

# Solar Wind Variation Throughout the Heliosphere

## Goals:

In this lab you use simulation results to explore the structure of the solar wind.

When you are finished with this lab you will have reviewed:

- the variation in solar wind plasma parameters as a function of distance from the sun
- the relationship between plasma flow and the magnetic field line topology
- the variation in solar wind plasma parameters as a function of solar latitude
- the difference in the overall structure of the solar wind between the solar minimum case to the solar maximum case
- the interaction of fast and slow solar wind flows

## Before You Begin:

- *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?*

## Part I: An Overview of the Solar Wind (30 minutes)

### Introduction

The iSWA layout below shows simulation results from the solar wind Enlil model. A brief description of the Enlil model can be found here,

<http://ccmc.gsfc.nasa.gov/models/modelinfo.php?model=ENLIL>.

[http://iswa.ccmc.gsfc.nasa.gov/lswaSystemWebApp/index.jsp?i\\_1=169&l\\_1=9&t\\_1=302&w\\_1=681&h\\_1=451&s\\_1=2013-07-01%2011:01:25.0\\_0\\_10\\_3&i\\_2=167&l\\_2=694&t\\_2=298&w\\_2=693&h\\_2=455&s\\_2=2013-07-01%2011:01:25.0\\_0\\_10\\_3](http://iswa.ccmc.gsfc.nasa.gov/lswaSystemWebApp/index.jsp?i_1=169&l_1=9&t_1=302&w_1=681&h_1=451&s_1=2013-07-01%2011:01:25.0_0_10_3&i_2=167&l_2=694&t_2=298&w_2=693&h_2=455&s_2=2013-07-01%2011:01:25.0_0_10_3)

- *What solar wind variables are you viewing in the iSWA layout? What range of values do they take?*
- *What other features are represented in the plots?*
- *What other variables might you expect from the Enlil model?*
- *What other information would you like from the model?*

### Cut Planes

The two cygnets in the layout above show cut planes through a 3-D volume of simulation results for a given variable - density and velocity.

- *On your group's shared pad, sketch the 3-D simulation volume showing the cut planes. (If you have trouble with this, ask an instructor)*
- *Can you describe the volume?*
- *Why do you think this volume was chosen by the model developers?*

Each cut plane is painted with a variable that is derived from the simulation results.

- *What is the scale (range) of the velocity variable?*

- **How is the “density” plotted? What simulation results are used to calculate it?**
- **What is its range? What is the expected density at 1 AU (Earth’s orbit)?**

### **Variation in Density and Velocity**

- **Describe how density and velocity vary with distance from the Sun.**
- **Can you explain these results in terms of fundamental physics?**
- **Consider the solar wind at Jupiter**
  - **What would the range of values of the plotted variable be at the orbit of Jupiter?**
  - **What would the solar wind density be? What would the velocity be?**
  - **How would the ram pressure compare to that at Earth?**

Consider just the velocity cygnet.

- **What is the direction of the velocity (say relative to the radial direction) as you move away from the Sun? Does the direction change further from the Sun? Why?**
- **What simulation results would you want to look at to answer this questions?**

*Be prepared to discuss your group answers with the whole room.*

## **Part II: A Second Look (60 Minutes)**

This page (<http://ccmc.gsfc.nasa.gov/support/cycles.php>) has a series of runs for Carrington Rotations during Solar Minimum and Solar Maximum. Click on one of these runs.

- *Click on the “3D Data” link.*

This links to a form page that allows the user to plot the simulation results in a variety of formats.

- *To start with click “Update Plot”*

You should see a plot very similar to the the plots you just looked at.

### **All Groups: Direction of the Solar Wind Velocity**

- *Scroll down a little on the page till you find the “quantity” section. Choose “V” from the “Q1” drop down menu and then click “update plot”*
- **Note the variation in scale for the velocity.**
- *Now choose different components of the velocity - “Vr”, “V\_lat”, and “V\_lon” - and plot each.*
- **Note the scales for each.**
- **What is the dominant component of the solar wind velocity vector?**
- **What is the direction is the solar wind plasma velocity at 1 AU? At 2 AU?**
- **What direction is the solar wind “flowing”?**

***Keep this Window available on a separate screen for reference as you continue.***

## 1. (Group 1 & 5) Variations in Density and Velocity

Use the case you looked at above.

You can look at the variation in the parameters along a line.

Scroll down the form and choose the following settings:

- From the "Plot Mode" drop down menu choose "Line 1D"
- From the "quantities" drop down menu choose:  
Q1: "N", Q2 "B", Q3 "N" (to keep it from plotting anything)
- In the "Choose Plot Area", set "Lon1", "Lon2", "Lat1", and "Lat2" to "0"  
(This is a plot along a line from the origin along the -x axis.)
- Hit the "Update Plot" button

You should now have a line plot showing the variation of the density and magnetic field strength along a radial line in the solar equatorial plane.

- **Where is this line in the equatorial plane that you plotted previously? Sketch it on your shared workspace.**
- **Compare the variation in the magnetic field to the density. Are they related? Why?**
- **Can you tell how the density varies with distance from the Sun? What would help?**
- Now scroll down to "Plot Options" and select "Log scale" under "Color Contour, (Vertical) Line", then hit "Update Plot"
- **Does this help you answer the questions above?**

### Rescaled Density

Finally, let's look at a rescaled density.

- Choose "Q1:  $Nr^2$ " and set Q2 and Q3 to the same so one only look at one variable
- You may want to turn off the "Log scale" option.
- **How would you describe this plot? How does it vary with distance from the Sun?**
- **What general conclusions can you draw about how the density varies with distance from the Sun?**

Look at the components of velocity.

- From the quantities drop down choose: Q1: "V\_r", Q2 "V\_lat", Q3 "V\_lon" and update the plot.
- Over what range do each of the components vary?
  - Range for V\_r
  - Range for V\_lat
  - Range for V\_lon
- What does this say about the general direction of the solar wind velocity?
- How does the solar wind vary with distance from the Sun?

Finally let's look at the correlation between the solar wind velocity and plasma density.

- From the quantities drop down choose: Q1: " $N \cdot r^2$ ", Q2 " $V_r$ ", Q3 " $V_r$ " and update the plot.
- **Are the velocity and density correlated? When the velocity is high what happens to the density? When the velocity is low? During the transition from high to low?**

## 2. (Group 2 & 6) Traffic Jams: Evolution of Co-Rotating Interaction Regions (CIR)

- Choose a "Solar Minimum" case. Click on "3D Data" and then hit plot "Update Plot".
- Notice spiral structure of Co-Rotating Interaction Regions (CIR's).
- **What are some of the characteristics of a CIR? How do the plasma variables -density, velocity, magnetic field - of the solar wind change as the CIR crosses Earth?**
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- In a separate window, plot the velocity by choosing "V" from the "quantity" drop down menu. You may also want to use the instructions from the beginning of "Activity 1" above to create line plots.
- **How does the variation in velocity compare to the density? What does this tell you about how the CIR forms?**
- **Can you identify a shock in the CIR? How does the shock form? How far from the Sun is the CIR when it develops into a Shock?**
- Using the same case, follow the directions for the previous group to plot a line across the CIR.
- **Is this result consistent the conclusions you drew already?**

## 3. (Group 3 & 7) Global structure of the solar wind during Solar Minimum and Solar Maximum

Compare the velocity and density of of the solar wind during solar minimum and solar maximum

- Choose the a Solar Minimum case and a Solar Maximum case.
- For each plot the density and velocity in the equatorial plane:
  - Choose "Plot3D" and click "Update Plot" to view the density
  - For the same case, in a separate window plot the velocity: before clicking "Update Plot", choose the quantity "V" from the Q1 drop down menu.
- **In the equatorial plane, can you distinguish between the minimum and maximum cases?**

Let's look at the meridian cut plane.

- In each case, scroll down to "Choose Plot Area" section.
- Select the "Lon=constant" (constant longitude) radio button and hit "Update Plot".
- **Now can you distinguish between the minimum and maximum case?**
- Choose different constant longitudes by entering them into the text box next to the "Lon=constant" button.
- **Are you observations the same for different longitudes? For different Carrington Rotations?**

#### 4. (Group 4 & 8) Comparison of Successive Carrington Rotations Solar Minimum and Solar Maximum

Choose the first Solar Minimum case.

- *Plot the density for it and successive cases in separate windows.*
- ***How does the global structure of the solar wind compare from one Carrington Rotation to the next? How many CR's does it take to see significant change in the global structure?***
- *You may want to fix the color scale in all the cases you plotted.*
  - *Choose a minimum and maximum value.*
  - *For each case, scroll down the the "Plot Options for selected Plot Modes" (about 1/2 way down the page).*
  - *Under "Color Contour" choose "Lock color range" and enter the "Min" and "Max" range.*
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- ***Again compare one CR to the other?***
- *Do the same for the velocity plot. Is this consistent with your conclusions from the density plots?*
- ***What are the implications for predictions and forecasting the solar wind structure?***