CISM Center For Integrated Space Weather Modeling

Summer School Lab Activities

Lab #5: Predicting and Modeling the Arrival of the May 12^{th} 1997 CME

In this lab we will use remote observations of the May 12, 1997 solar flare and halo CME made at and near the Sun by the SOHO spacecraft to predict the time of its arrival at Earth.

Goals: When you are finished with this lab you should be able to:

- interpret satellite data for use in space weather forecasting
- identify Earth directed CME from satellite data
- understand that a CME interacts with the ambient solar wind
- learn procedures for predicting arrival time for a CME
- understand how global structure of a CME evolves for different solar wind conditions (solar min vs. solar max)

Before Beginning

Consider what you have learned about the structure of the solar wind. In your groups discuss the following.

- ***As a CME travels from the Sun to the Earth, how will its shape evolve?***
- ***Does your answer change from solar minimum to solar maximum?***
- ***Draw diagrams to illustrate your answers.***

Activity 1: Exploring Satellite Images of Solar Activity

In this part we will carefully inspect a series of 36 images from SOHO that span the whole day, 12 May 1997, in order to examine the sequence of events that occurred. Start by viewing the movie contained in the c2eit.html file that should be with the lab 5 materials (either double click on the file on use the command **firefox c2eit.html** in the terminal window). Use the pause feature and other controls on the web page to explore the events that occur in this movie.

Each image in this movie was made by combining data from two instruments:

1. The green images of the sun's disk (center of each frame) are extreme UV (EUV) images made by the Extreme-ultra-violet Imaging Telescope (EIT). These particular images are in the 195Å line of Fe XII (that is eleven times ionised iron, or Fe^{11-}) which exists in equilibrium at a temperature of around 1.5×10^6 K, a temperature corresponding to the lower/middle corona. Thus the brightness of these images is proportional to the density of gas at this temperature in the corona.
2. The blue, outer part of each image was made by the Large Angle Spectroscopic Coronagraph (LASCO). This instrument measures the white light scattered by electrons within the corona (effectively measuring the coronal electron and hence plasma density). It consists of a suite of 3 separate imagers that look at 3 height ranges above the solar surface (though C1, the inner coronagraph is no longer functional). In these images from the intermediate height C2 coronagraph, the solar disk is hidden behind an occulting disk to allow the much dimmer outer corona to be imaged.

Look at the individual images and notice the following points:
(Images can be found with the lab 5 materials. The last six digits of each png file indicate the time.)

1. ***In your notebook, record the events that occur in this video including the time. In particular, identify when and where the CME is initiated from.***
2. ***Discuss this sequence in your group and sketch what you think this process looks like from the side (looking from a line of sight that is at right angles to the line of sight of these images).***

Activity 2: Differenced Coronagraph Images

As you have just seen, halo CMEs are difficult to see in coronagraph images. One effective way of improving the contrast is through a "running difference" technique. The previous coronagraph image is subtracted from the current image, so that only changes in the coronal brightness are seen: bright features are regions of increased electron density, whilst dark features correspond to decreases.

The following locations each contains a sequence of differenced coronagraph images for the entire day, May 12, 1997:

C2 (measures the coronal brightness from ~2 to ~5 solar radii, **c2_rdif.html)**.

C3 (measures the coronal brightness from ~4 to ~30 solar radii)
in the top level of the lab 5 directory, **c3_rdif.html**.
Note: Real time images of the sun in various wavelengths can always be found at the SOHO website: http://sohowww.nascom.nasa.gov

Activity 3: Estimate the plane of sky speed of this halo CME, and use that to predict its arrival time at Earth.

Estimate the expansion speed of the leading edge of the CME as projected onto the plane of the sky using the hard-copy versions of the differenced coronograph images.

- Procedure:
- Locate the outermost portion of the CME, and draw a radial line at this clock-angle (i.e. a line joining this outermost CME portion and the centre of the Sun).
- Measure the height of the CME leading edge at this clock-angle (i.e. the distance along your radial line) for each time-step. Normalise your measured distance by the apparent radius (or diameter) of the Sun (R_S = 695, 000 km and so the solar Diameter is about 1.39 x 10^6 km)
- The slope of the height versus time plot will give the plane of sky speed of the CME. Calculate this slope. An OpenOffice Spread Sheet called "CME-Plot.ods" is available in the lab5 folder to help with your calculations and to plot the data.

1. ***Based on the speed you calculated, calculate the CME transit time to Earth. (a distance of 1 AU = 1.5×10^8 km).***
2. ***In calculating the arrival time, discuss the assumptions we have made to do this calculation?***

Activity 4: Interplanetary Acceleration

- Using the graph below of interplanetary acceleration, IP Accn., versus CME speed, V_{CME}, find the expected interplanetary acceleration for a CME with the velocity you deduced.
- Assuming that the interplanetary acceleration is constant, find the time it will take this CME to travel to Earth given the initial speed and acceleration you calculated. (Remember that for constant acceleration, distance and time are related by: $s = ut + \frac{1}{2} at^2$). Hence, estimate the date and time this CME arrived at Earth assuming it was launched at the time of the flare.

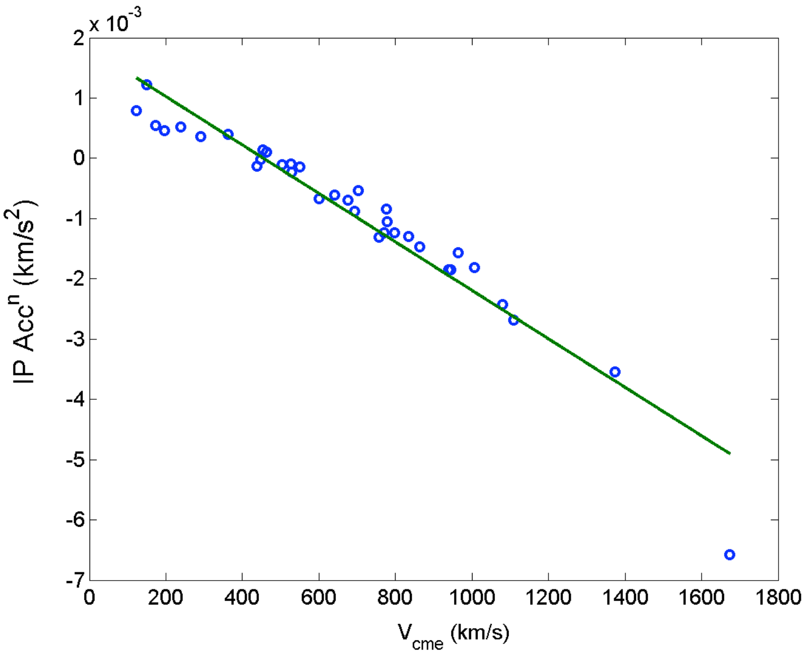


Figure 1: Correlation between effective acceleration and the CME speed calculated from the coronagraphs. Notice the vertical scale is in 10^{-3} km/s^2.

Discussion Questions:

1. ***What additional information would you like to have in order to improve your prediction of the CME arrival time?***
2. ***What additional parameters would you like to have in order to be able to predict the effect of the CME on the Earth's magnetosphere?***

Activity 5: Identifying the CME Arrival from Measured Solar Wind Data

The CME arrival can be seen in satellite measurements of the solar wind parameters such as:

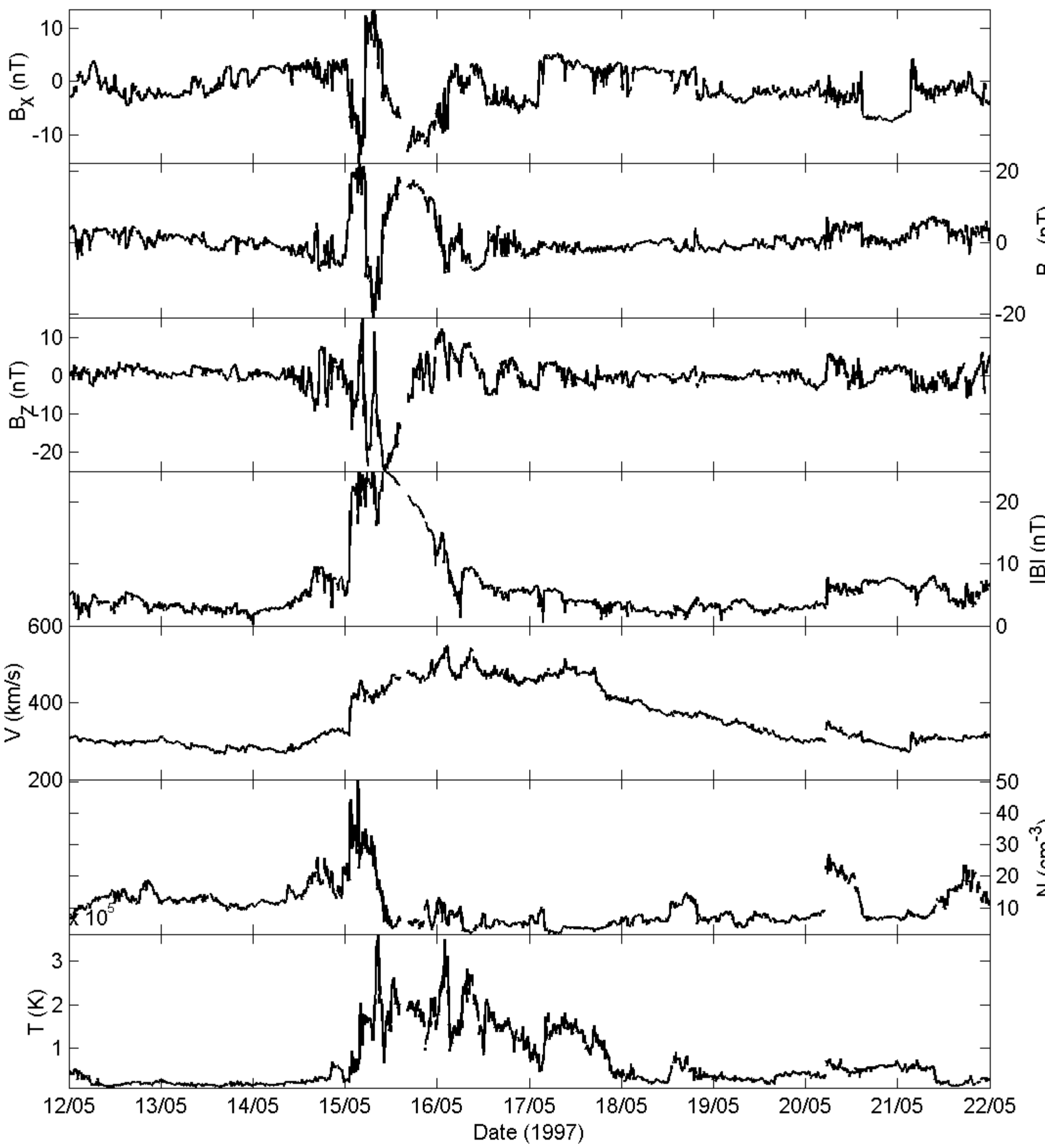
- $|B|$, B_x, B_y, and B_z – the magnitude and three components of magnetic field (measured in nano Tesla or 10^{-9} Tesla; for comparison, the Earth's magnetic field is 10's of micro Tesla or 10^{-6} Tesla)
- V – the solar wind speed (in km/s. This is actually the proton speed). Almost all the speed is in the radial direction.
- N – the proton density (measured number of particles per cubic centimeter),

- T – the solar wind proton temperature (in Kelvin)

The coordinates used to define the magnetic field are Geocentric Solar Ecliptic Coordinates (GSE), where: the positive z-axis is in the northward direction perpendicular to the ecliptic plane, the positive x-axis points from the Earth to the Sun, and the y-axis is defined by the right hand rule.

Below is a plot of solar wind data from the WIND space craft (http://www-istp.gsfc.nasa.gov/istp/wind/) which, at the time was near the L1 (1st Lagrange) point about 1.5 million km "upstream" in the solar wind.

1. ***Can you identify the arrival of the CME? What is your evidence for it?***
2. ***Can you identify different aspects of the arrival?***



10
0
-10
B_X (nT)
20
0
-20
B_Y (nT)
10
0
-10
-20
B_Z (nT)
20
10
0
|B| (nT)
600
400
200
V (km/s)
50
40
30
20
10
N (cm^{-3})
x 10^5
3
2
1
T (K)
12/05
13/05
14/05
15/05
16/05
17/05
18/05
19/05
20/05
21/05
22/05
Date (1997)

Activity 6: Seeing the Unseen: Simulating the Evolution of the Global Structure of a CME at Different Phases of the Solar Cycle

Before moving on to the simulations, try to visualize what the CME looks like as it travels from the Sun to the Earth.

1. ***Sketch the CME from a view point that has the Earth on one side and the Sun on the other.***
2. ***How will the "shape" CME evolve as it moves towards the Earth?***
3. ***Does your answer change depending on whether it is a solar min or a solar max situation?***

Now let's use the results from the simulations to see if we can answer these questions. Start CISMDX in the lab 5 directory ("**cd swss-lab/lab5**"). Load and execute the network called Cone_Model.net. The image window that appears shows two cut planes through the solar wind with the magnitude of the solar wind velocity painted on them. There is also a white translucent isosurface that represents the outer boundary of a transient density used to represent the CME in this simulation.

The event being simulated here took place on May 12th, 1997. To simulate the CME, a "blob" of plasma was placed at the inner boundary of a simulation of the solar wind using the ENLIL code. Keep in mind that this inner boundary is at approximately 21 solar radii which is much larger than the pictures that were analyzed in the previous sections.

- First, choose some field lines using the "Pick" mode in the "View Control" window (**Image Window->Options->View Control…**)
- Choose a set of field lines that are near the Earth's position.
- Now, rotate the image so that you are looking from the point of view of an observer on the Earth (with the CME traveling towards the observer).

Up till now, when we have used simulations we have explored mainly static images. In order to explore the evolution of the CME, we will have to use a series of snapshots that can then be played as a flip book movie. In the CISMDX main window (the VPE window) select the "Import" tab near the top. Inside this page you should find a module (box) labeled "Sequencer". Double click on this. A window should pop up with VCR type controls on it. There is a "play" button, a "stop" button (stopping the simulation and starting it again from the beginning when the play button is selected again) and a "pause" button (which allows for restart from the point of pausing) Click on the "play" button and watch the CME isosurface evolve in time. Notice on the VCR controls window that there is a counter which indicates the frame number. You can use this as time marks.

4. ***Is the image you see from the Earth observer point of view consistent with "Halo CME" coronagraph images you analyzed earlier?***

Now rotate the view so that the Earth is to one side and rerun the sequence.

5. ***Is the evolution of the CME shape consistent with your original prediction? Describe any differences and suggest possibilities as to why it is different.***
6. ***Have the field lines changed much as the CME swept past them? Are they still connected to the same region of the sun?***

This event happened just after a solar minimum where there are few solar equatorial active regions and the solar wind is well organized (remember the results from the previous lab). To compare, let's look at a hypothetical solar maximum case. In any CISMDX window, click on the "Windows **-> Open Control Panel by Name**" menu option and select the "**Event Directory**" panel. In the new window, replace "may12" with "solarmax" without changing anything else. Select "Execute" if it does not happen automatically. This new image is of a simulation that uses the input data from Carrington 1961 which began in late March of 2000. This was near a solar maximum situation. A hypothetical CME was placed in simulation and allowed to evolve interacting with the solar wind. Using the VCR controls from the Sequencer module, view the evolution of this CME. Look at it from a few different points of view.

7. ***Is the solar wind structure consistent with what you learned about the solar wind under solar max conditions?***
8. ***Describe the shape of the CME. How is it different from the May 12th event near solar minimum? How does this compare to your original prediction about the shape of the CME? How is the evolution of the field lines different?***