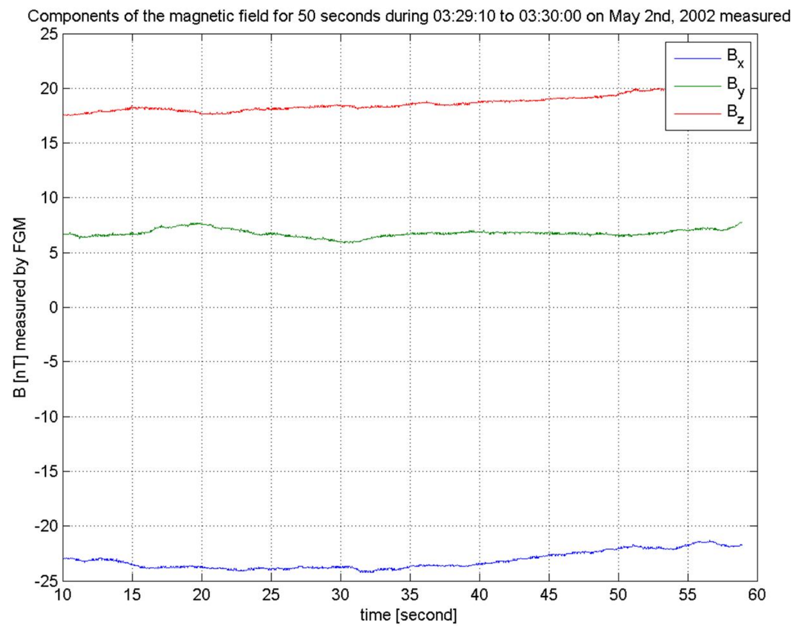

Figure 4 – Magnetic field (static and low-frequency) measured by the FGM

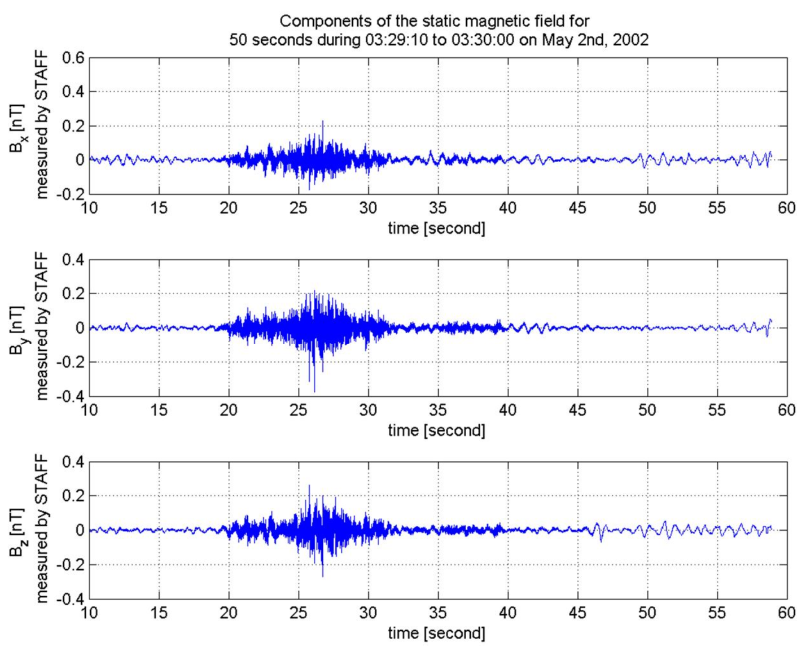

Figure 5 – Magnetic field (wave field) measured by the STAFF

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

The estimated frequency by means of a rough estimation is 115 Hz. We found this value by taking the average of 10 oscillations peaks and knowing this period we were able to estimate the frequency.

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 identify 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?*

The estimated fundamental frequencies before transition are the following:

- Minimum Electron gyrofrequency: 0.82 kHz
- Maximum Electron gyrofrequency: 0.88 kHz
- Minimum Proton gyrofrquency: 0.45 Hz
- Maximum Proton gyrofrquency: 0.48 Hz
- Electron Plasma frequency: 12.7 kHz (considering a density of 2 cm^{-3})

To calculate the gyrofrequencies values we look for the maximum and minimum magnitude of the magnetic field components on the 50 seconds period measured by the FGM, since this was the only varying parameter we were able to estimate maximum and minimum gyrofrequencies.
To calculate the electron plasma frequency we needed the electron density, this data was obtained from the plots on figure 6. As it was already mentioned the spacecraft is on a transition area and because of this we can see on the plots how around 03:30 there is a drastic change on the electron density (electron density is the third plot from top to bottom). We know that the measurements were made before this transition therefore we estimated from this plot an electron density of 15 cm^{-3}, once having the data we were able to calculate the electron plasma frequencies.
By looking the plot of the WHISPER instrument we estimated a frequency around 16 kHz, using this frequency value we were able to estimate a density of approximately 3.2 electrons/cm^3.
By comparing the wave frequency with the fundamental frequencies we found that the wave frequency is smaller than the fundamental frequencies. We can conclude based on our interpretations is that the wave properties depends on the plasma fundamental frequencies, all this components summed together cause the fundamental elements and frequencies to have the behavior they have.

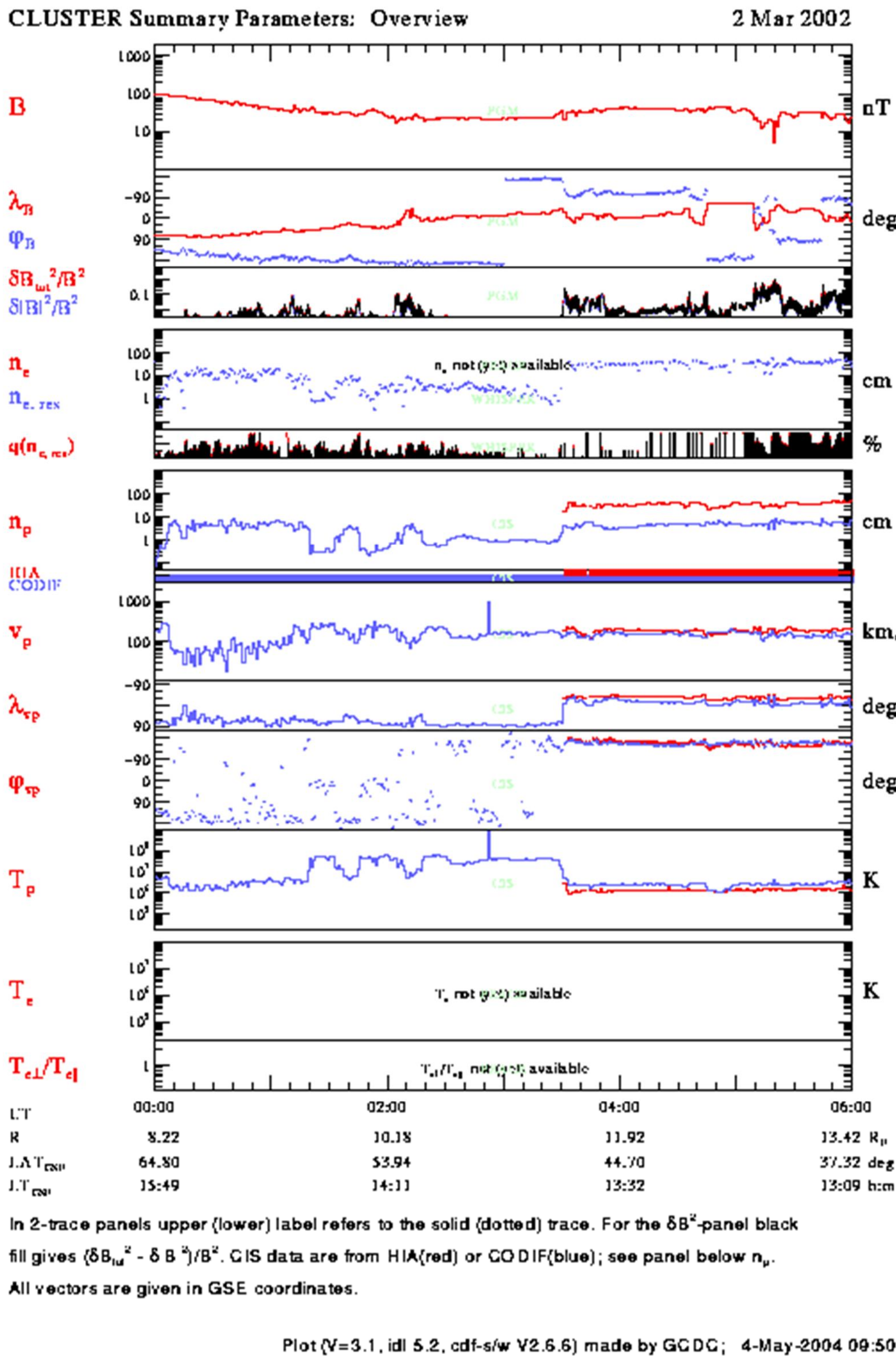

Figure 6 – Measurements taken by the Cluster spacecraft.

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. Change the resolution of the PSD to clearly resolve the frequencies you found in 2. The frequency resolution is given by Δf=1/NΔt, where Δt is the time between two samples and N is the record length used in the Fourier transform.*

As it can be seen from figures 7 and 8 the peaks occurs around 100 and 120 hertz which correspond to the frequency estimated on question 3 which were for 120 hertz.

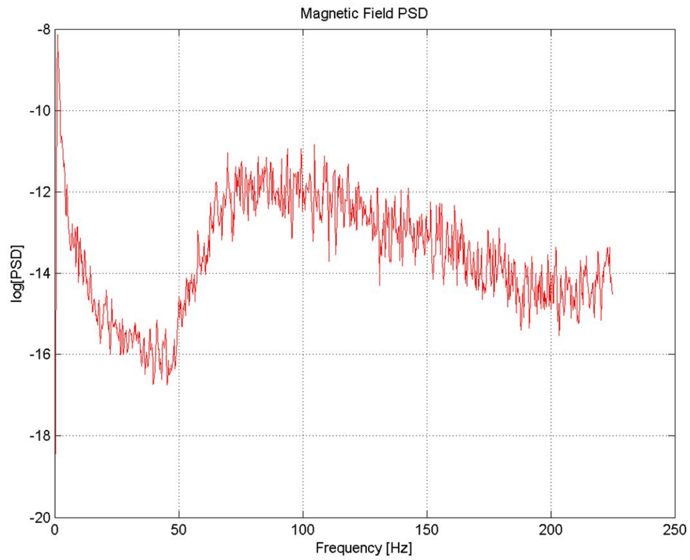

Figure 7 – Power Spectral Density of the magnetic field.

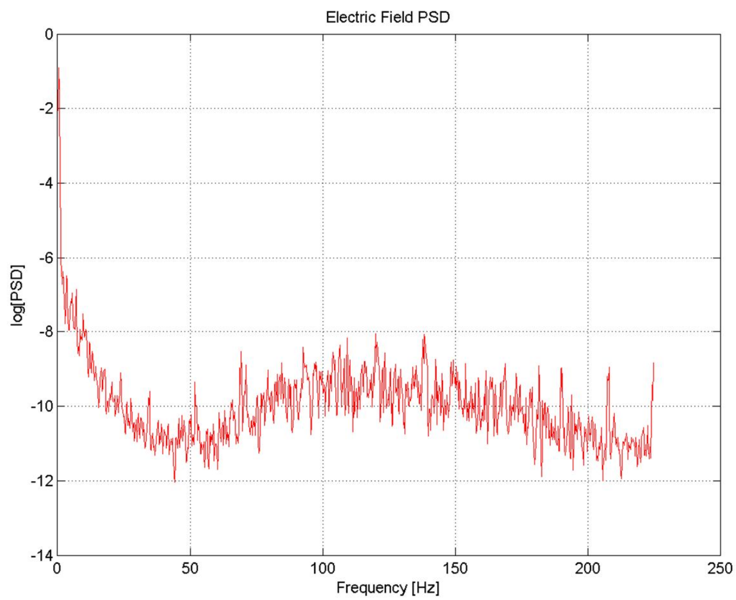

Figure 8 – Power Spectral Density of the electric field.

6. *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. What are you conclusions?*

In order to take be able to make the spectrograms we need to take the background magnetic field as the reference and transform the data to this system which is the OB system. This way, we have one component along the background field and the other two perpendicular to this line.
Looking at the spectrograms we can see an increase on the spectral density at around seconds 25 and 30 (UT – 15 or 20 seconds since start to measurement) at almost all frequencies. The intensity at the lower frequencies could be caused by the change of the magnetic field direction at the reconnection point.

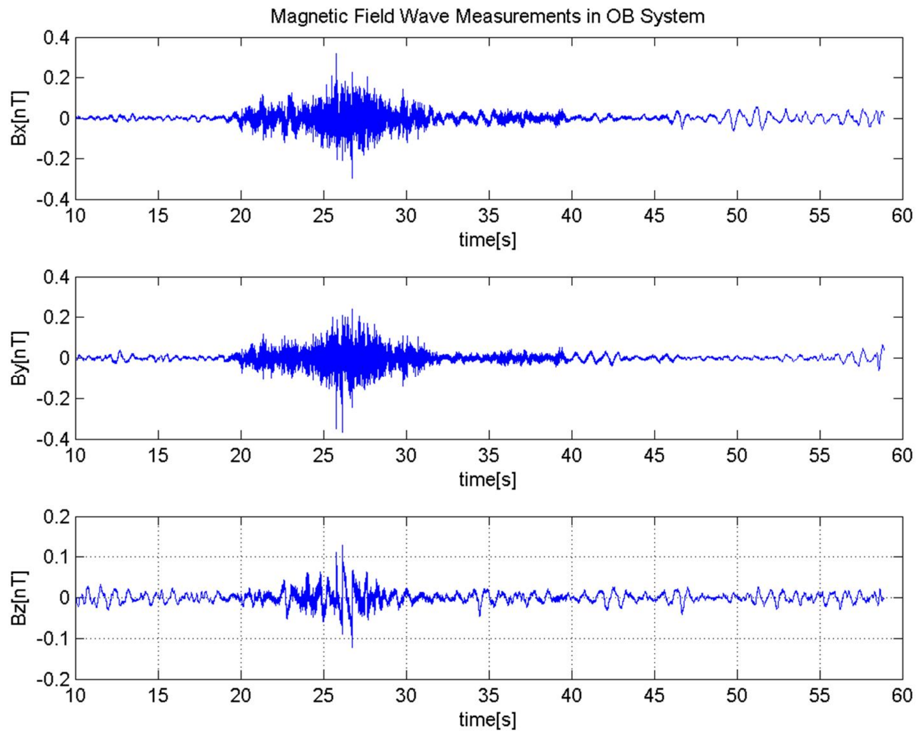

Figure 9 – Time series of the Magnetic Field components on the OB System

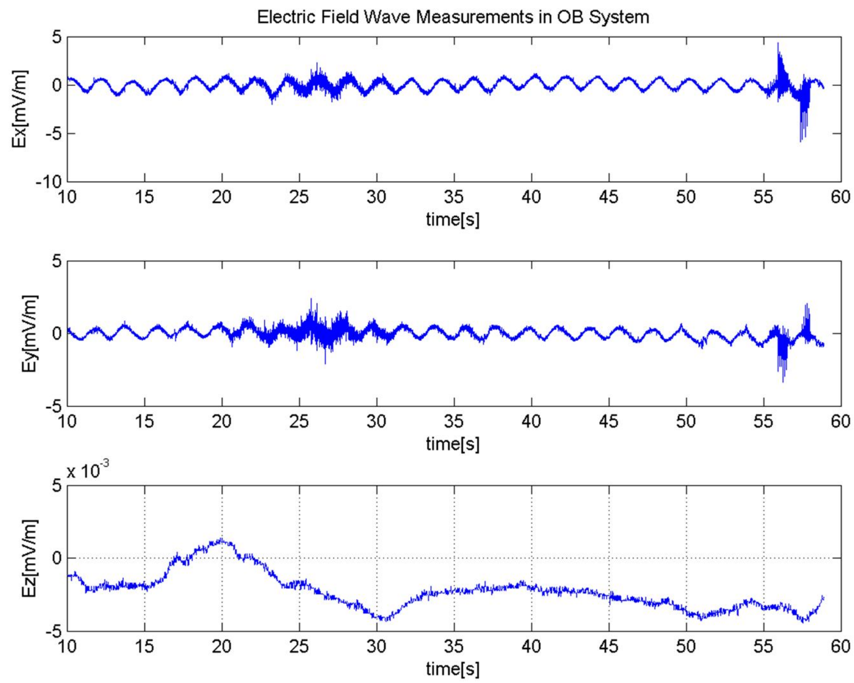

Figure 10 – Time series of the Electric Field components on the OB System

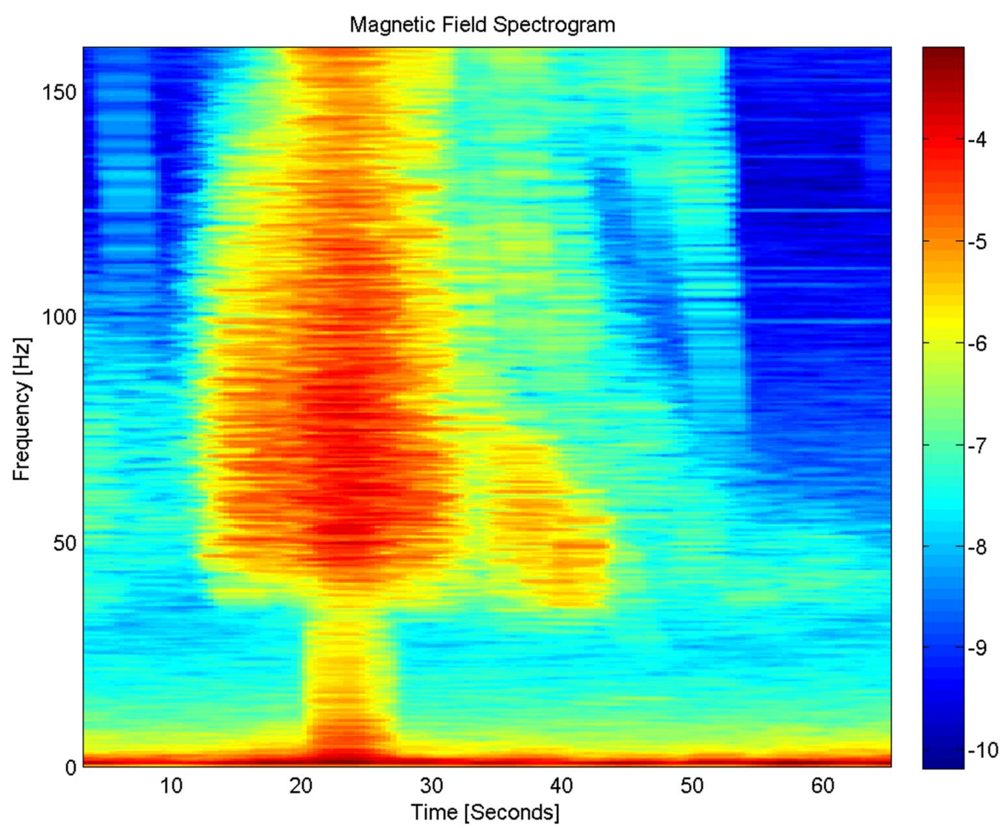

Figure 11 – Spectrogram of the Magnetic Field.

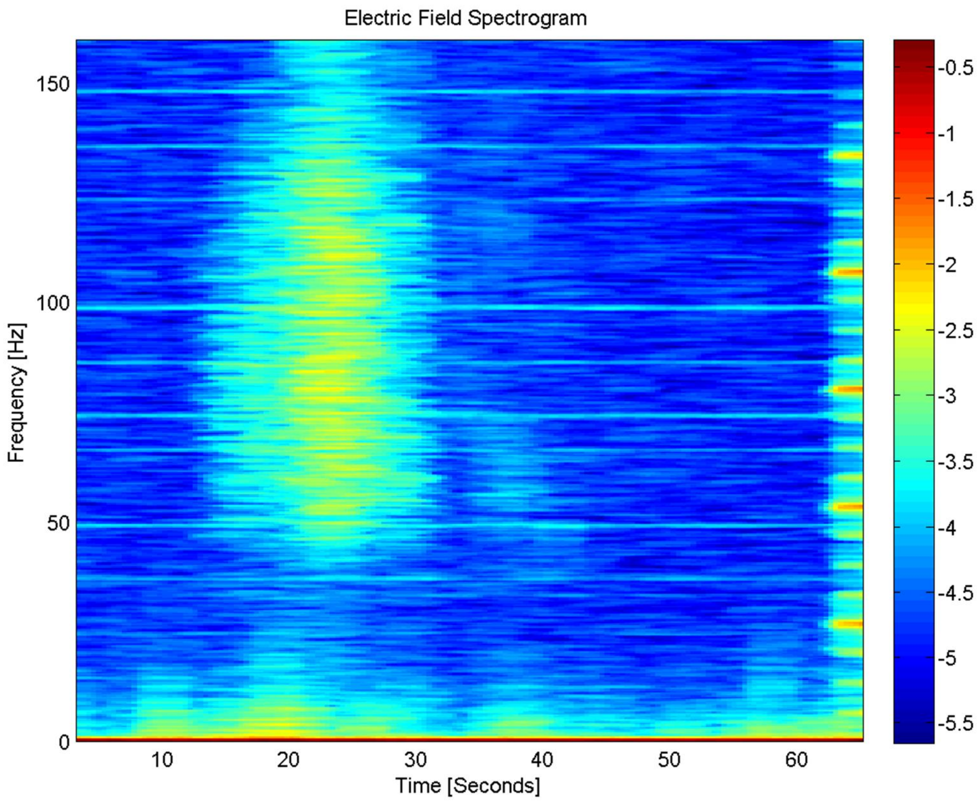

Figure 12 – Spectrogram of the Electric Field.

7. *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 **B0**. 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 righthand 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.*

In order to see the direction of the field vectors we colored a certain amount of samples to see were it started and to where it was moving, it started with red, then green and finally blue. It can be seen in that the rotation is counter-clockwise (right movement) in the Hodogram of the Magnetic Field and with this we can know the polarization of the field vector which would be right-hand polarized and the hodogram of the electric field shows no polarization.

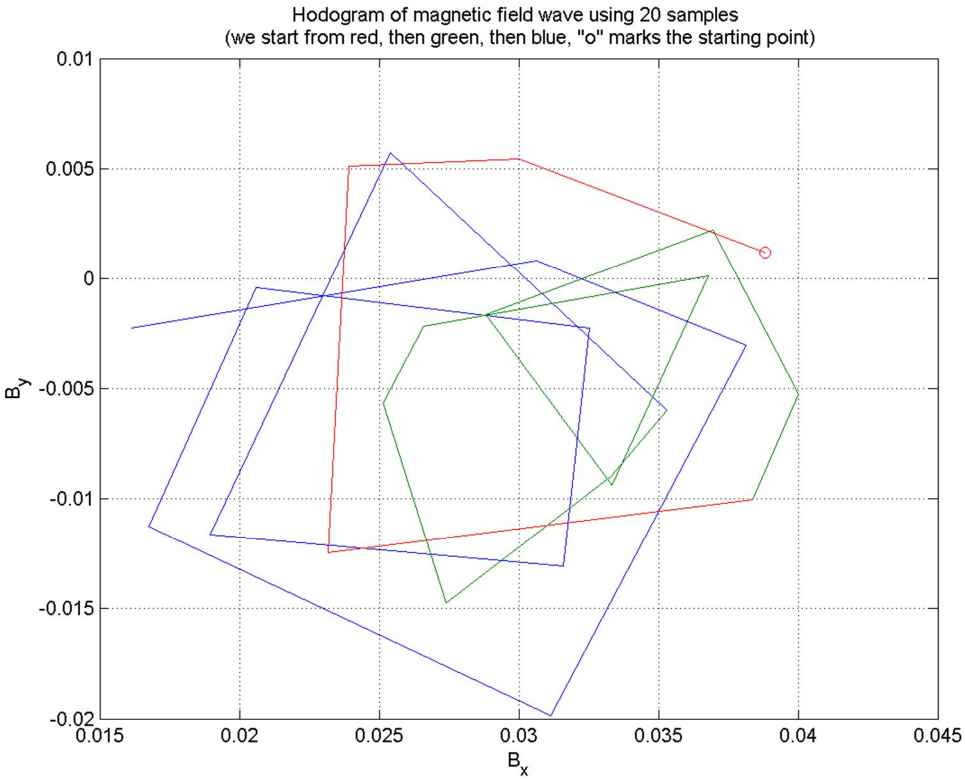

Figure 13 – Hodogram of the Magnetic Field.

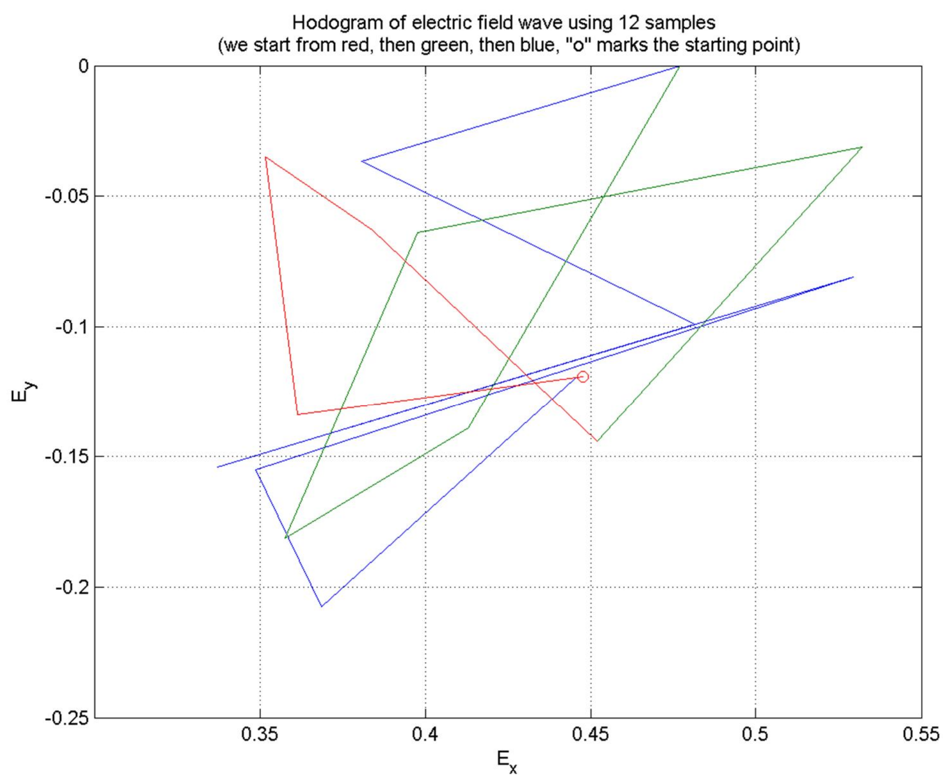

Figure 14 – Hodogram of the Electric Field.

Particle Measurements

This part of the report consists in the analysis of particle from the SWIM instrument on board the Chandrayan-1. This spacecraft orbits the moon at an altitude of 100 km.

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.*

The SWIM instrument see the solar wind once every orbit, this occurred between the minutes 20 and 40 for orbit 1069 and minutes 5 and 25 for orbit 1070. The times are defined according to the period of the instrument. We know that the instrument is looking at the solar wind because of the high energy count.

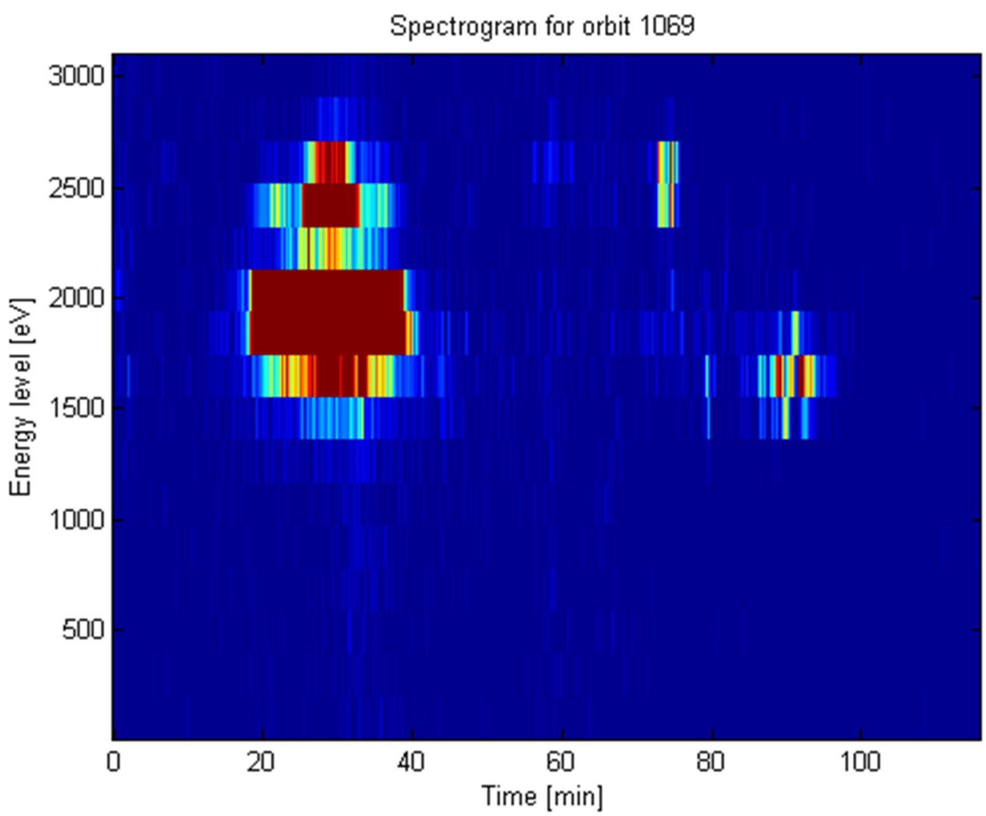

Figure 15 – Spectrogram for orbit 1069.

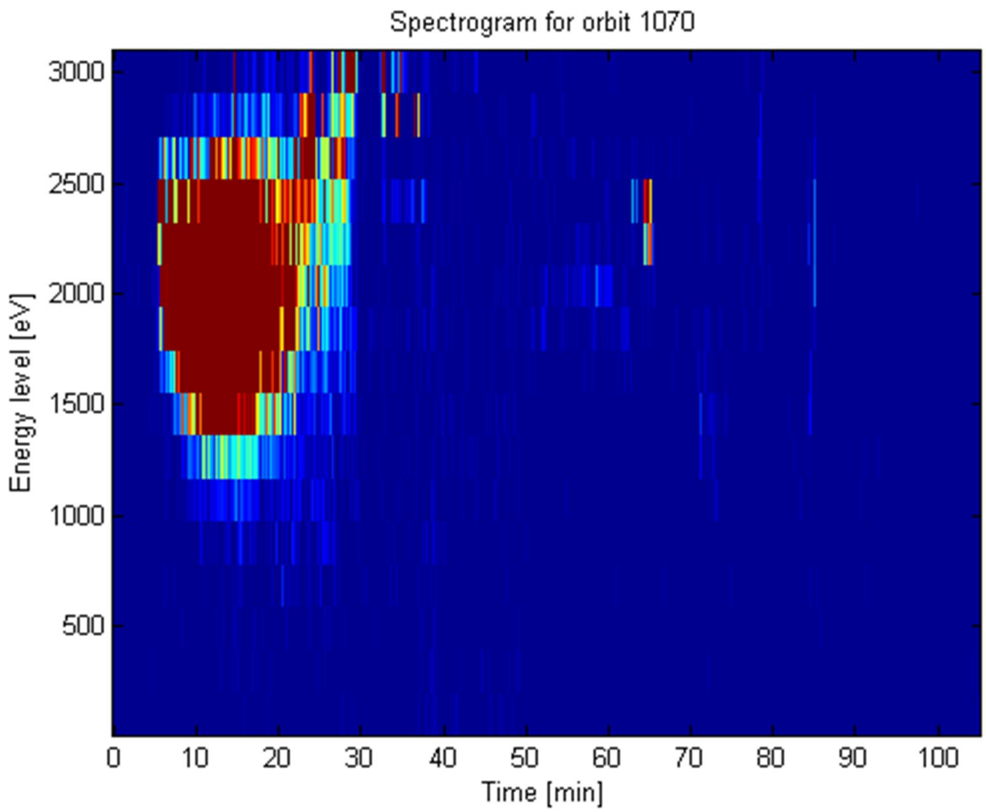

Figure 16 – Spectrogram for orbit 1070.

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

Looking at the spectrogram for orbit 1069 we can see two red areas, one are is of higher energy than the other area, this might lead to suggest that there are two different components. The bigger area is formed by the protons since these are the main ions in the solar wind. The second and smaller area, which is of a higher energy, could be Helium ions. We are making this assumption since Helium ions are the second most common element coming out of the solar wind. The confirmation of the elements that form this solar wind could be obtained with measurements using a mass analyzer. The reason Helium ions have more energy is because of the following. All the elements of the solar wind move with the same velocity given that the mass of Helium is bigger than the mass of a proton (4 times bigger) the amount of energy of both elements will depend entirely of the mass of the particles. Therefore the energy of the ions could up to 4 times bigger than the energy of the protons.

Looking at the spectrogram for orbit 1070 we see one big red area which encompasses the same energy levels than the tow observed on the orbit 1069. Given that the covered area is approximately the same and considering there is not a difference in the composition of the solar wind in the time lapse of 2 hours between the measurements; it is assumed that during orbit 1070 there are still protons and Helium ions on the area and the solar wind is formed by them.

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

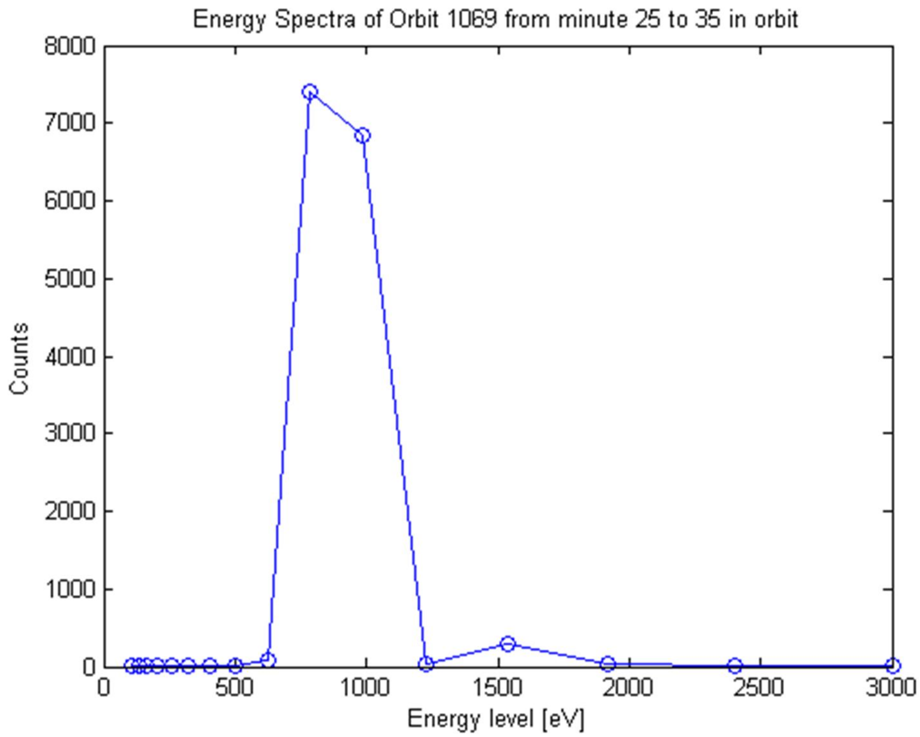

Figure 17 – Energy Spectra for orbit 1069.

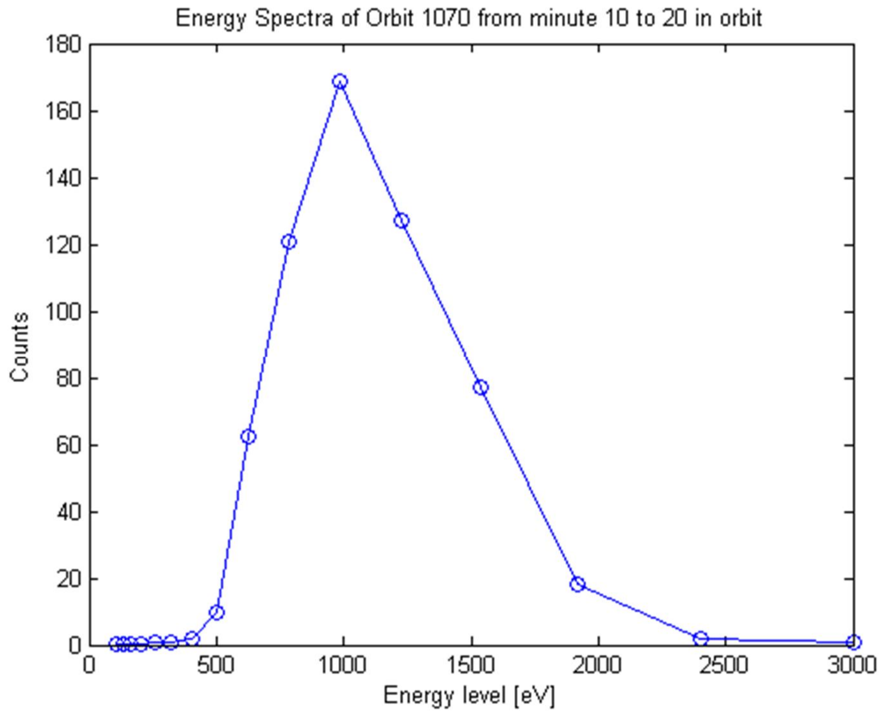

Figure 18 – Energy Spectra for orbit 1070.

4. *Determine the solar wind proton velocity and temperature by 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?*

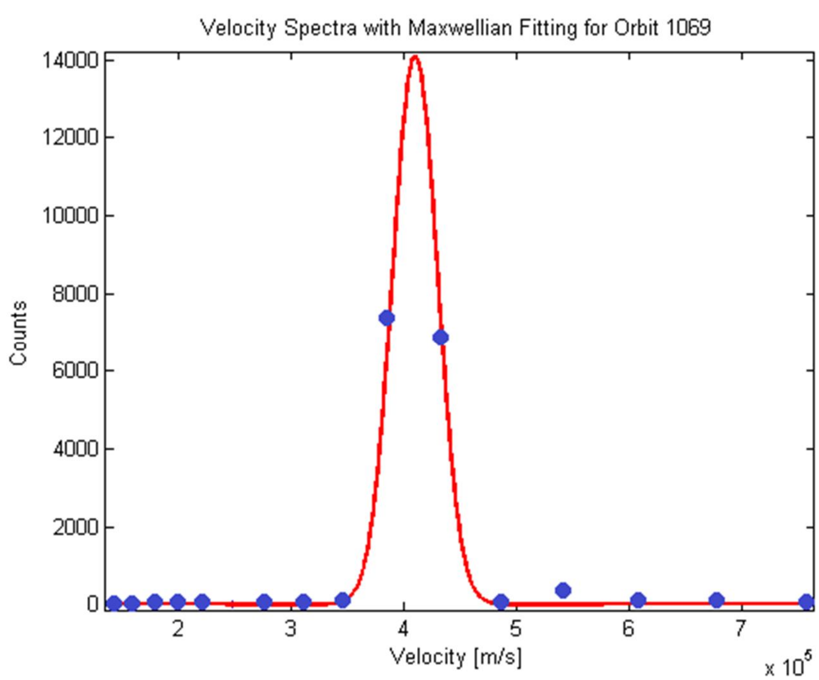

Figure 19 – Orbit 1069 on velocity space with Maxwellian distribution fitting.

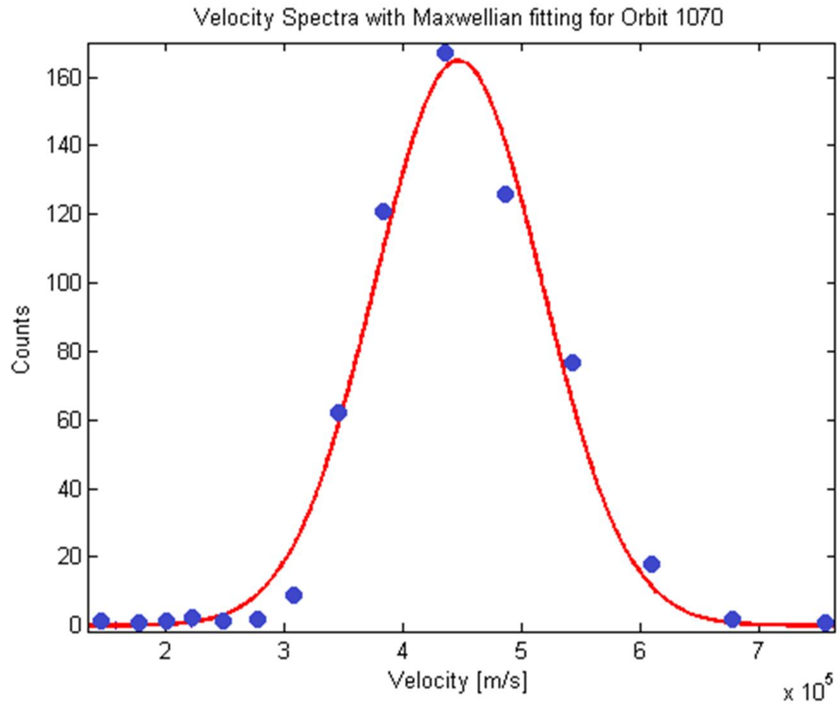

Figure 20 – Orbit 1070 on velocity space with Maxwellian distribution fitting.

The data was transformed to velocity space, this transformation allowed us to fit a Maxwellian distribution on it and therefore be able to calculate the protons' velocity and temperature. The results of this approximation are:

- Orbit 1069
  - Velocity: 410.3 km/s
  - Temperature: 46644 K
- Orbit 1070
  - Velocity: 447.0 km/s
  - Temperature: 59727 K

The two orbits are the same and both of them are circling around the moon. However, the amount of counts on each orbit is not the same, with a greater amount counted on orbit 1069. The difference could be due to the fact that there are not 10 minutes of recorded data on orbit 1070 during the period of solar wind measurements (from 07:41 to 07:51) and possibly this period could had allowed to have a greater amount of counted particles. In both cases the selected time interval was the interval with the biggest count which is not the same time as part of the orbit. However, even with the difference on the counted particles the approximated temperatures and velocities are similar. In addition, the differences on these values could be due to the fact that the spacecraft is approaching to the bow chock therefore causing a small change on the estimated values. The reason we say the satellite is approaching to the bow shock is based on the interpretation of the images shared to us by the professor. In addition that of the fact that an increase in temperature means that the bow shock is erossing.

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

You can use a double Maxwellian distribution where the mass of the proton should be considered. The instrument measured the E/q relationship and this relationship would be different for the analyzed elements depending entirely on the mass. In addition, we are assuming that the other component is ionized Helium, the mass of the Helium would be 4 times the mas of the proton, therefore in order to know the velocity of the elements we need to know the energy value and the mass.
The value of the speed of Helium would be similar to the proton velocity already calculated given that is the same solar wind. The results by doing are the following:

- Orbit 1069
  - Helium velocity: 388.2 km/s
- Orbit 1070
  - Helium velocity: 429.9 km/s

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.

By looking at the data of the spacecraft ACE, we found that the recorded values by the spacecraft for the same measurements that we have are the following:

- Orbit 1069 "2009 36 4 40 31.000 4.8148e+04 3.8255e+02"
  - Velocity: 382.55 km/s
  - Temperature: 48148 K
- Orbit 1070 "2009 36 6 20 47.000 5.1222e+04 3.7389e+02"
  - Velocity: 373.89 km/s
  - Temperature: 51222 K

As it can be seen the results obtained from the spacecraft ACE are similar to our calculated results, the actual values might not be the same but these results are on the same order of magnitude.
The results we are taking from the ACE spacecraft were compensated by distance between the location of ACE and the Chandrayaan-1.

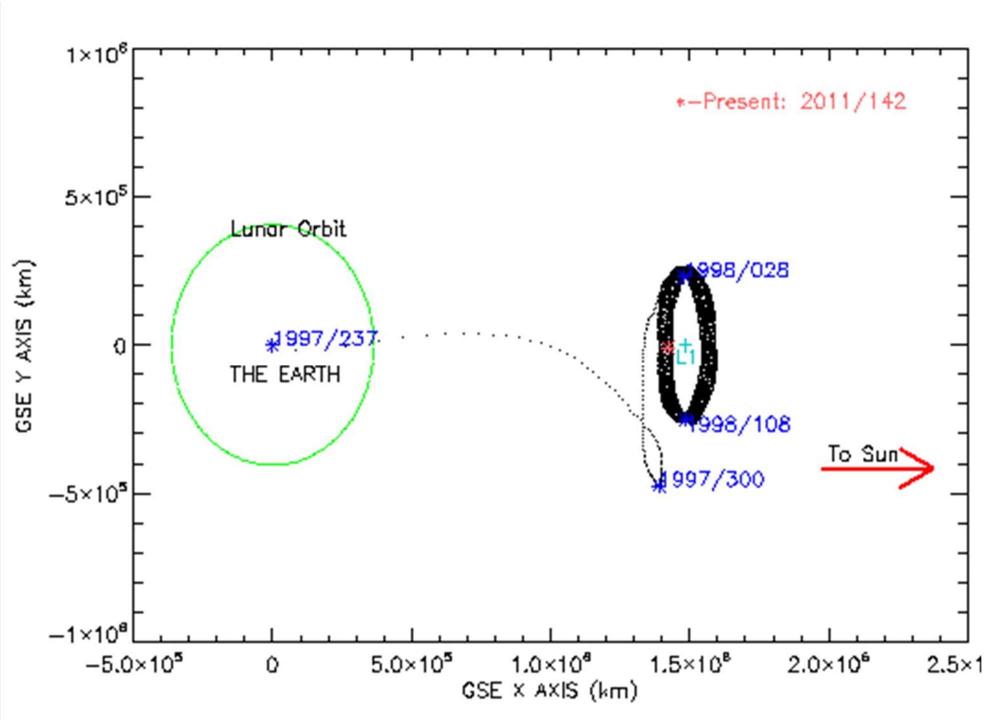

Figure 21 – Location of spacecraft ACE and moon.

As it can be seen by the figure the spacecraft ACE and Chandrayaan-1 are not on the same location on the same location in the space therefore to make an adequate comparison with the date taken by ACE we need to take into account the time it takes the solar wind to fly from ACE to the moon. Since the distance between the ACE and the Earth is approximately is $1.4*10^6$ km (data gotten by the GSE coordinates provided by the ACE) and taking into account a solar wind velocity of approximately 400 km/s, we can assume that the time taken for the solar wind to travel from ACE to the moon would be approximately 1 hour, therefore we took the ACE data from one hour prior to the time provided by Chandrayaan-1.

References

[1] *ACE SWEPAM Level 2 Data*, URL
http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_SWEPAM.html
Last updated May 23rd, 2011.

[2] *EFW, The Electric Field and Wave Experiment on the Cluster Spacecraft*. URL http://www.cluster.irfu.se/ Last Updated March 30th, 2011

[3] Georgescu, E., Plaschke, F., Auster, U., et al. *Modelling of Spacecraft spin period during eclipse*. Annales Geophysicae, 29, 875-882, 2011, May, 2011.