Lab #4: Exploring the Structure of the Solar Wind

Introduction

In this activity we will examine the structure and properties of the solar wind out to ~1 AU by visualizing results from the ENLIL 3-D MHD solar wind model initialized (at an inner boundary $R = 30 R_s$) by the MAS model. We will examine structure of the solar wind in two situations: at the beginning of the last solar cycle near solar minimum (CR 1919), and near solar maximum of the last cycle (CR 1960). You will be to look at how the plasma parameters vary in space through out the inner heliosphere, and how the magnetic field lines and flow velocities are related.

When you are finished with this lab you will have reviewed:
- the variation of solar wind plasma parameters as a function of distance from the sun
- the variation of solar wind plasma parameters as a function of latitude above the solar equator
- the difference in the overall structure of the solar wind from solar minimum to solar maximum
- the relationship between plasma flow and the magnetic field line topology
- the interaction of fast and slow solar wind flows and how they affect the solar wind structure

Before Beginning

In your groups consider the following questions.

- How should the various plasma parameters of the solar wind change with distance from the sun? In particular, consider: density, speed, magnetic field strength.
- How would you describe the overall flow of the solar wind? What direction does it flow in? Does the direction change as it moves further from the sun?

Getting Started

Change to the lab4 directory [cd swss-labs/lab4] and start CISMDX [cismdx &].

In the menu bar for the VPE (Visual Program Editor) select the File option and from the pull down menu select Open Program…. Choose EnlilLab.net and select “Execute Once”. Two image windows will pop up.

One image is of a solar equatorial cut plane and a meridian cut plane through the solar wind along with a sphere at 30 solar radii near the inner boundary of the simulation. Each cut plane is painted with a plasma parameter labeled on the color scale of the window. The small red cube represents the position of the earth and is roughly the size the earth’s magnetosphere. The solar wind data depicted here is simulation results for CR1919, which is near solar minimum. You can use the Rotate and Pan/Zoom features in
the View Control Panel (under the Options menu on the image window) to explore this image.

The other window has a plot of the parameter as a function of distance from the Sun along a line that is indicated in the cut plane window. The radial distance is in AU’s [one AU or Astronomical Unit is the mean distance from the Earth to the Sun].

**Activity 1: Exploring the Global Structure of the Solar Wind**

We will first explore the how different plasma parameters of the solar wind change in the ecliptic plane in a global way. For now we are only concerned with general trends. We will look at specific details later. We will start with the s

Open the “Main Panel” for this network using the Window -> Open Control Panel by Name option in the “Visual Program Editor” window. This control panel will allow you explore the data set using the tools provided.

**In the Equatorial Plane**

We will start by exploring how the plasma parameter changes in the solar equatorial plane. On the Main Control Panel choose the “Log[Den]” Plasma Parameter to see a color map and plot of the density. (Note that the log is used here to enhance variations in the color map)

1) Along with the cut plane visualization, use the line plot to explore how the plasma variables vary with distance. The “Line Angle” selector on the Main Control Panel allows you to change the azimuthal angle of the line. Remember, we are concerned with overall trends here.
   
   • *Describe the overall variation in density relative to distance from the sun. Is it increasing or decreasing? Be sure to plot a graph for the line along a several different angles. Sketch a general plot in your lab notebook.*

2) Using the control panel, choose the “Den*r^2” Plasma Parameter. This will plot the plasma density multiplied by $r^2$.
   
   • *Overall, is this increasing or decreasing? (pay careful attention to the scale on the vertical axis). What does that say about the dependence of density on the distance from the sun? Sketch a general plot in your lab notebook.*

   • *Explore the log of the magnetic field strength, “Log|B|”, “|B| *r^2”, and the velocity magnitude, |V| in the same way. Sketch a general plot for each of these in your lab notebook.*

   • *In your group, discuss the general trends you see in the results. Are they consistent with the continuity equation? How? What other generalizations can you see in the data?*
Out of the Equatorial Plane

So far we have only focused on the solar equatorial cut plane. Now look at the how things vary as a function of latitude using the meridional cut plane. You can move the meridional cut plane by varying the azimuthal angle from 0° to 359°. Keep in mind that this Carrington Rotation is near a solar minimum and so the Sun has well defined coronal holes at the poles.

- Explore density first. Should you look at “Log(Den)” parameter or the “Denr^2” parameter? How does the density change as you move away from the equator and towards the poles?

- Now explore velocity. In general, is the outflow from the sun faster or slower near the poles?

- Explore temperature and magnetic field. Note if and how they change as you move towards higher latitude.

- Again discuss your findings in your group in light of the continuity equation. How do your findings correspond to what you have learned about the magnetic field structure of the sun from previous labs?

Solar Maximum Case

In the “Main” control panel, change “cr1919” to “cr1960”. Look at the global structure and compare it to the solar minimum case.

- Are the velocity and the density related to each other in the same way as in the solar minimum case?

- How does the velocity and density change as you go to higher latitudes? How does this compare to the solar minimum case?

- On the paper provided, sketch a solar minimum and solar maximum case highlighting the differences.

- Are the similarities and differences between solar minimum and solar maximum consistent with space craft data presented in the lectures?

Below in image from the Ulysses mission. You can find a full size version at http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=33482

Are the findings from your study of these simulation results consistent with this data? Discuss, draw pictures and save images.
Lab #4: Exploring solar Wind Structure Using the ENLIL Model
Activity 2: Comparing the Plasma Flow Direction to the Magnetic Field Structure

By now you have noticed the “spiral” structure in the solar wind that was first described by Parker. To explore this further the visualization package includes a feature that allows the users to pick points where field lines and flow vectors can be shown.
1. In the “View Control” window ("Image” window-> “Options” - > “View Control”) choose “Pick” from the “Mode” menu.
2. In the “Image” window, click a few points on the equatorial cut plane.
3. In the Main Control Panel, select the “Field Lines” toggle switch and execute the network. (If you have “Execute on Change” on, turn it off).

There should now be several magnetic field lines in the image, each corresponding to a point you choose. At each of those points there is also a vector representing the velocity vector at that point.

- What happens to the direction of the magnetic field as the plasma moves further from the sun?
- What happens to the direction of the velocity vector as the plasma moves further from the sun?
- Sketch a plot of the angle between the velocity vector and the magnetic field as a function of distance from the sun.

Activity 3: Magnetic Sectors and the Solar Current Sheet

Now that you have obtained a global view of the solar wind for both the solar minimum and solar maximum cases, return to CR1919 and concentrate on the wind near the equatorial plane. Switch the Plasma Parameter to “polarity”.

- How many magnetic sectors are there (regions of “positive” or “negative” polarity) in the equatorial plane?

Now turn on the “Current Sheet” in the control panel.

- Where does the current sheet intersect the equatorial plane?
- What can you say about the polarity above and below the current sheet?

Switch to the solar maximum case (CR 1960) and see if these same rules apply.

- Is a sector boundary more likely to cross the Earth during solar minimum or solar maximum? Draw a picture or save an image to explain way.
Activity 4: Fast and Slow Streams & Corotating Interaction Regions (CIRs)

Compare and contrast the plasma properties of fast and slow streams (focus on the clearly fast and slow wind streams). For this Carrington Rotation you should see one fast stream near the equator. Study the interfaces between the fast and slow wind (i.e., look at the CIRs).
- Can you determine some of the general properties of CIRs?
- Describe what happens to density in this region?
- Is it near or far from a sector boundary? From the current sheet?

Try plotting the different plasma parameters lying along the radial line near the CIR boundary. You may want to use “Pick” feature to draw field lines near the boundary as a way to mark it.

Wrap Up Discussion

Consider the questions from the very beginning of the lab. How has the lab results confirmed or refuted your original thinking? Draw pictures and save images to argue your case.