CISM Center For Integrated Space Weather Modeling

Summer School Lab Activities

Lab #6: Exploring Magnetospheric Structure Under Varying IMF Conditions

In this lab activity we will examine the configuration of the magnetosphere by visualizing results from the LFM for three different directions of the interplanetary magnetic field (IMF) in a solar wind with constant parameters. The network we have created will allow you place Cut Planes at various locations within magnetosphere. On these cut planes you can place a variety of scalar parameters, e.g., Density, V_X, $J \cdot E$, etc. In addition to the cut planes we have provided an interface which will allow to select points from which magnetic field lines can be traced through out the computational domain.

The goals for this lab are for you to:

- identifying structures in the magnetosphere: bow shock, magneto-pause, magneto-sheath, lobes, plasma sheet
- identifying Dynamic structures: current systems, reconnection points, plasmoid, earthward flows from the tail
- the structure of open and closed field lines under varying solar wind conditions

Getting Started

Change to the lab6 directory [**cd swss-labs/lab6**] and start CISMDX. Use the **File** menu of the VPE to load the "**LFMlab.net"** visual program. Once the new network is loaded, **Execute** it. A window will open with a cut plane painted with a plasma parameter labeled by the color bar. This image shows the results of a Lyon-Fedder-Mulberry (LFM) simulation of the magnetosphere. A blue-green sphere in the middle represents the Earth. Notice that the inner boundary of the simulation is 3 R_e. The view point is from above the north pole (notice that the z-axis points out of the page).

- ***Which direction points towards the sun?***

On this image you will also see a red line. This line is a reference for the plot window that also came up. This window shows a plot of the plasma parameter along each of the line.

Open the main control panel using the VPE menu bar **Window** menu and select **Open Control Panel by Name** -> **Main Control Panel** option. This main control panel contains several dialog boxes that we will use to investigate the structure of the magnetosphere. Three interactors that can be used immediately to explore this image are:

- "Cut Plane" – sets the axes of the cut plane (XY, XZ, or YZ)
- "Cut Plane Scalar" – selects the plasma parameter that the cut plane is painted with
- "Plot Line Angle" – angle of the reference line for the plot

Plotting Field Lines

We have implemented a process that will allow you to set the starting location for a set of field lines. In order to understand this process we need to execute the network once. Once you have the image window visible go ahead and bring up the **View Control Panel** by typing

Ctrl-V in the image window or using the **Options** menu.

In the **Mode** dialog box choose **Pick** and at the bottom of the **View Control Panel** you will see a **Pick(s)** scroll list with **Red Field Lines** visible. Use the mouse to select three points inside the magnetosphere as origins for field lines and **Execute** the network. The **Pick** module is designed to set the points on the cut plane that you can see in the Image Window. After these field lines are visible in the Image window change the **Pick(s)** scroll list to **White Field Lines** and choose a few outside the magnetosphere as points for new field lines which will appear after you **Execute** the network.

NB: In order for both colors of field lines to appear in the Image window at the same time you must first set the locations the **Red Field Lines** and then Execute network. After field lines are visible you can then create the **White Field Lines**.

Activity 1: Static Features of the Magnetosphere

The **Main Control Panel** contains an interactor labeled "**HDF Data File"** which should read "**north-imf.hdf**". This is and "ideal" case where the solar wind has a constant speed of 400 Km/s with an Interplanetary Magnetic Field (IMF) that is pointing purely northward. These ideal cases are often used to study the effects of the solar wind on the magnetosphere. For this lab, files named "**south-imf.hdf**" and "**west-imf.hdf**" are also available.

The following are definitions or descriptions of various regions of the magnetosphere. Uses these along with the questions the follow them to try and identify the region in the simulation. Be sure to save snapshots of the image window and the plot window that justify your claims.

Bow Shock

The bow shock is the surface where the solar wind slows down dramatically as it runs into the magnetosphere. It is characterized by:

1. a sharp decrease in the plasma velocity
2. a sharp increase in the plasma density

- ***Use the above characteristics to identify the bow shock in the simulation. Can you identify it in both the XY and XZ cut plans?***
- ***Is it clearly defined on the dayside? Is it clearly defined behind the dawn-dusk meridian?***
- ***Using the line plot, identify the position of the front edge of the bow shock***

Use the "**HDF Data File**" interactor on the **Main Control Panel** to change to the southward case ("**south-imf.hdf**"). You may want to start a new instance of CISMDX and open up the southward case there.

- ***How does the position of the bow shock change when the IMF goes from north to south?***

Magneto-sheath

This is the region between the magnetopause and the bow shock. Plasma in the magneto-sheath typically is "shocked" plasma, that is it has passed through the bow shock but will "ideally" be directed around the magneto-pause.

Characterized by:

1. Bounded by the Bow shock and magneto-pause

2. Dominated by thermal pressure
3. Contains plasma stream lines that have passed through the bow shock (To view streamlines, change the "**Vector**" parameter in the "**Main Control Panel**" to "**V**" for "velocity". Then set "**Pick**" points to trace the streamlines through those points.

- ***Is it clearly defined on the dayside? Is it clearly defined behind the dawn-dusk meridian?***
- ***Identify the magneto-sheath on the dayside of the magnetosphere. Which parameter is most useful in identifying the magneto-sheath? Do the streamlines help? Is it clearly defined further down the tail?***
- ***Again compare the northward to the southward case. How doe the features of the Magneto-sheath change?***

Magneto-pause

The magneto-pause is the surface that separates the region of space dominated by the Earth's magnetic field, the magnetosphere, from the region that is dominated by the thermal pressure of the plasma, the magneto-sheath.
Characterized by:

1. Thermal pressure is high outside the magneto pause
2. There is a strong negative gradient in plasma density crossing from the magneto-sheath to the magneto-sphere.
3. The ratio of the thermal pressure (P) to the magnetic pressure (B^2) is greater then one outside the magnetopause and less then on inside it.
4. Strong currents exist on the surface of the magneto-pause due sharp changes in the magnetic field.

- ***Identify the magneto-pause on the dayside of the magnetosphere. Can you see it in all three cut planes?***
- ***Which parameter is best to use to identify the magnetopause?***
- ***Can you identify it further down the tail?***

Magneto-sphere

This is the region inside the magneto-pause that is dominated by the Earth's magnetic field. For the most part, solar wind plasma does not have "direct" access to the magneto-sphere (see questions below). The thermal pressure and plasma "beta" are low except in the region of the plasma sheet. In an idealized steady state case magneto-sphere field lines do not cross the magneto-pause, so magnetic field lines either close on the Earth or have one foot point on the earth head down the tail. Realistically (both "Reality" and "Virtual Reality", field lines with one foot point on the Earth may eventually cross the magneto-pause to connect with the IMF.
Characterized by:

- Low density and low plasma "beta" except near the plasma sheet
- Field lines partially contained inside the magneto-pause

- ***Describe or draw the difference in the shape of the magnetosphere during northward and southward IMF.***
- ***What differences do you notice in the interior of the magneto-pause***

Cusp Region

The cusp regions are regions near the poles where the magneto-sheath extends down to the top of the ionosphere.

- ***Are the field lines in the Cusp region open or closed with northward IMF? southward?***
- ***In which case, northward or southward, is the solar wind most likely to have access to the cusp region?***
- ***In which case is there an reconnection point near the Cusp region?***

Magneto-lobes

The magneto-lobes are regions in the tail of the magnetosphere that are very low density and pressure. There are two lobes one north and one south of the plasma sheet.

Characterized by:

- Low pressure region down the tail north and south of the plasma sheet
- ***Find the magneto-lobes. Which cut plane and plasma parameter shows them best? How far down the tail do they extend?***
- ***Where are the magnetic field lines in the lobes connected?***
- ***Do they differ in the northward and southward IMF?***

Plasma Sheet

A plasma sheet is present in the tail Pressure dominates in the plasma sheet and a current is present that separates nearly parallel opposing magnetic fields.

Characterized by:

- Pressure greater then surrounding regions (see "Lobes" below)
- Current loop systems from the magnetopause close in the plasma sheet
- Opposing field lines bound the plasma sheet
- ***Find the plasma sheet. Which parameter and cut plane best illustrates the plasma sheet?***
- ***What features of the plasma sheet do you observe?***
- ***How far down the tail does the plasma sheet extend?***

Activity 2: Dynamic Features of the Magnetosphere

X-Points:

The x-points occur when opposing field lines come close together and form an "X" and reconnection occurs causing plasma to be sent away from the reconnection points.

Characterized by:

- Field configuration forms an "X" geometry around a point
- High speed plasma flows on either side of the x-point
  - ***Look for x-points in the magneto-tail in the southward case. How many do you find***
  - ***Are there any in the magneto-tail for the northward case? Are there x-points anywhere in the northward case?***

Plasmoid:

A plasmoid develops between two x-points where the magnetic field has been pinched off. High flows occur near the plasmoid and the magnetic field in the plasmoid has closes on

itself.
Characterized by:

- Confined between to x-points
- Field lines in the plasmoid close on themselves
  - ***Find the plasmoid in the tail of the southward case. What is the field configuration in the plasmoid?***
  - ***Do you expect to find a plasmoid in the tail of the northward case?***

Activity 3: Westward IMF

Now lets look at the structure for westward IMF. Set the **HDF Data File** to "**west-imf.hdf**" and choose the XZ cutplane.

- ***Using what you have learned already, identify the bow shock and magnetopause. Choose field lines both inside and outside the magnetopause and compare their orientation.***
- ***Is there an X-point or reconnection point in this simulation result?***
- ***What happens to field lines in the cusp region?***

Activity 4: Realistic Solar Wind Conditions

All of the cases in this lab have used idealized solar wind conditions as inputs to the LFM magnetospheric model. In each case the solar wind speed was held constant at 400 Km/s and the Interplanetary Magnetic Field (IMF) was directly purely in one direction.

- ***Which if any of the solar wind conditions that we looked are most realistic?***

To answer this question start by going to the *Space Weather Prediction Center's* "Space Weather Now" page (http://www.swpc.noaa.gov/SWN/index.html) and use the "Real Time Solar Wind" tools and links at the bottom of the page. Also, look at the solar wind data from a storm that accorded in December of 2006 that was Collected by the ACE satellite (http://www.srl.caltech.edu/ACE/ASC/browse/view_browse_data.html)

- ***Assuming the variation in the solar wind during the December 2006 storm is typical, what changes would you expect in the magnetosphere during the storm?***

Activity 5: Open Exploration

Please feel free to use the remaining time to any other parameters that define the magnetosphere that might interest you. A number of possibilities exist:

1. We haven't examined the plasma pressure in the magnetosphere.
2. The ram pressure in the solar wind is constant for each IMF condition. Is the location of the magnetopause the same?
3. Sweep cut planes up and down the magnetotail and examine the spatial variation of the plasma parameters.
4. Use the $J \cdot E$ to examine where energy is removed from the solar wind and transferred to the magnetosphere.
5. Mapping out currents with streamlines can be quite challenging, how successful can you be?

Don't be limited by these suggestions, explore and let us know what you discover!

Appendix

Control Panel Interactors

- **HDF Data Filename**
  This dialog box allows you choose the data file from which data is imported. The button on the right with the three dots will bring up a File Selector, which you can use to choose between the three IMF directions.
- **Cut Plane**
  This dialog box allows you to choose between three different cut plane directions, e.g., XY, XZ, and YZ. Remember the positive Z-direction points north while the positive X-direction points towards the sun.
- **CutPlane Scalar**
  In this dialog box you can chose the scalar parameter to be plotted on the Cut Plane. In addition to the MHD parameters, e.g. Density, V_X, B_X, etc., you can also plot the magnitudes of the vectors and the dot products $J \cdot B$ and $J \cdot E$.
- **CutPlane Location**
  Here you can set the value for constant direction of the cut plane.
- **CutPlane Transparency**
  In this dialog box you can set the transparency of the Cut Plane. A transparency of 1 makes the cut plane a solid object. A value around 0.8 will allow you to see through the cut plane, which can be very helpful in examining field lines.
- **Vector**
  In the final dialog box you can choose the Vector quantity used to drive the field line tracing. In this lab we will leave this set on B, but after the lab is complete you are welcome to try tracing field lines for other vector parameters.
- **Plot Line Angle**
  Changes the position of the reference line on the cut plane. The values of the plasma parameter on the cut plane along this line are plotted against position along the line in the plot window.