1.1. Purpose of LabWork-2 This Lab Work aims to introduce you the near-Earth space environment using Earth centered spacecraft. You are expected to analyze spacecraft data with various orbits using simple statistical data analysis methods.

1.2. Event Interval : 2009/07/04 15:20:00.000 - 2009/07/05 01:05:59.968 – Inbound

Bow Shock : 2009/07/04 18:12:05.971

Magnetopause : 2009/07/04 23:40:43.351

1.3. Name of the Instruments

Fluxgate Magnetometer (FGM)

Electrostatic Analyzer (ESA)

2. Orbit Plot

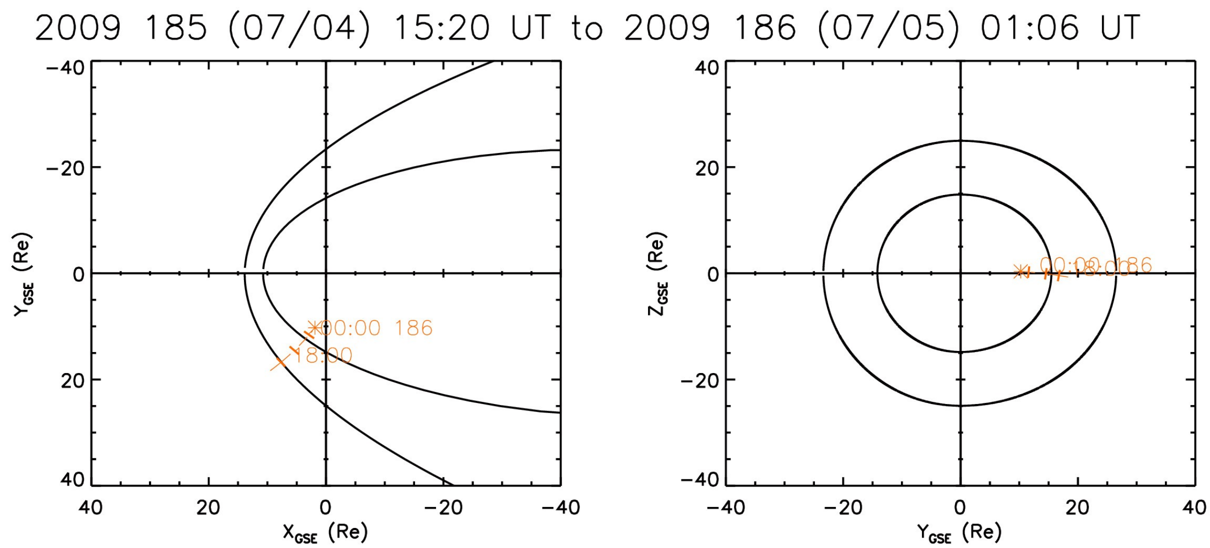

Figure 1: Themis B Orbit Plot

3. Time Series Plots

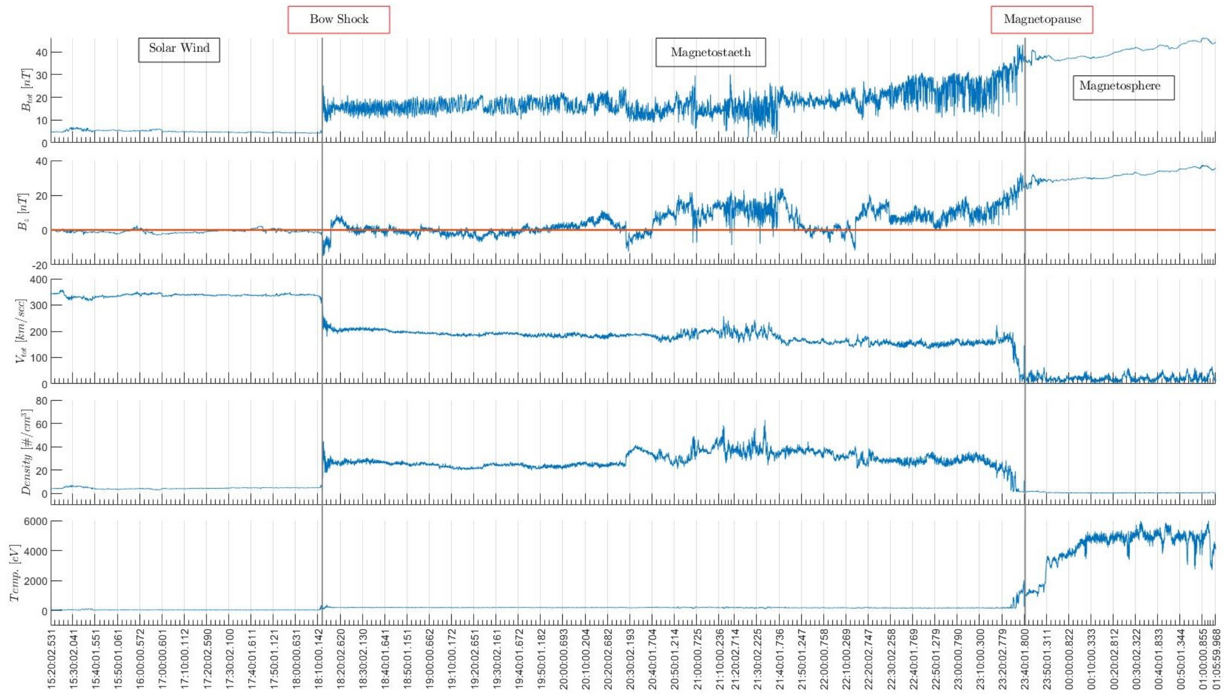

Figure 2: Time Series Plot

4. Statistical Tables

B_{tot} (nT)	Mean	Std	Median	Max	Min
Solar Wind	4.951247	0.525083	4.808450	8.157910	4.130310
Magnetosheath	18.223674	5.356230	17.289950	43.229700	1.869580
Magnetosphere	40.958881	2.954121	41.405100	46.243600	33.867700

$B_z \geq 0$ (nT)	Mean	Std	Median	Max	Min
Solar Wind	0.804086	0.586776	0.710403	2.610540	0.001684
Magnetosheath	8.147444	6.070574	7.386010	32.903900	0.004703
Magnetosphere	32.592435	3.069190	32.608600	37.514900	23.478400

$B_z < 0$ (nT)	Mean	Std	Median	Max	Min
Solar Wind	-1.155544	0.630395	-1.080070	0.000000	-3.389460
Magnetosheath	-2.430307	2.205149	-1.885115	-0.000422	-14.870900
Magnetosphere					

V_{tot} (km/sec)	Mean	Std	Median	Max	Min
Solar Wind	337.095942	5.921884	337.728712	357.436118	288.795472
Magnetosheath	177.924225	25.199599	183.199579	304.752554	6.523718
Magnetosphere	21.395753	11.096071	19.356138	65.625442	1.569204

$Density$ $(\#/cm^3)$	Mean	Std	Median	Max	Min
Solar Wind	4.443889	0.672146	4.393332	12.033011	2.901778
Magnetosheath	28.272594	6.910677	26.773998	62.901075	0.957420
Magnetosphere	0.589470	0.338795	0.472329	2.310603	0.348080

$Temperature$ (eV)	Mean	Std	Median	Max	Min
Solar Wind	46.478403	24.206751	42.311488	374.522125	31.106495
Magnetosheath	204.221579	111.929472	193.792282	2007.390849	88.619990
Magnetosphere	4247.810214	1170.841749	4704.487010	5979.902444	914.486475

5. Interpretations

5.1 : Magnitudes

•B_{tot} : In solar wind region, total magnetic field ($IMF\ B_{tot}$) has smaller values than other regions (mean : 4.951247 nT). When Themis B satellite enters the magnetosheath region and meets bow-shock, B_{tot} value increase suddenly -the magnitude almost doubles (mean : 18.223674 nT). At the magnetopause, magnitude increases with relatively little sharpness and it continues to increase slightly and it have the highest values than other regions (mean : 40.958881 nT).

•V_{tot} : Magnitude of total velocity V_{tot} have highest values in solar wind region (mean : 337.095942 km/sec). At bow-shock V_{tot} drops significantly and it starts to fluctuate in magnetosheath region (mean : 177.924225 km/sec). At the magnetopause, there is a sudden drop again and lowest values of magnitude of V_{tot} are seen in after magnetopause, in magnetosphere region (mean : 21.395753 km/sec).

•$Density$: The largest density values are reached in the magnetosheath region (mean : 28.272594 $\#/cm^3$), while the smallest values are seen in magnetosphere region (mean : 0.589470 $\#/cm^3$). In solar wind region, density values are lower than the magnetosheath region and higher than the magnetosphere region (mean : 4.443889 $\#/cm^3$). Sudden rise is observed at bow-shock and sudden drop is observed at the magnetopause.

•$Temperature$: While solar wind moves with relatively lower temperature values (mean : 46.478403 eV), after bow-shock magnitude of temperature highly increases and it reaches significantly higher values than solar wind in magnetosheath region (mean : 204.221579 eV). After magnetopause values dramatically rise and highest values of temperature are observed in magnetosphere region (mean : 4247.810214 eV)

5.2 : Direction and Magnitude of Bz : In solar wind region, z component of magnetic field $IMF\ B_z$ have mostly negative values that means directions of $IMF\ B_z$ are mostly southward. But in magnetosheath region B_z is mostly positive -direction is mostly northward- and there is no negative value in magnetosphere region -direction is northward all the time.

In solar wind region, magnitudes of negative B_z (mean : -1.155544 nT) are higher than positive B_z (mean : 0.804086 nT). Magnitudes of negative B_z (mean : -2.430307 nT) are smaller than positive B_z (mean : 8.147444 nT) in magnetosheath region and both have higher values than solar wind region. In magnetosphere region, all B_z values are positive and they have highest values than other regions (mean : 32.592435 nT).

5.3 : Fluctuations : Except temperature, largest fluctuations are seen in magnetosheath region for all properties. Except temperature values, magnitudes of all properties changes slightly in solar wind and magnetosphere regions. While lowest fluctuation is observed in magnetosphere region in density graph; in other graphs the lowest standard deviations are seen in solar wind region. Due to temperature table and graph, largest fluctuations are observed in magnetosphere region.

6. Calculation and Compare the Sound Mach Numbers (Ms)

$Ms = \frac{V}{C_s}$; $C_s = \sqrt{\frac{\gamma P_{gas}}{\rho}} = \sqrt{\frac{\gamma 2kT}{m_p}}$; where $\gamma = 5/3$, k is Boltzmann's constant ($k = 1.38 \times 10^{-23}$ $joule/^{\circ}K$) , $m_p = 1.67 \times 10^{-27}\ kg.$

Mach #	Mean	Max	Min
Upstream	2.8982	3.2492	1.0054
Downstream	0.8315	1.5658	0.5110

According to above Mach Number Table; the upstream (solar wind) part is supersonic for all time periods (mean : 2.8982). Although supersonic streams (max : 1.5658) are captured in the downstream (magnetosheath) part, these are negligibly rare and it can be said that the downstream is subsonic (mean : 0.8315).

$\#M_{Sw}(mean) > 1 \rightarrow$ Supersonic ; $\#M_{Msheath}(mean) < 1 \rightarrow$ Subsonic

7. Determination of How Strong the Bow Shock

Assuming flow is steady-state and plane parallel and gravity and viscous effects are negligible. Frozen in flux conditions are valid. Then due to continuity and conservation of momentum and energy equations

$$\rho u = \text{constant} = \rho_{up} V_{up} = \rho_{down} V_{down} = n_{up} V_{up} = n_{down} V_{down}$$

$$\left(\frac{V_{up}}{V_{down}}\right)_{\text{mean}} = 1.6103$$

$$\left(\frac{n_{down}}{n_{up}}\right)_{\text{mean}} = 5.4943$$

8. Learning Outcomes

What are done?

Continuous data of magnetic field and plasma properties (proton number density and components of temperature and velocity) are obtained from Themis B for chosen 10 hours interval. Bow shock and magnetopause times were determined by looking time series plot. After clean up multiple shocks or multiple magnetopause crossings, data containing a single bow shock and magnetopause was obtained. Orbit plot was made in XY and YZ planes with given scales. Time series of requested properties are plotted due to final data. Statistic of quantities belong to chosen event are made then tables at Statistical Tables Section are prepared and interpreted. Mach number values for upstream and downstream are calculated with proper equations and considering only 20 minutes data before and after from bow-shock and Mach numbers are compared. Comments about magnitude of all properties and fluctuations at each regions are made due to time series plot and statistical tables. To determinate how strong bow shock is Rankine Hugoniot Jump conditions are used. For calculations MatLab is used.

What are learned?

Magnitudes of properties change suddenly due to bow-shock and magnetopause. The ratio of negative $IMF\ B_z$ values -direction of southward- is much higher than the ratio of positive $IMF\ B_z$ values -direction of northward- in solar wind region. Due to this open magnetosphere is seen at our case. Even large fluctuations are observed in magnetosheath region, solar wind and magnetosphere regions are relatively stable. Largest fluctuations are observed in magnetosphere region for temperature values due to atmosphere of Earth. Mass, momentum and energy must be conserved at each side of bow-shock. Because of that; while total velocity decreases at bow-shock, density increases. When only 20 minutes before and after from bow-shock data are considered, it can be seen clearly that particles moving at supersonic speeds start to move at subsonic speeds when they encounter the bow-shock. Actually changes in velocity and density are expected to be close to 4 due to Rankine Hugoniot Jump conditions. However when only density change is considered it can be said that there is a highly strength bow-shock while change in velocity values point opposite.