What is a CME/ICME ?

A coronal mass ejection (CME) is an ejection of material from the solar corona, detected remotely with a white-light coronagraph.

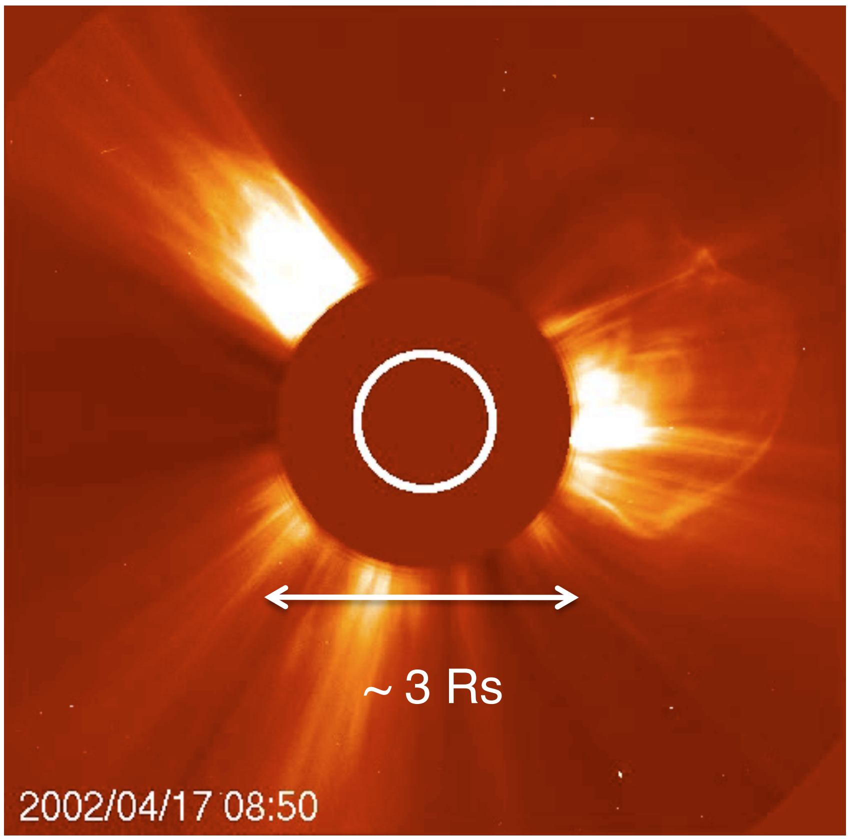
When the CME reaches the Earth as an ICME (Interplanetary CME), it may disrupt the Earth's magnetosphere, compressing it on the dayside and extending the nightside tail.

The most severe geomagnetic storms are caused by CME events. CMEs can result in damage to satellites, disruption of radio transmissions, damage to electrical transmission lines and power outages. That is why knowing the arrival time of CMEs at the Earth accurately and it’s possible magnitude of impact is of crucial importance in predicting space weather.

Here we are studying a CME that was ejected from the sun on April 17, 2002 and reached the Earth approximately 48 hours later.

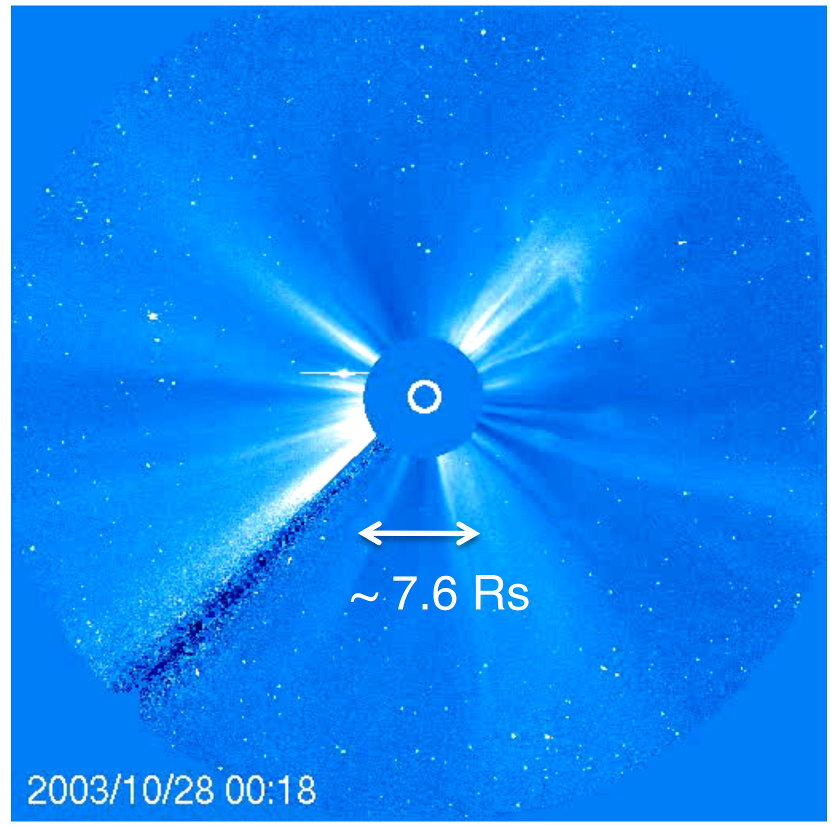
LASCO - Large Angle and Spectrometric Coronagraph

SOHO Lasco C2 coronograph



~ 12 Rs

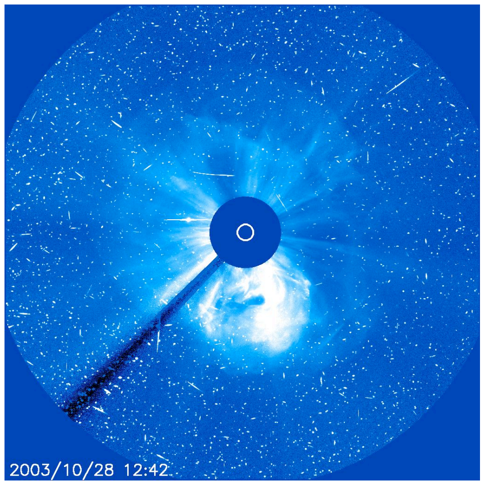
SOHO Lasco C3 coronograph



~ 60 Rs

Lasco C3 images, difference images

Regular images



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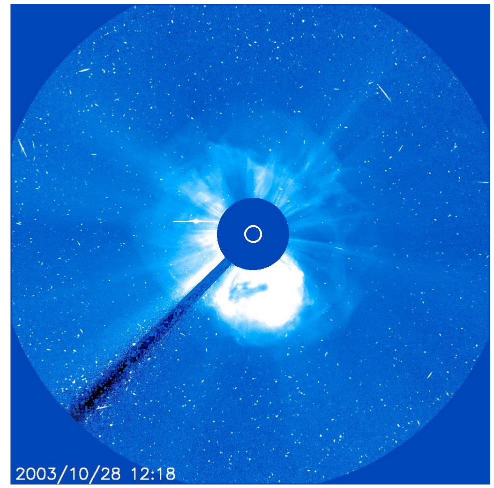
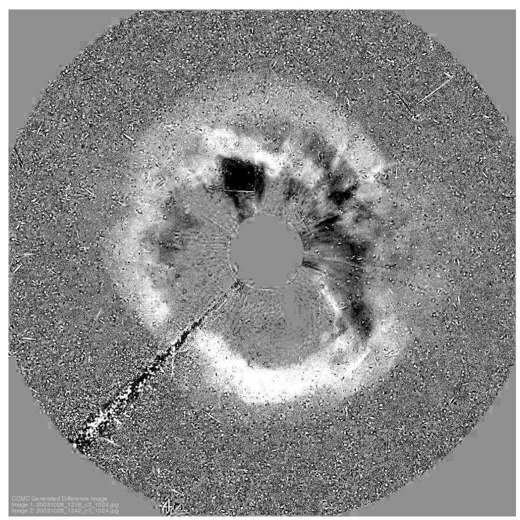


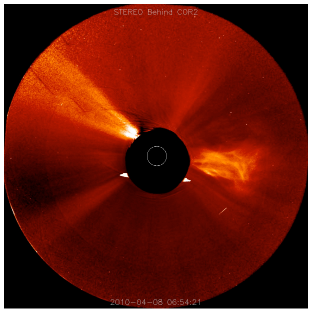
Difference image

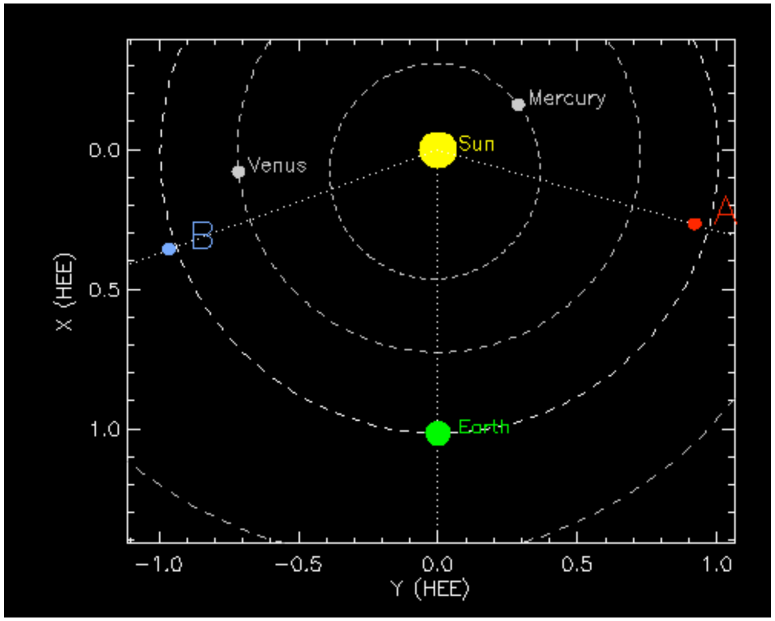
=



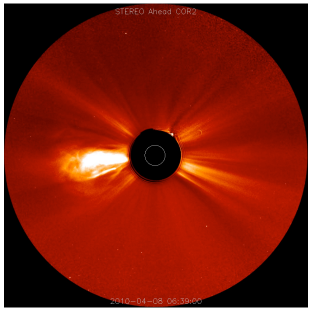
Stereo A and Stereo B satellite images – other instruments to extract CME info

View from
Stereo B
(Behind)

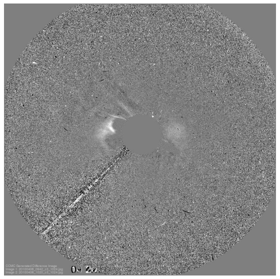




View from
Stereo A
(Ahead)

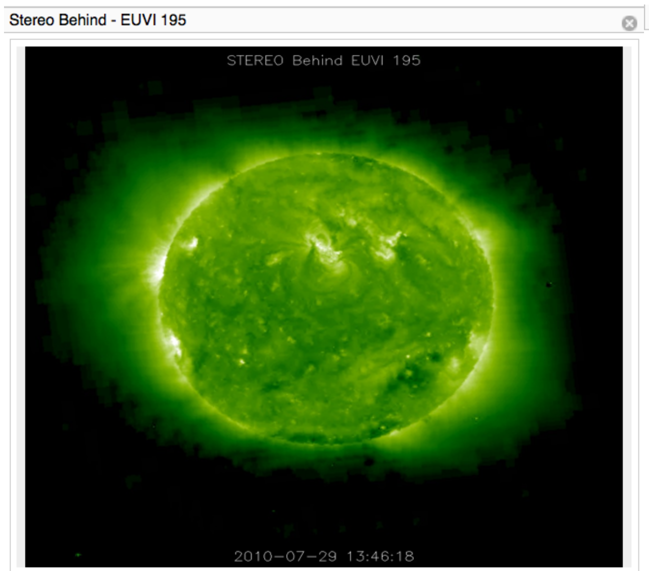


View from SOHO Lasco C3

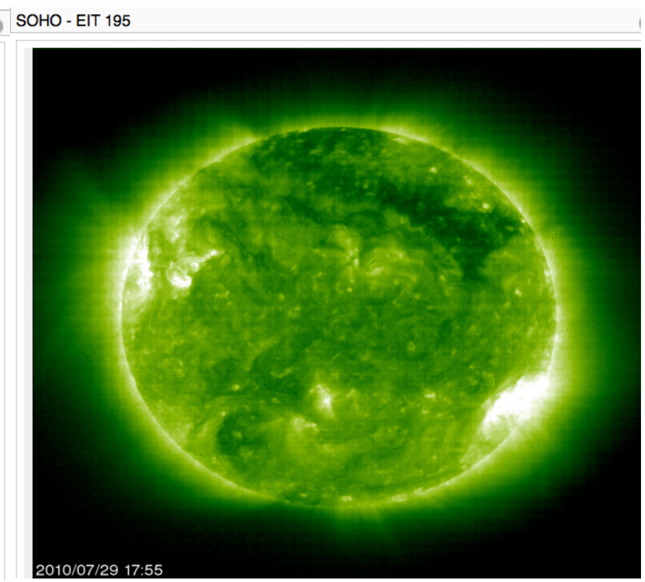


Full Disk Images of the Sun:

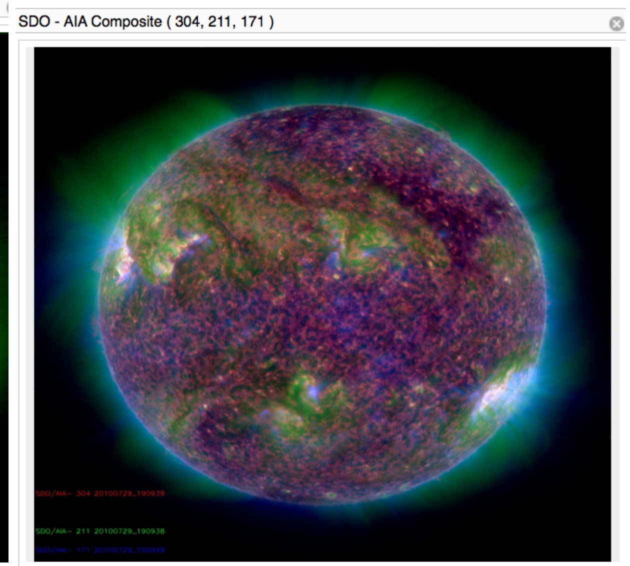
STEREO B



SOHO

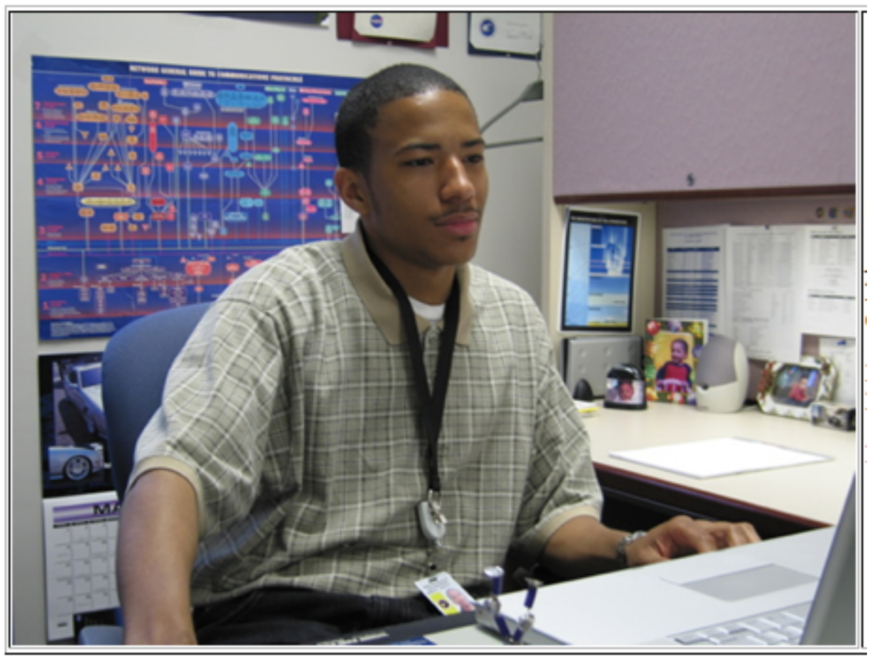


SDO



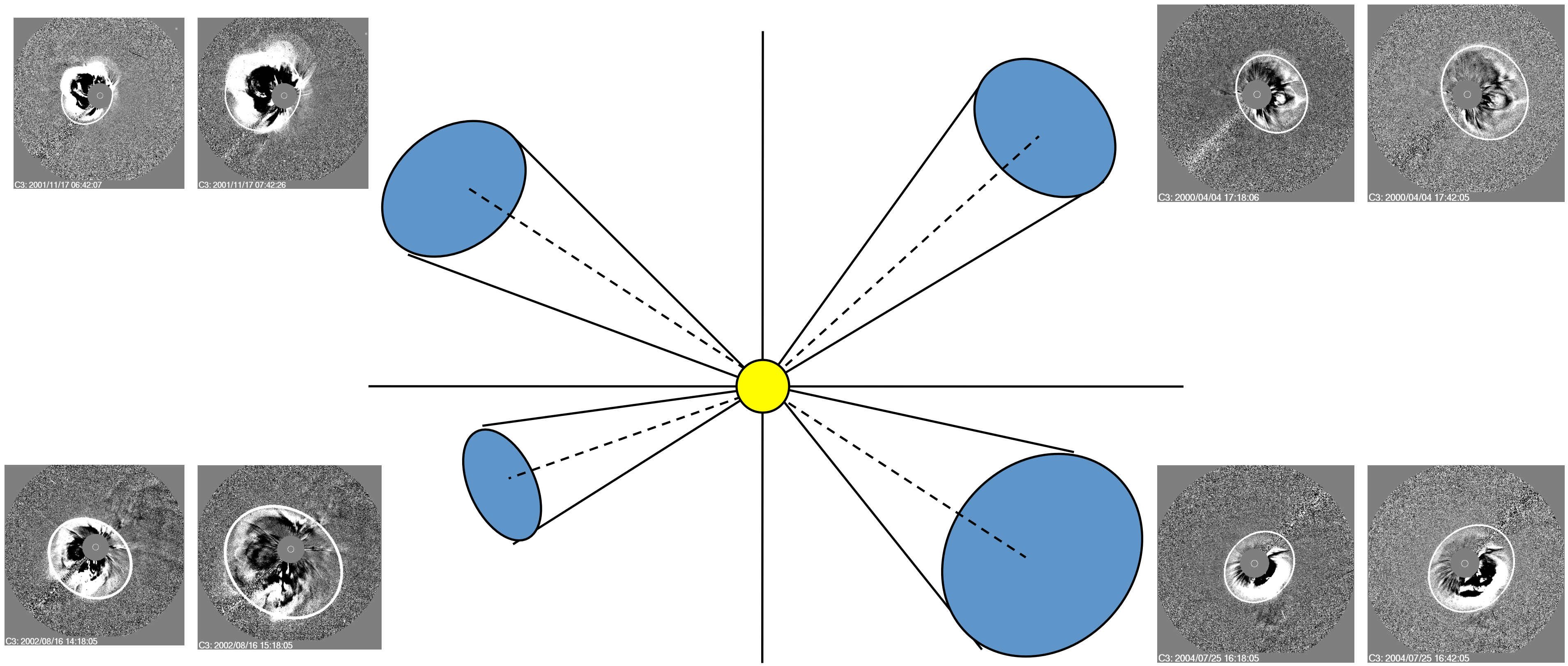
iSWA – Integrated Space Weather Analysis System

iSWA – http://iswa.gsfc.nasa.gov



Lead Developer: **Marlo Maddox**
Marlo.m.maddox@nasa.gov

CME Cone - a flashlight beaming from the center of the sun.

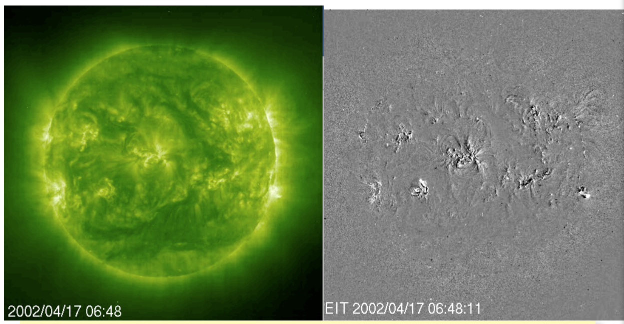


The geometry of the ellipses defines the cone direction and 2 consecutive images - how fast the ellipses grow in time, i.e. speed.

CME detection by SOHO Satellite Instruments
(Exercise 1)

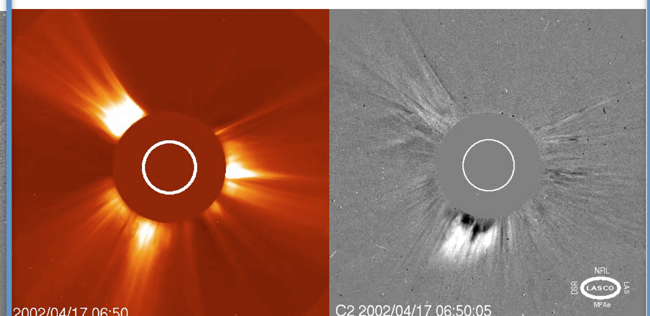
3 SOHO instrument images and the corresponding running difference images (rdiff).
(rdiff images are obtained by subtracting two consecutive regular images pixel by pixel).

EIT - EUV Imaging Telescope.



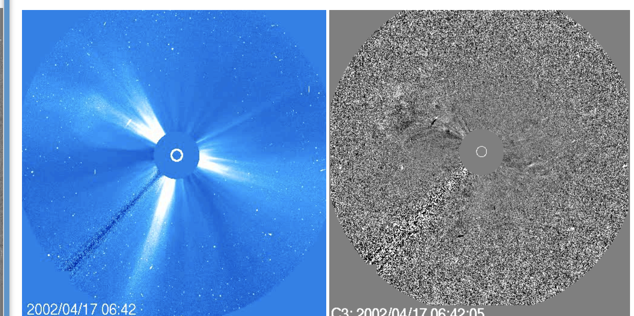
The color coded 195 A wavelength image of the sun by the Extreme Ultraviolet wavelength telescope (EIT) and the corresponding running difference image.

LASCO C2 Coronograph



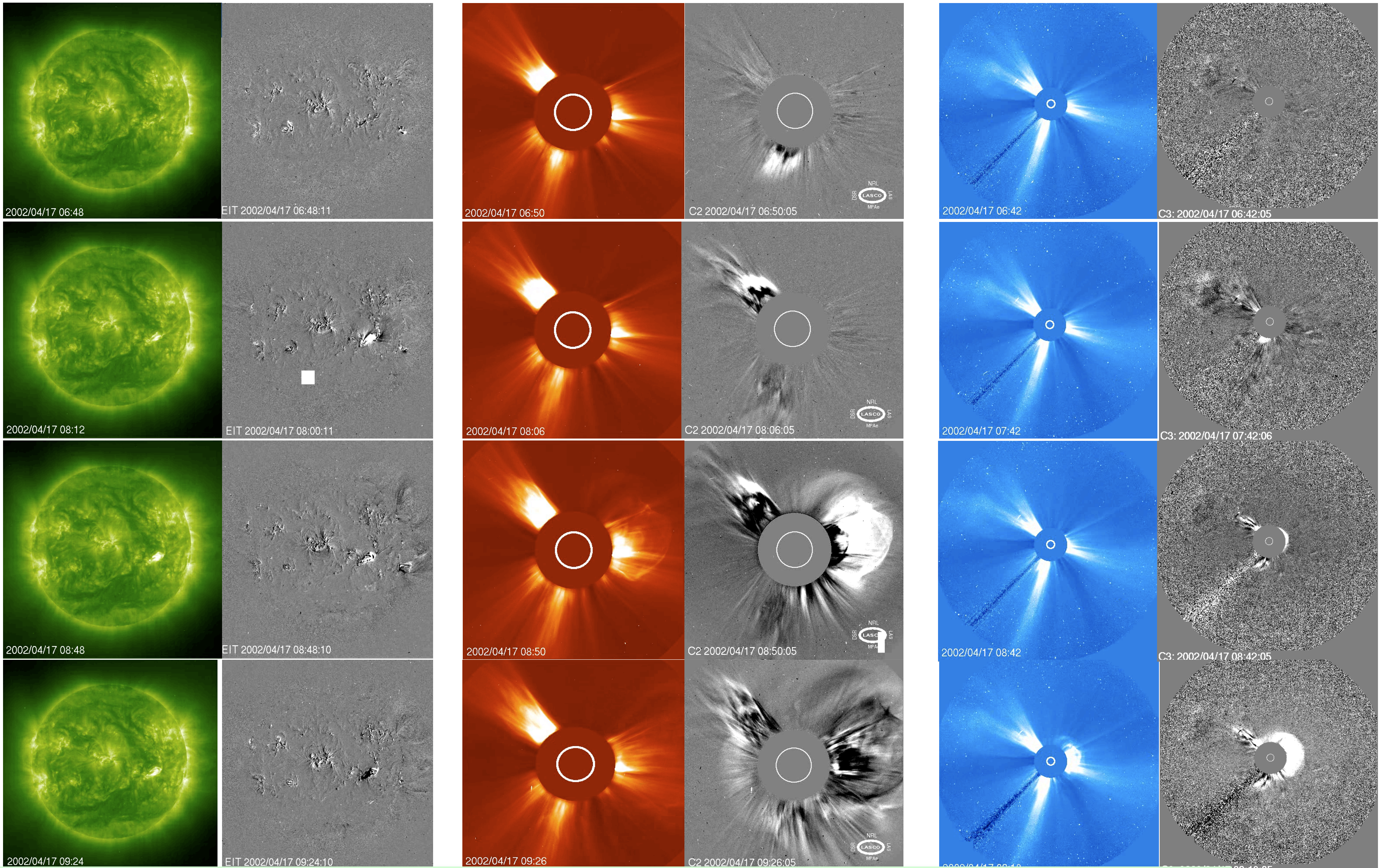
C2 white light image of the solar corona (the color is artificial) and the rdiff image. The circle in the occulter depicts actual sun location and dimension. The field of view in horizontal direction is ~ 2-4 Rs (1.5 – 6)

LASCO C3 Coronograph



C3 white light image of the solar corona (the color is artificial) and the rdiff image. The circle in the occulter depicts actual sun location and dimension. The field of view in horizontal direction is ~4-28.6 Rs (3.5 – 60)

SOHO Satellite Instrument Images for 4 Moments of time t1<t2<t3<t4.



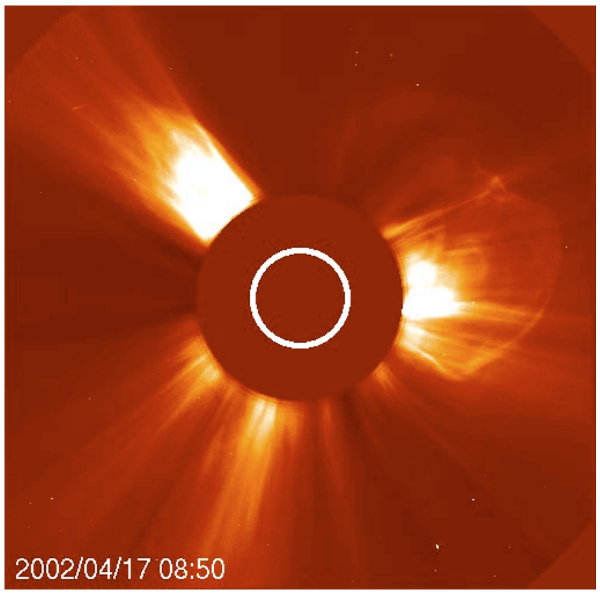
Exercise 1: Which instrument has detected the CME appearance first and when?

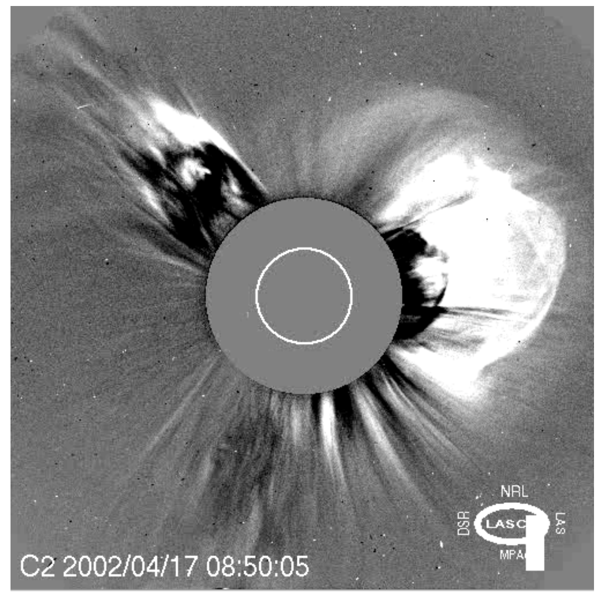
CME Velocity Estimate
(Exercise 2)

C2 Coronograph Image for the Moment of Time t3

The CME is very prominent in C2 image, but yet barely noticeable in C3 image.

t3





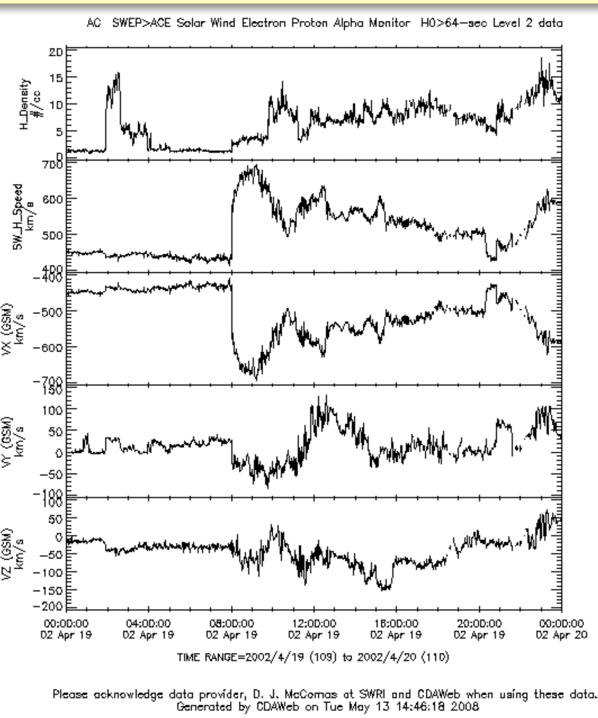
Exercise 2:

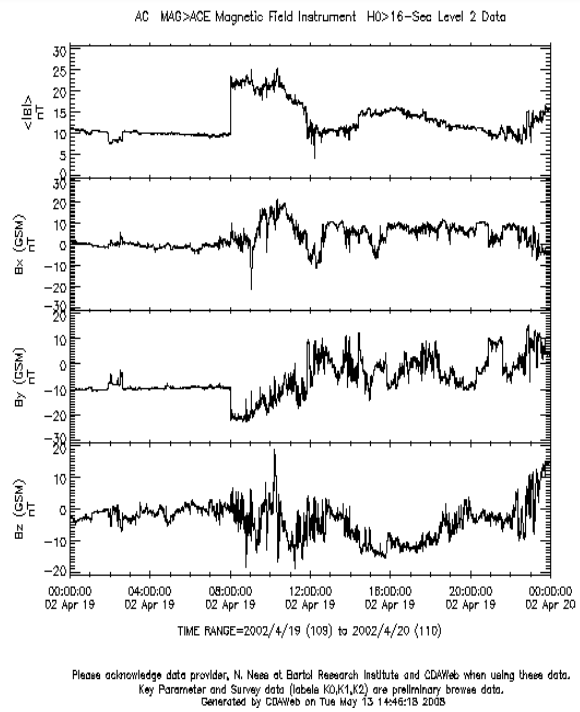
Estimate the projection of speed of the CME on the plane of sky V. Assume that the CME leading edge reached the C2 window edge in horizontal direction (4.5 Rs, solar radius Rs=700,000 km) at the moment of time 2002/04/17 08:50 UT. The CME start time 2002/04/17 08:00 UT.

ICME Detection by ACE Satellite

(Exercise 3)

The CME shock arrival is characterized by the sharp jump in all measured parameters.





Exercise 3:

Assuming that the ICME propagates with the speed V calculated in the Exercise 2, estimate the ICME arrival date and time to the Earth, given that the distance from the sun to the Earth is 1AU~ 150,000,000 km .
What is the difference with the actual arrival time detected by the ACE?

Average CME Speed from the Catalog at IACS CUA

(http://cdaw.gsfc.nasa.gov/CME_list/)

(Exercise 4)

There were 8 halo CMEs in March and April of 2002 listed in this catalog.

CME date	Catalog POS speed At 2 Rs (km/sec)
2002/03/10	1429
2002/03/11	950
2002/03/14	907
2002/03/15	957
2002/03/18	989
2002/03/20	603
2002/03/22	1750
2002/04/15	720

The table shows halo CMEs in March and April 2002 listed in the catalog, just before 2002/04/17 CME occurred. One of the ways of forecasting CME arrival times is to estimate the propagation time of an "average" speed CME.

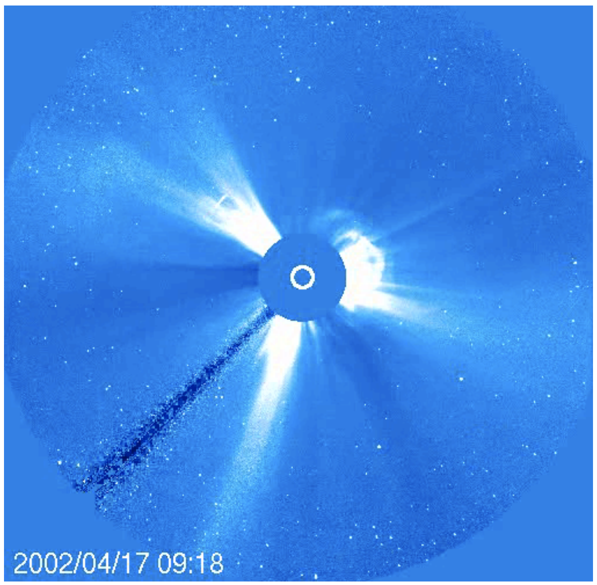
Exercise 4:
Taking the average of halo CME speeds listed in the Table estimate the arrival time of the "average" speed CME to the Earth and compare it to the observed arrival time and the arrival time obtained in the Exercise 3.
Which of the estimates worked better?

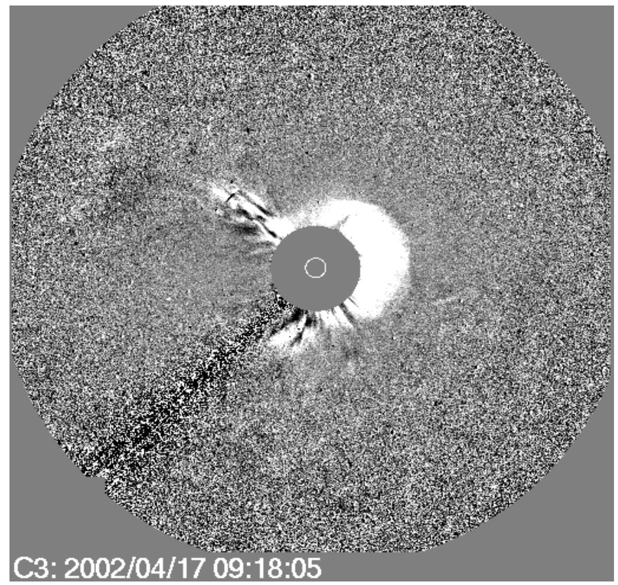
Cone model for CME/ICME propagation (Exercise 5)

C3 Coronograph Image for the Moment of Time t4

The CME is noticeable already in C3 image.

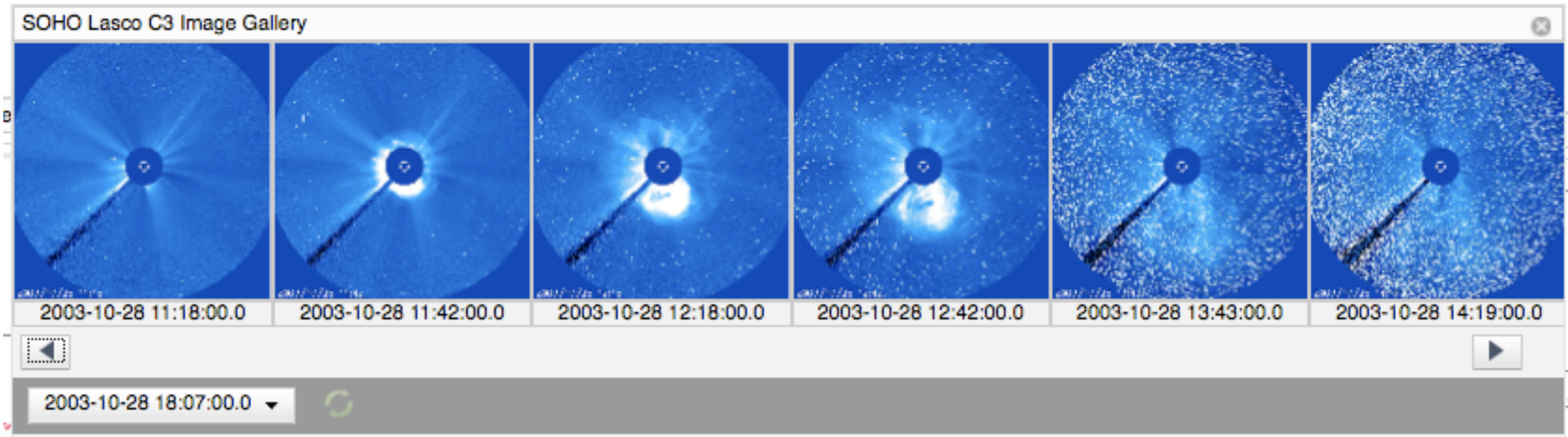
t4

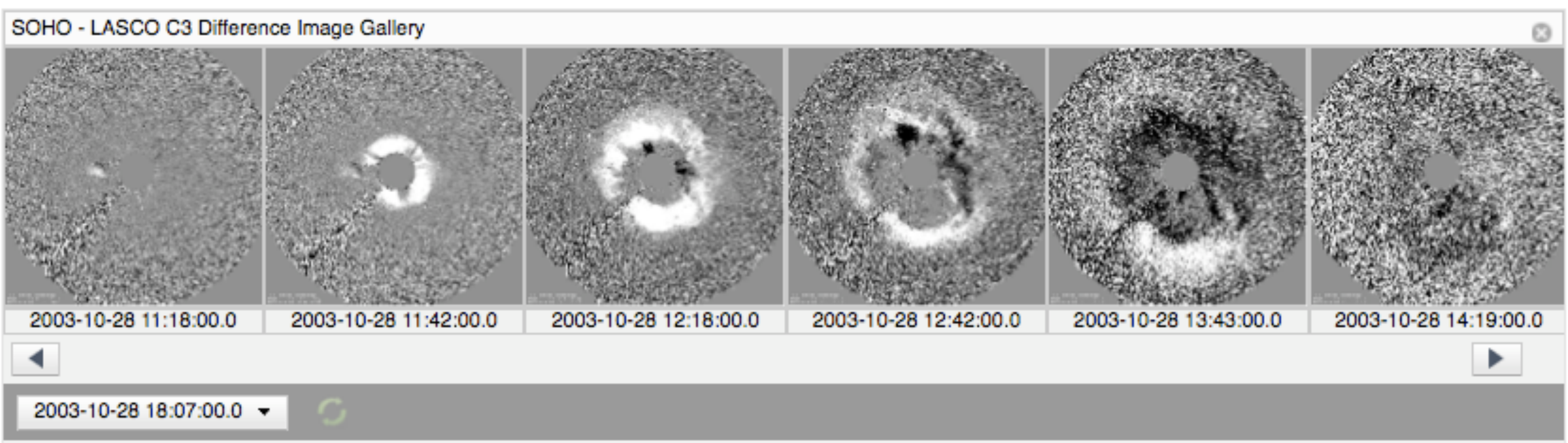




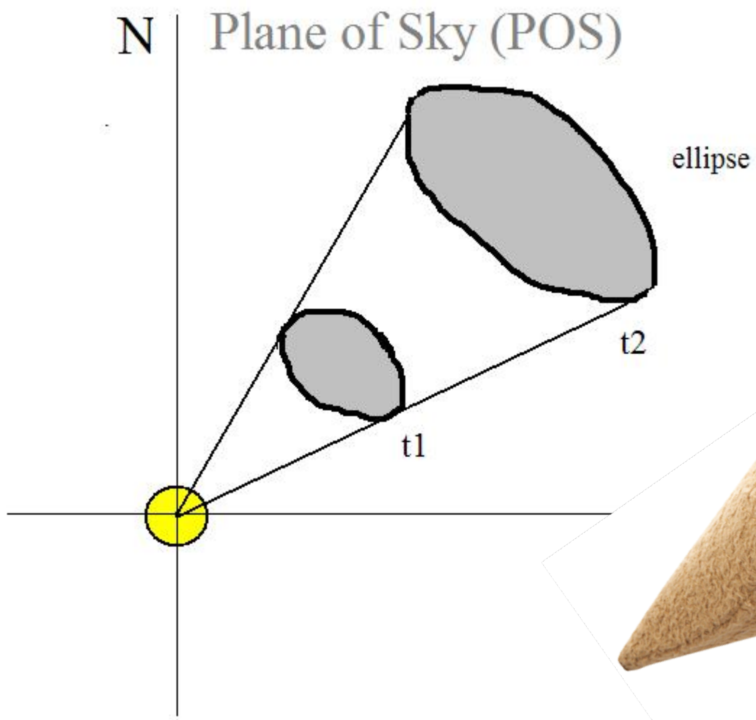
LASCO C3 images are used in the Cone Model analysis for Halo CMEs to estimate the CME speed more accurately and deduce the orientation of the CME propagation- input needed for ENLIL heliosphere model.

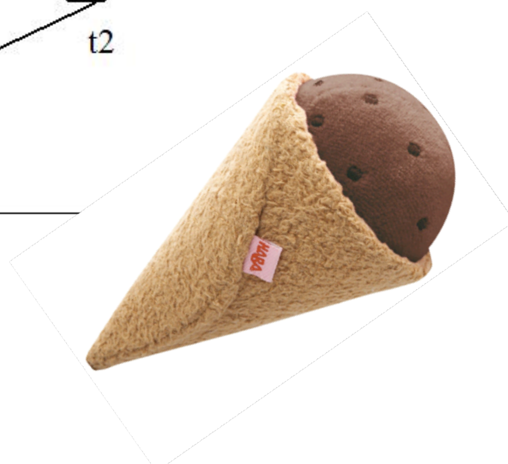
iSWA Lasco C3 image gallery

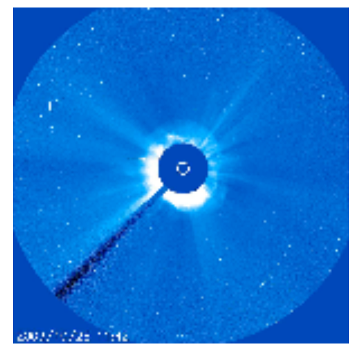


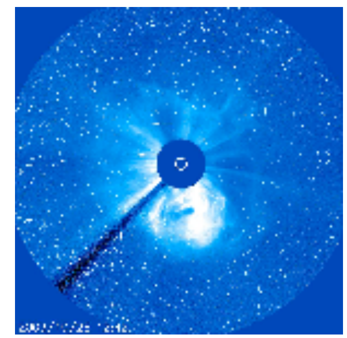


Lasco C3 images -> extract CME info.
Cone model concept.



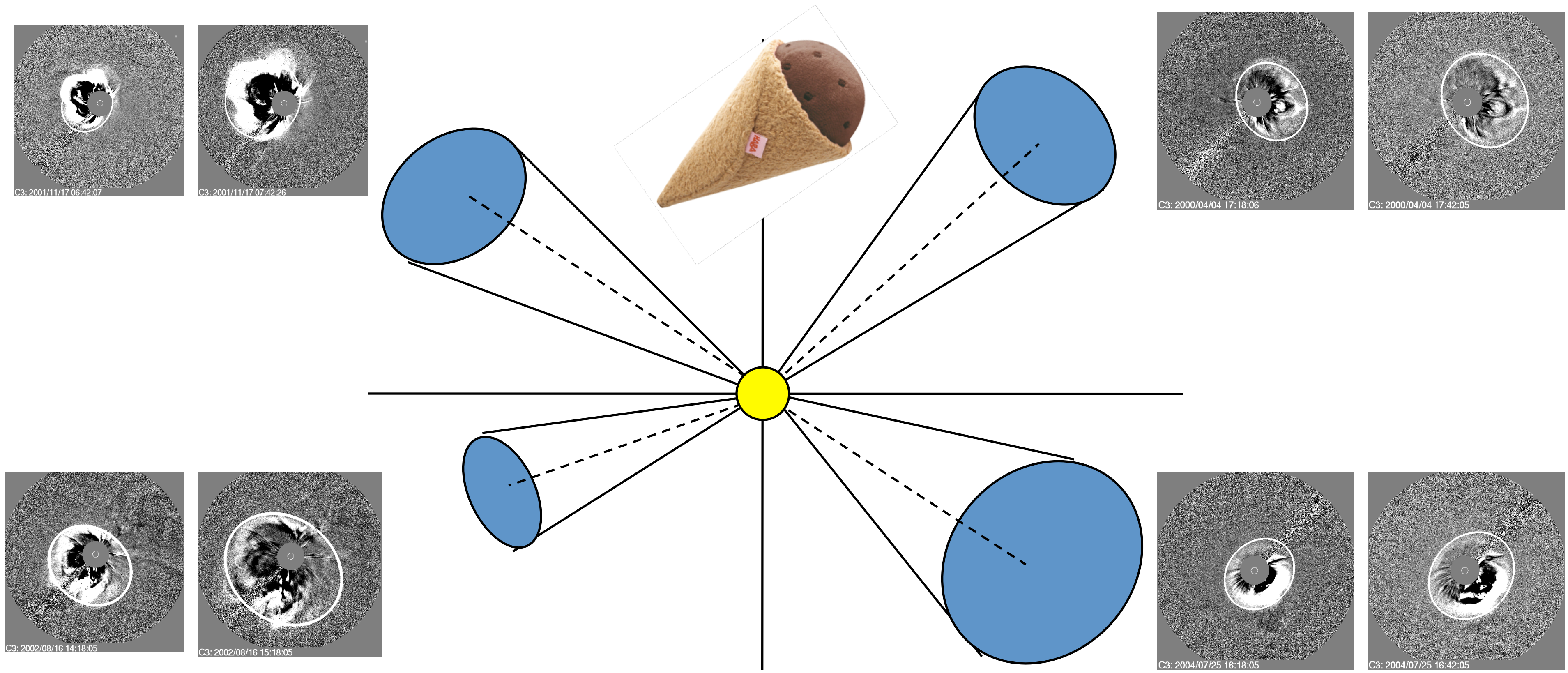






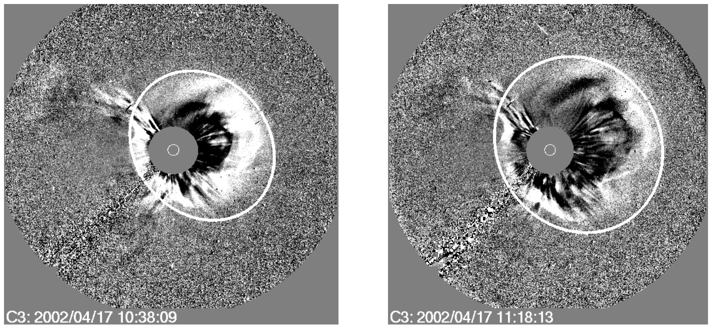
CME image is a projection of the cone in POS

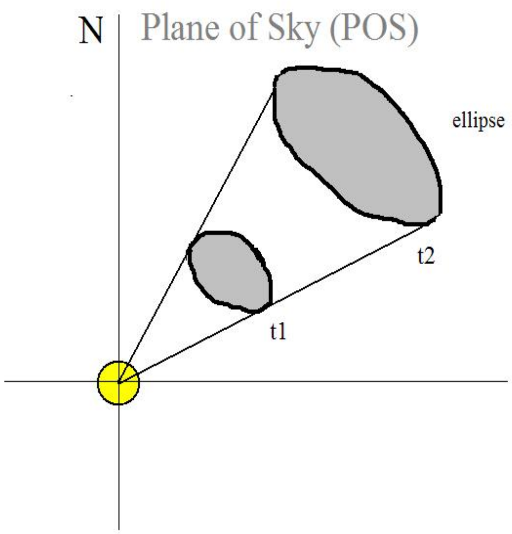
CME Cone - a flashlight beaming from the center of the sun.



The geometry of the ellipses defines the cone direction and 2 consecutive images - how fast the ellipses grow in time, i.e. speed.

Cone Model for Halo CME





The concept:

• CME propagates with nearly constant angular width in a radial direction

• The source is near the solar disc centre

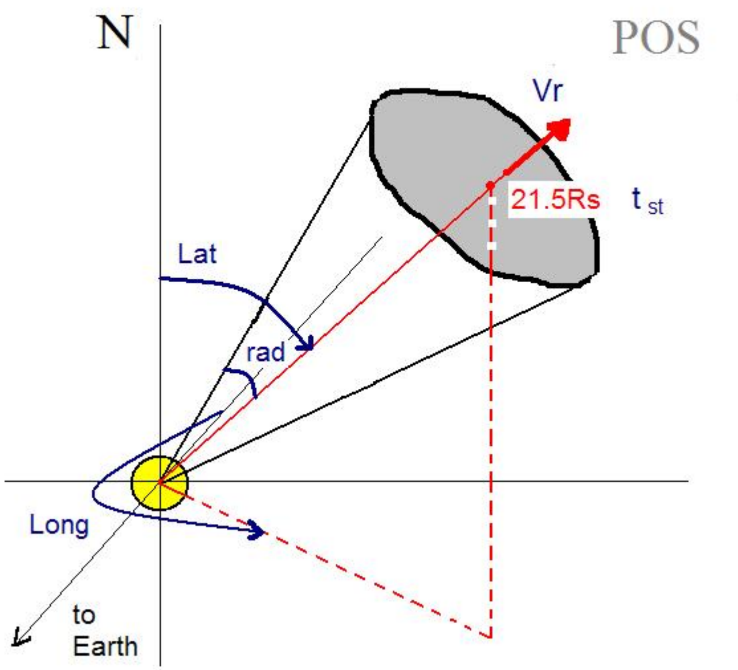
• CME bulk velocity is radial and the expansion is isotropic

Analytical method:

• The projection of the cone on the POS is an ellipse

• From two ellipses of two consecutive C3 running difference images we can derive the CME radial speed and the cone orientation – input to the ENLIL heliosphere model

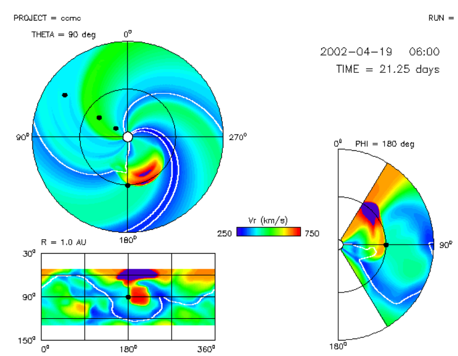
Cone Model Parameters – Input to the ENLIL Cone Model



Date=2002-04-17
Tstart=11:20 (UT)
Lat=77 deg
Long=202 deg
Rad=49 deg
Vr=1134 km/s

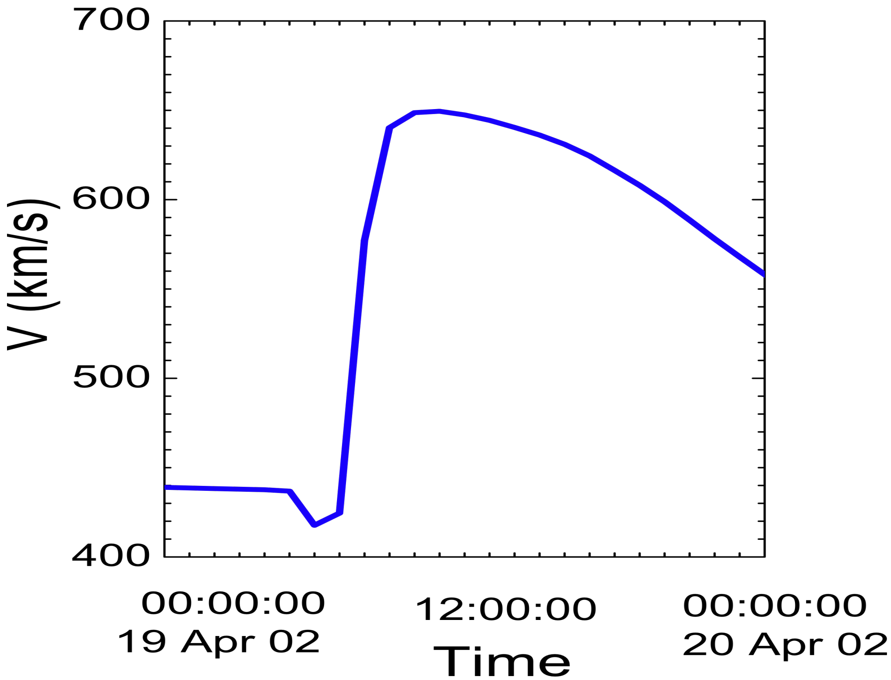
Input to ENLIL cone model run

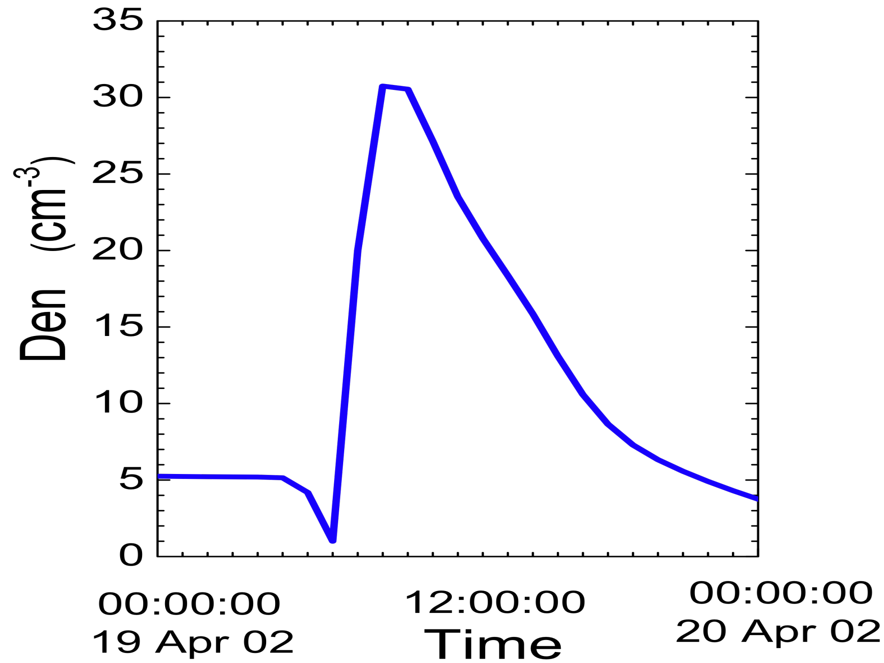
ENLIL cone model



- t_{start} - when cloud at 21.5R_s
- Latitude
- Longitude
- Radius (angular width)
- V_r - radial velocity

ENLIL Cone Model Result for the 2002/04/17 CME





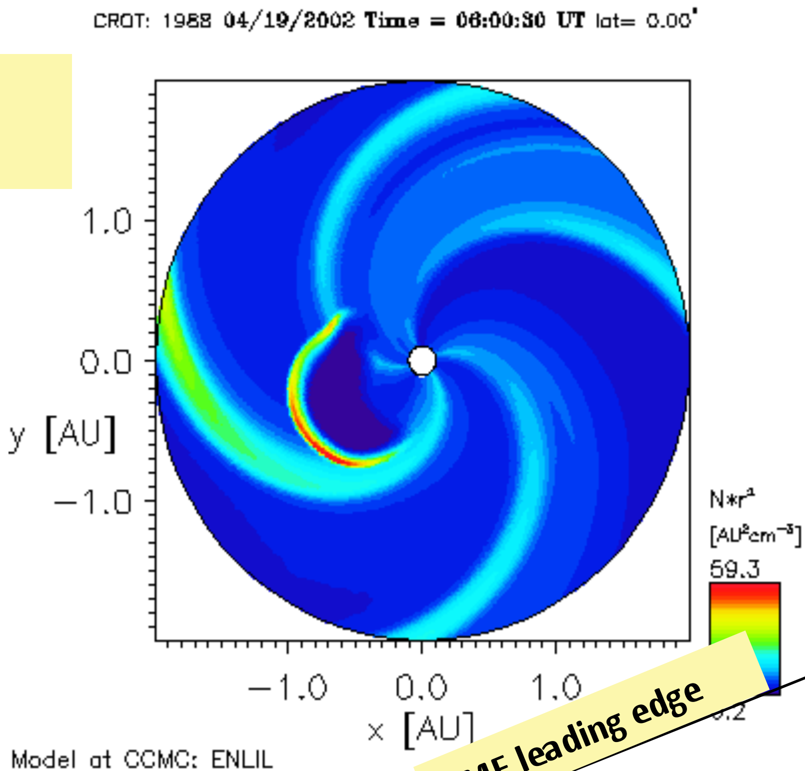
ENLIL: Density and velocity magnitude of the solar wind at the ACE position (R=0.99 AU, Latitude=0 deg, Longitude=180 deg)

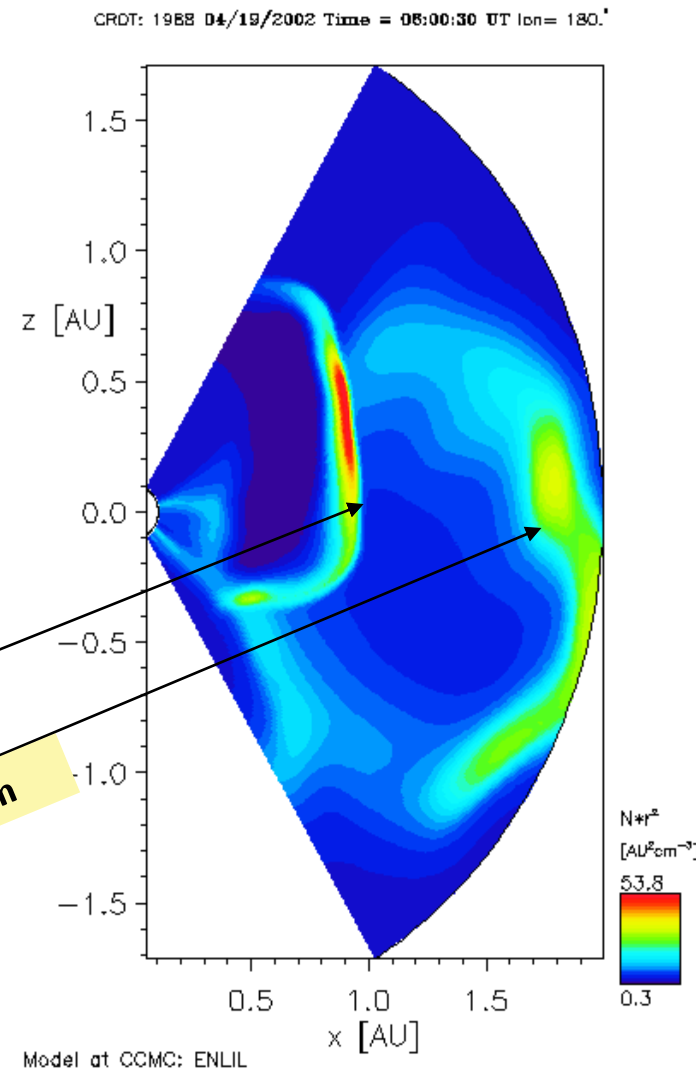
Exercise 5:

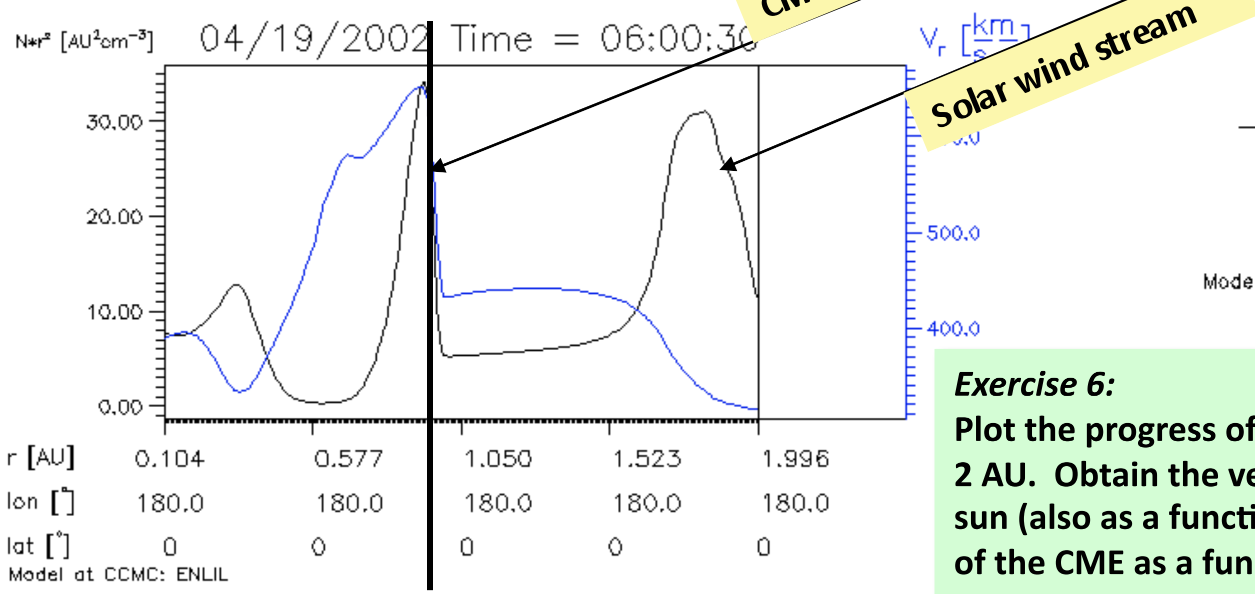
From the ENLIL results for density and velocity (above, plot to the right) determine the ICME shock arrival time and compare it to the observed arrival time and the arrival times obtained in the previous Exercises.

Which of the estimates worked better?

The CME when it reaches 1 AU

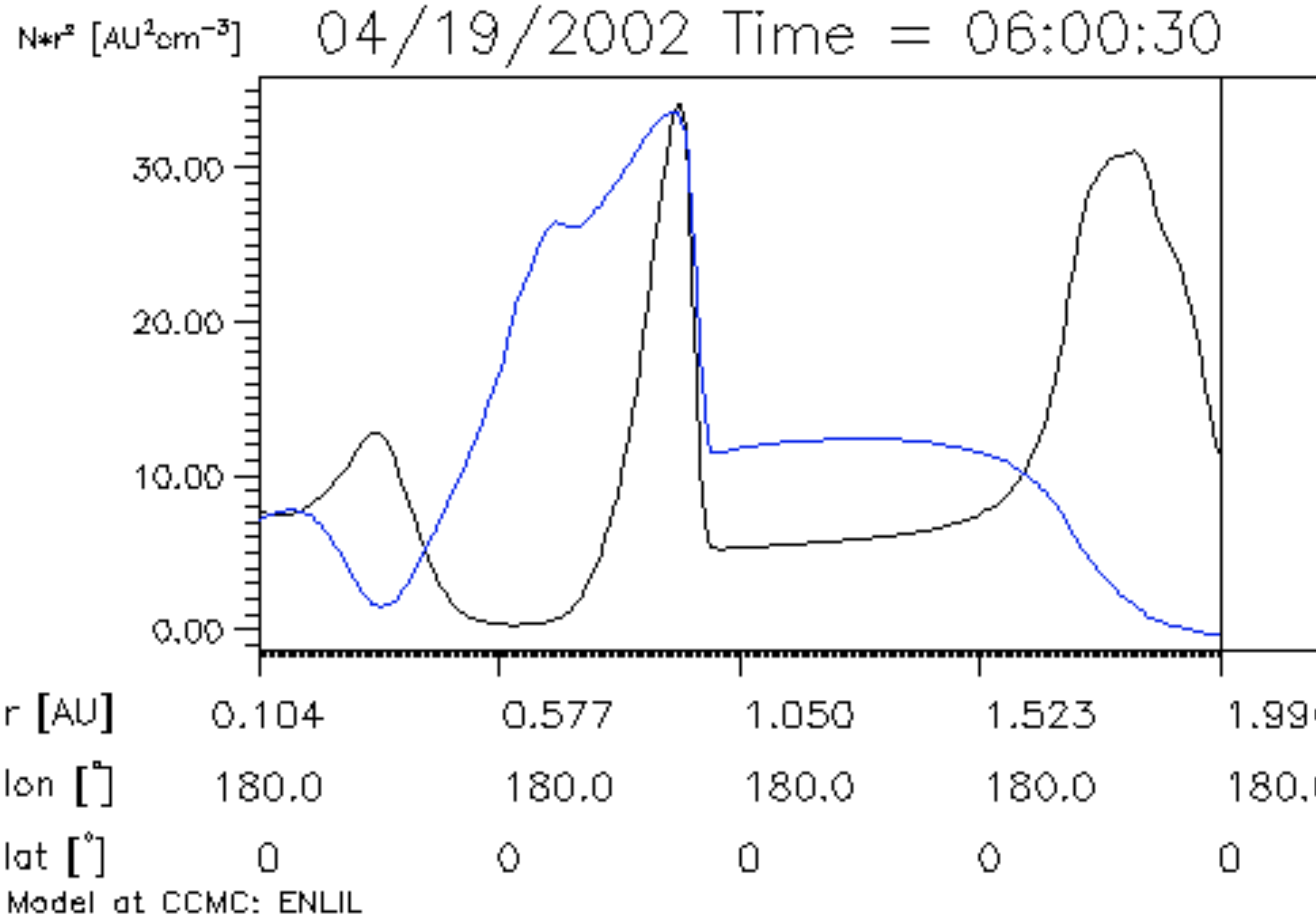






Exercise 6:

Plot the progress of the CME leading edge from its origin to 2 AU. Obtain the velocity as a function of distance from the sun (also as a function of time). Estimate the deceleration of the CME as a function of distance.


N*r² [AU²cm⁻³]
04/19/2002 Time = 06:00:30
30.00
20.00
10.00
0.00
r [AU]
0.104
0.577
1.050
1.523
lon [°]
180.0
180.0
180.0
180.0
lat [°]
0
0
0
0
0
Model at CCMC: ENLIL