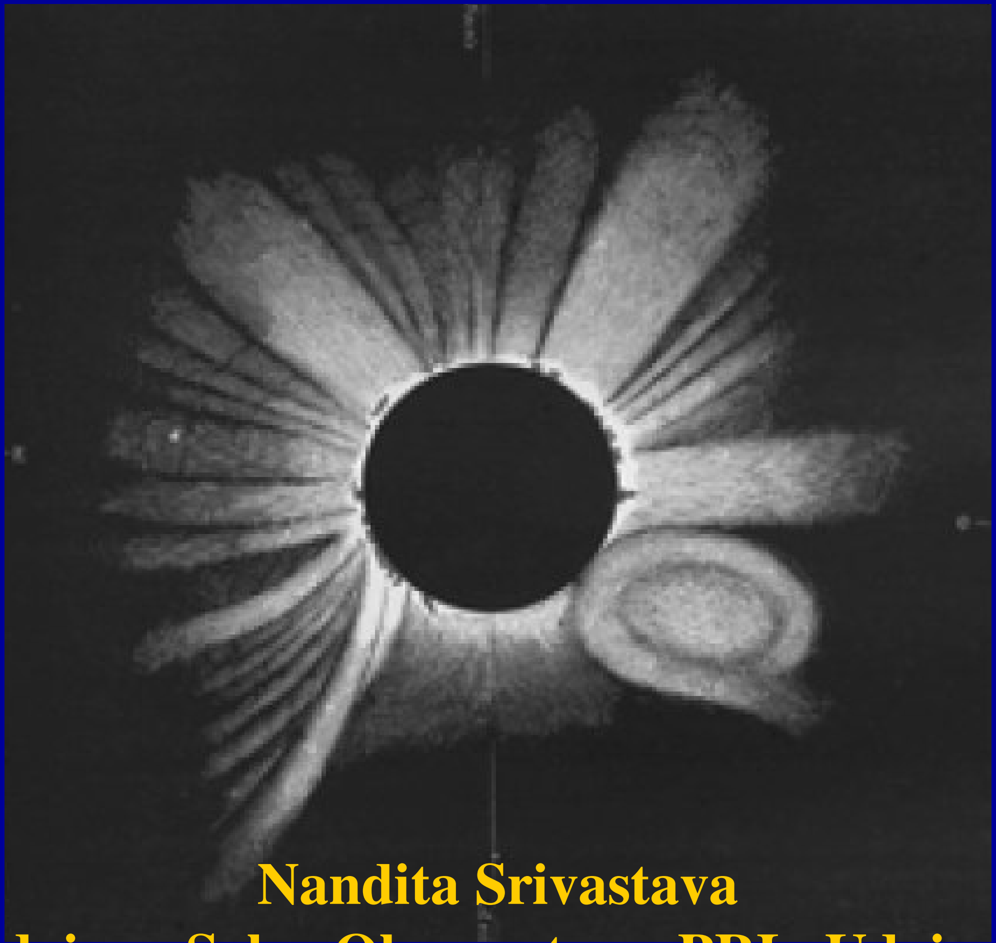
Statistical studies on Coronal Mass Ejections



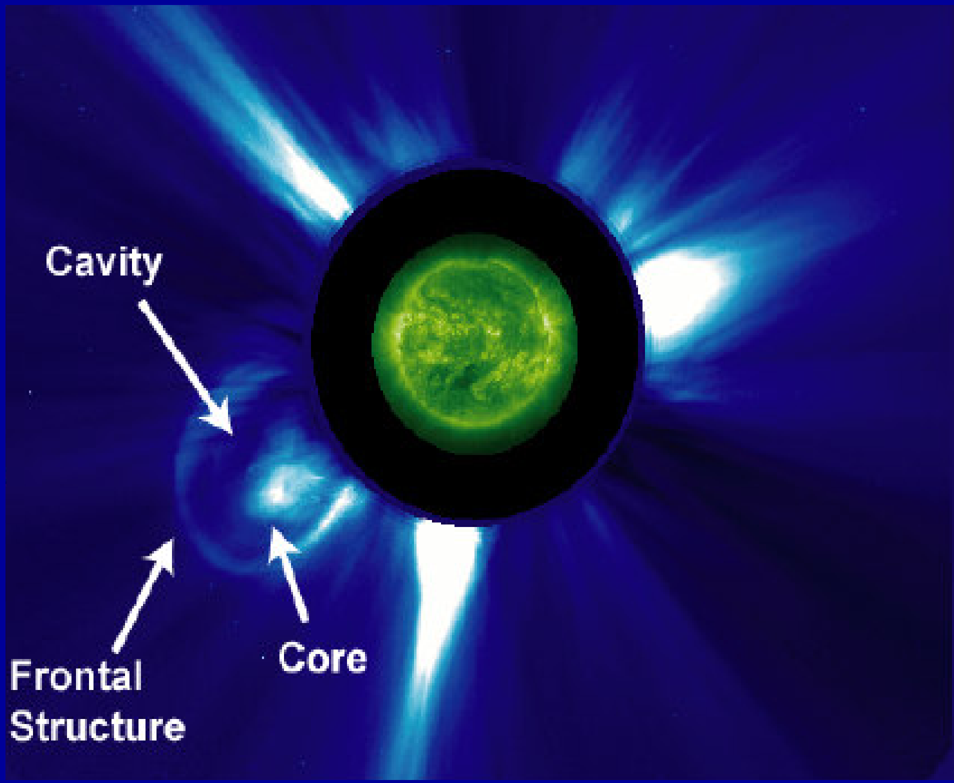
Nandita Srivastava
Udaipur Solar Observatory, PRL, Udaipur

Bangalore, Dec 2-5, 2008

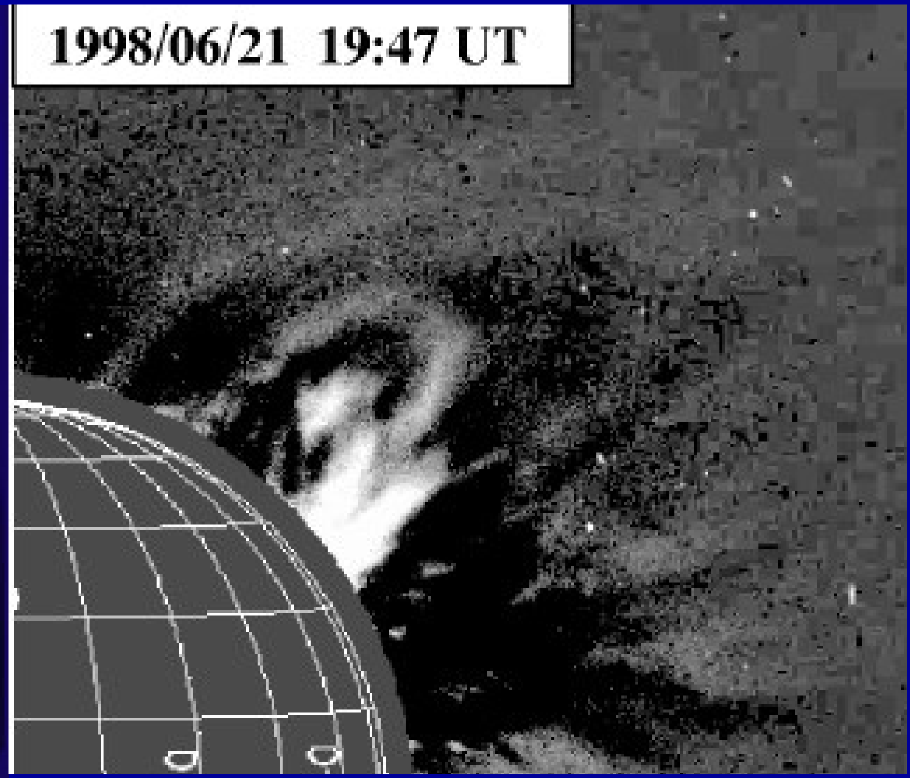
Outline of the talk

1. What have we learnt from SoHO observations?
2. New views of Coronal Mass Ejections from STEREO

Morphological Properties



White light (Gopalswamy et al. 2006)



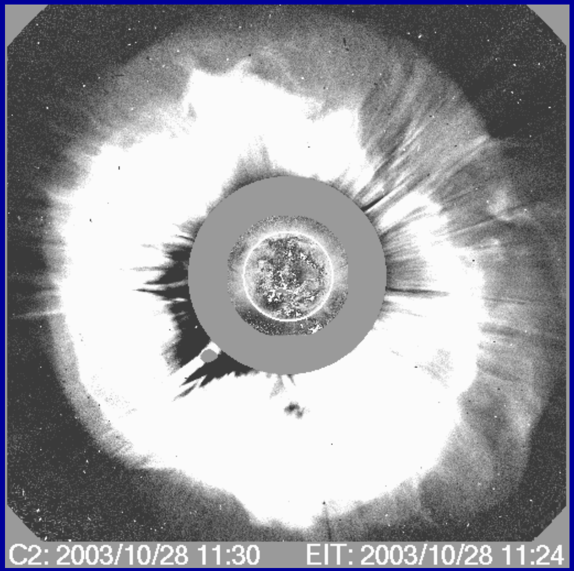
FeXIV –LASCO-C1, Srivastava et al. (2000)

Three part Structure

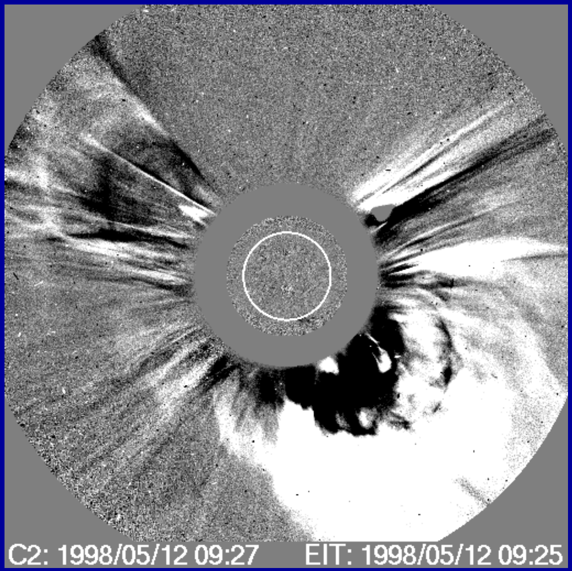
- Bright Leading edge
- Dark cavity
- Bright Knot has mostly dense prominence material

Types of CMEs

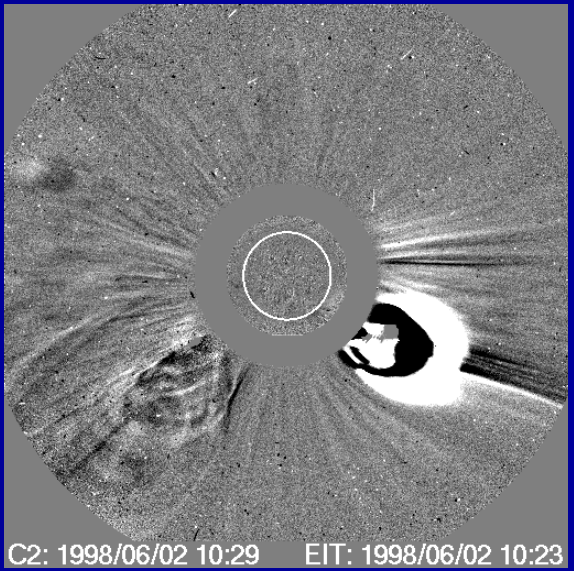
Full halo

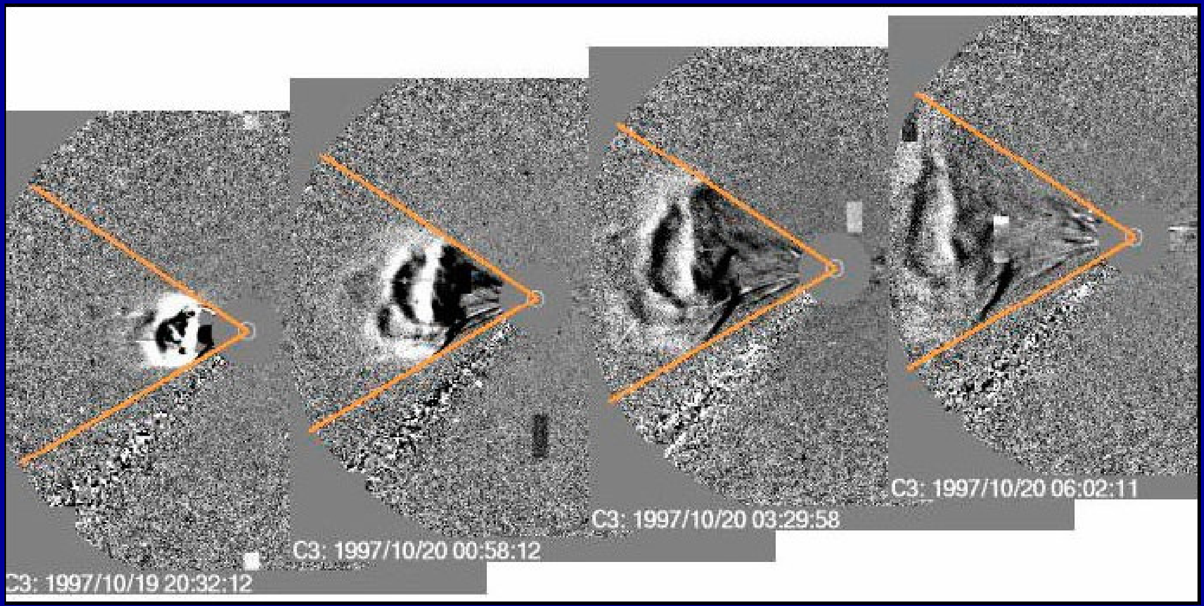


Partial halo



Limb CME



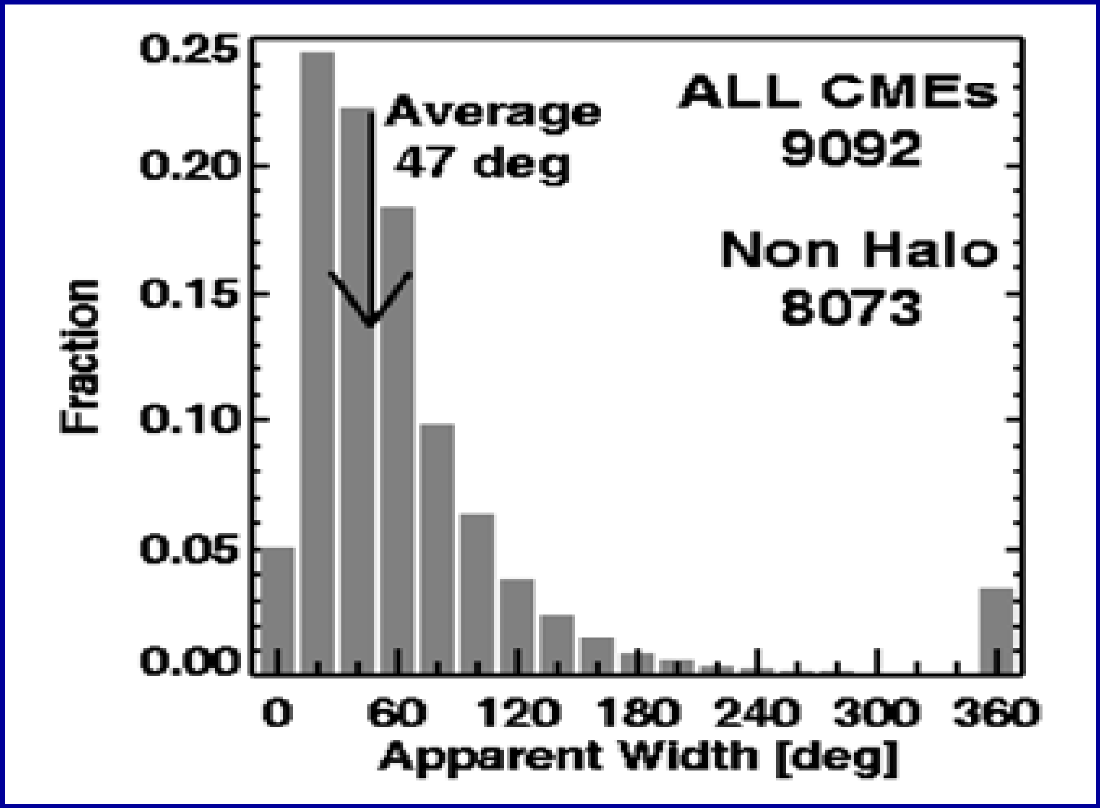


The cone angle and the general shape of CME is maintained (Plunkett et al. 1998, Schwenn et al. 2005). Ratio between the lateral expansion and radial propagation remains constant.

Vrad=0.88 Vexp

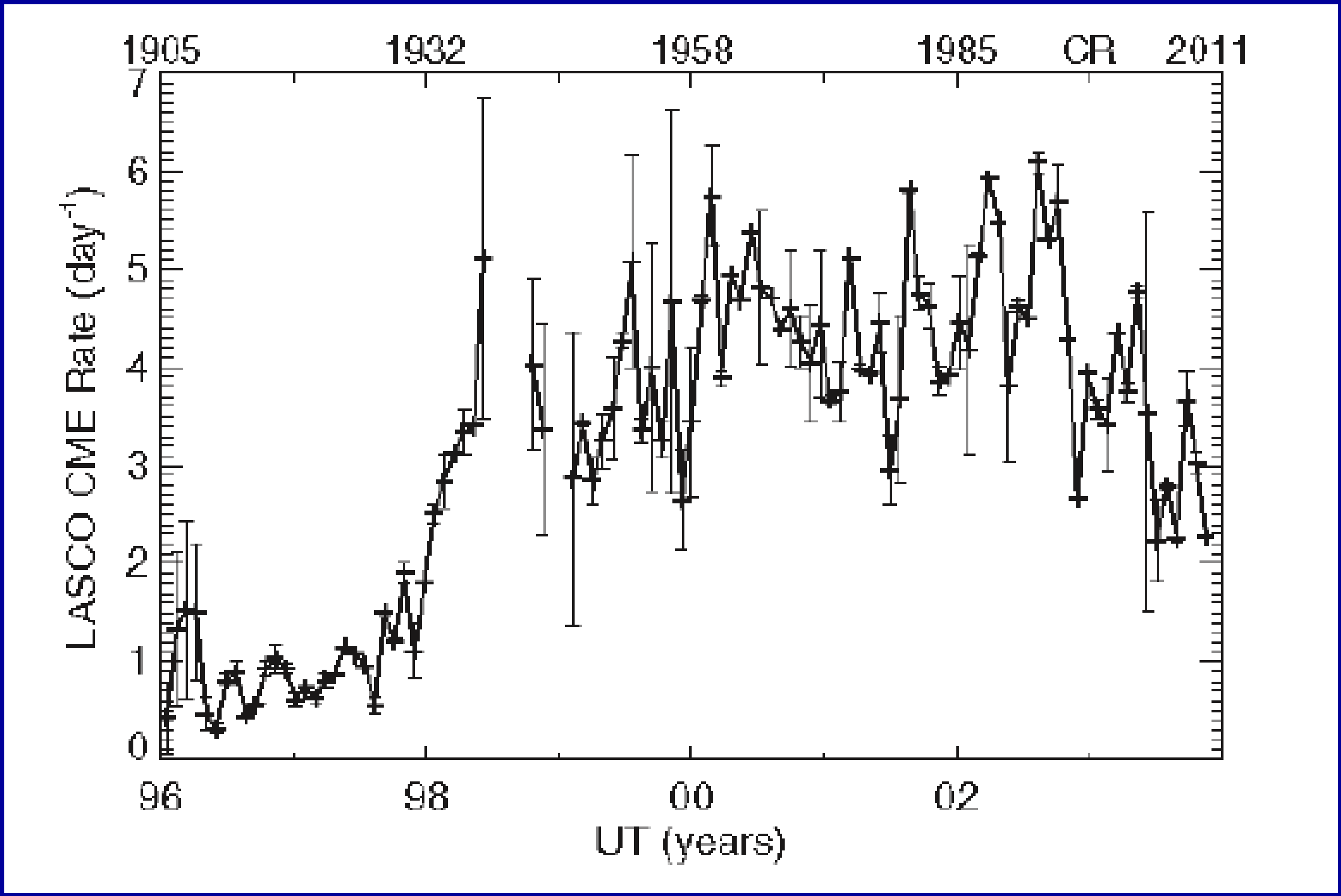
Morphological Properties

Angular Size or apparent widths



Yashiro et al. (2004)

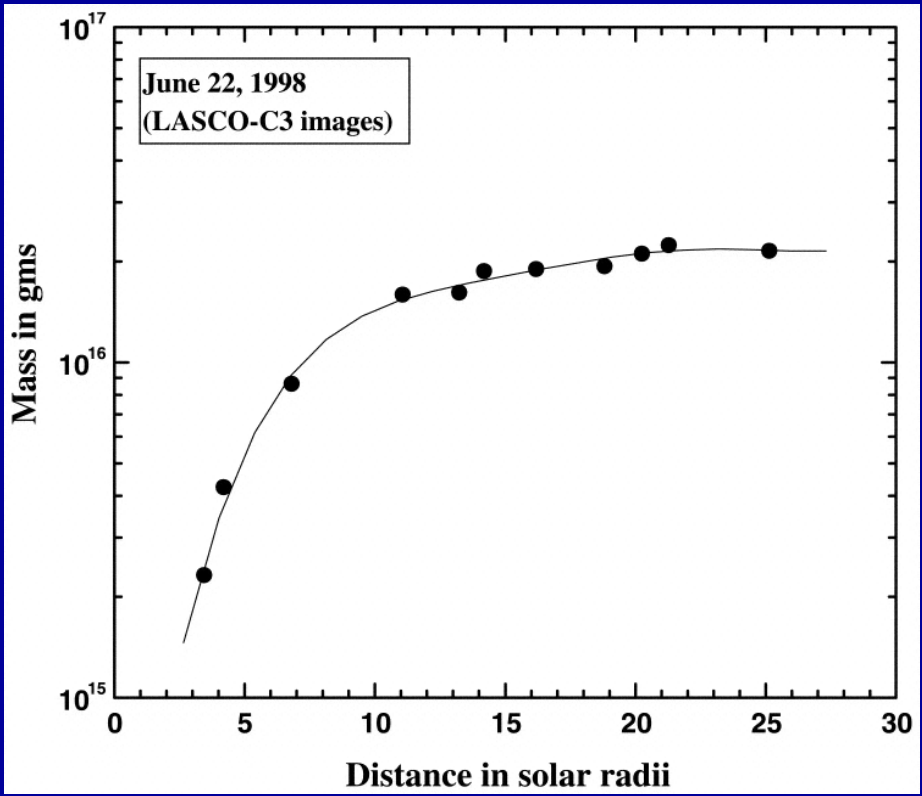
CME Occurrence Rates



0.3 per day (solar min) to 4-5 per day (solar max)

Gopalswamy et al. (2004)

CME Mass Estimates



Srivastava et al. (2000)

Masses: Derived from white light images 10^{15} -10^{16} gm

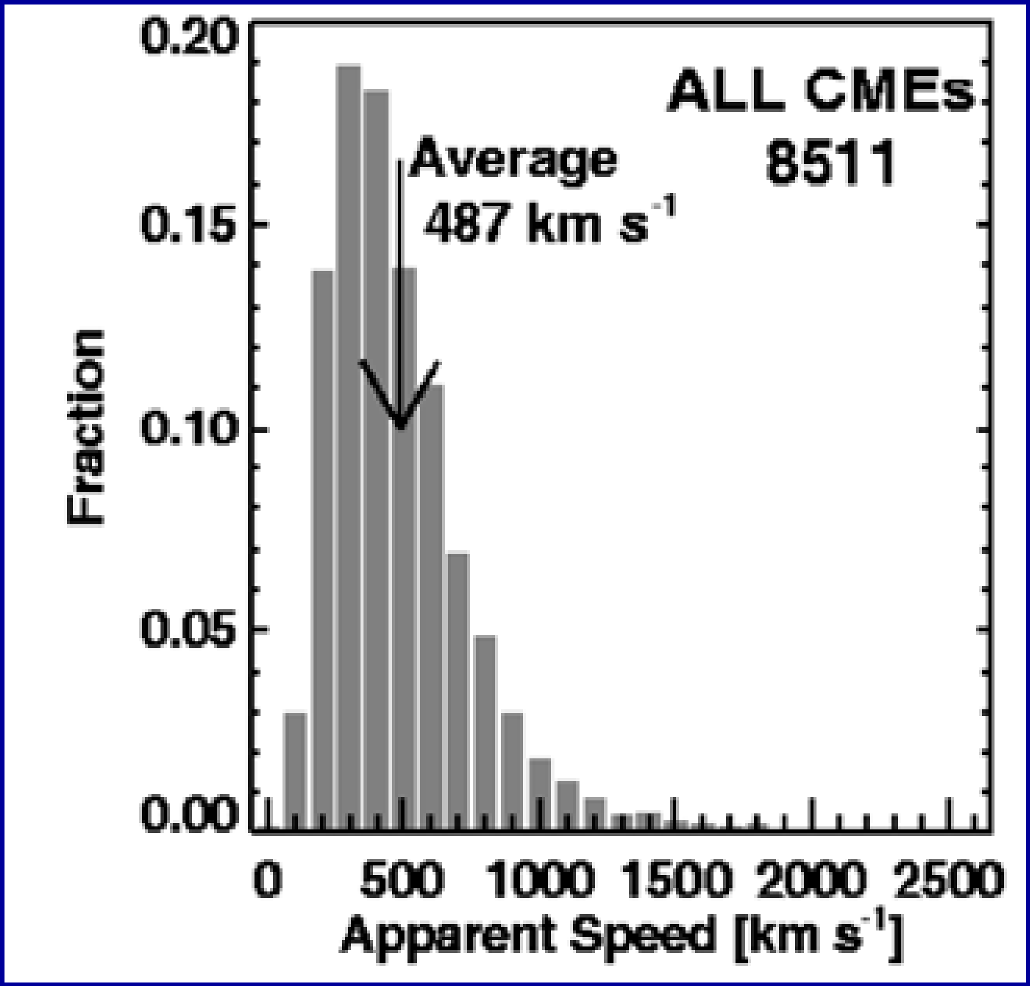
•Kinetic Energy: 10^{31}-10^{32} ergs.

Average CME Properties

Parameter	LASCO	Solwind
Observing Duty cycle	81.7%	66.5%
$\langle E_{kin} \rangle$ (erg)	2.6×10^{30}	3.5×10^{30}
$\langle$Mass$\rangle$ (g)	1.4×10^{15}	4.1×10^{15}
Mass Flux (g/day)	2.7×10^{15}	7.5×10^{15}

Vourlidas et al. (2002)

Kinematics



Speeds

Range of speeds: 10-3000 Km/s

Average speed is 470 km/s

But varies with solar cycle

Speeds in descending phase lower than in the minimum

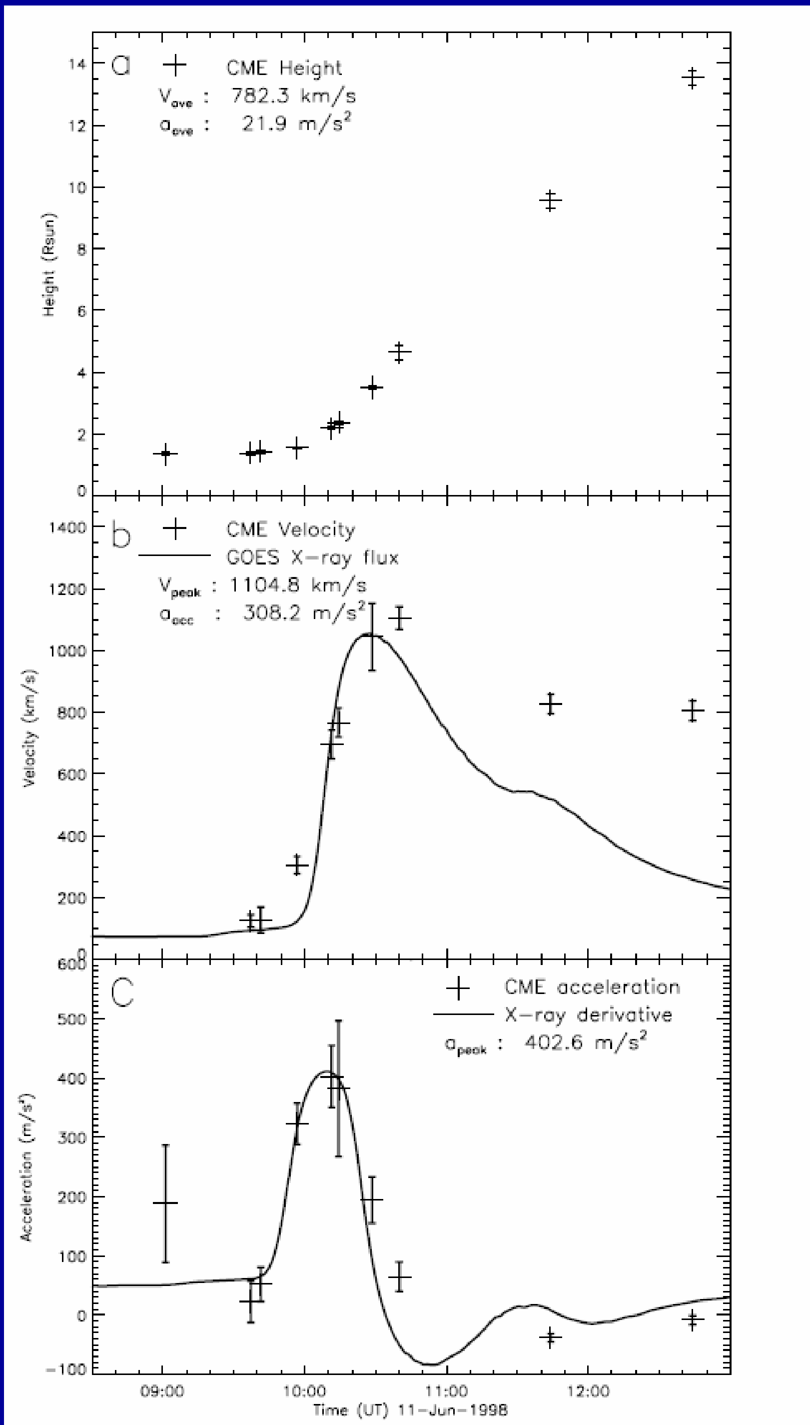
Maximum speed during maximum phase

Acceleration

Very fast CMEs (>1000 km s^{-1} have low acceleration (<1 cms^{-2})

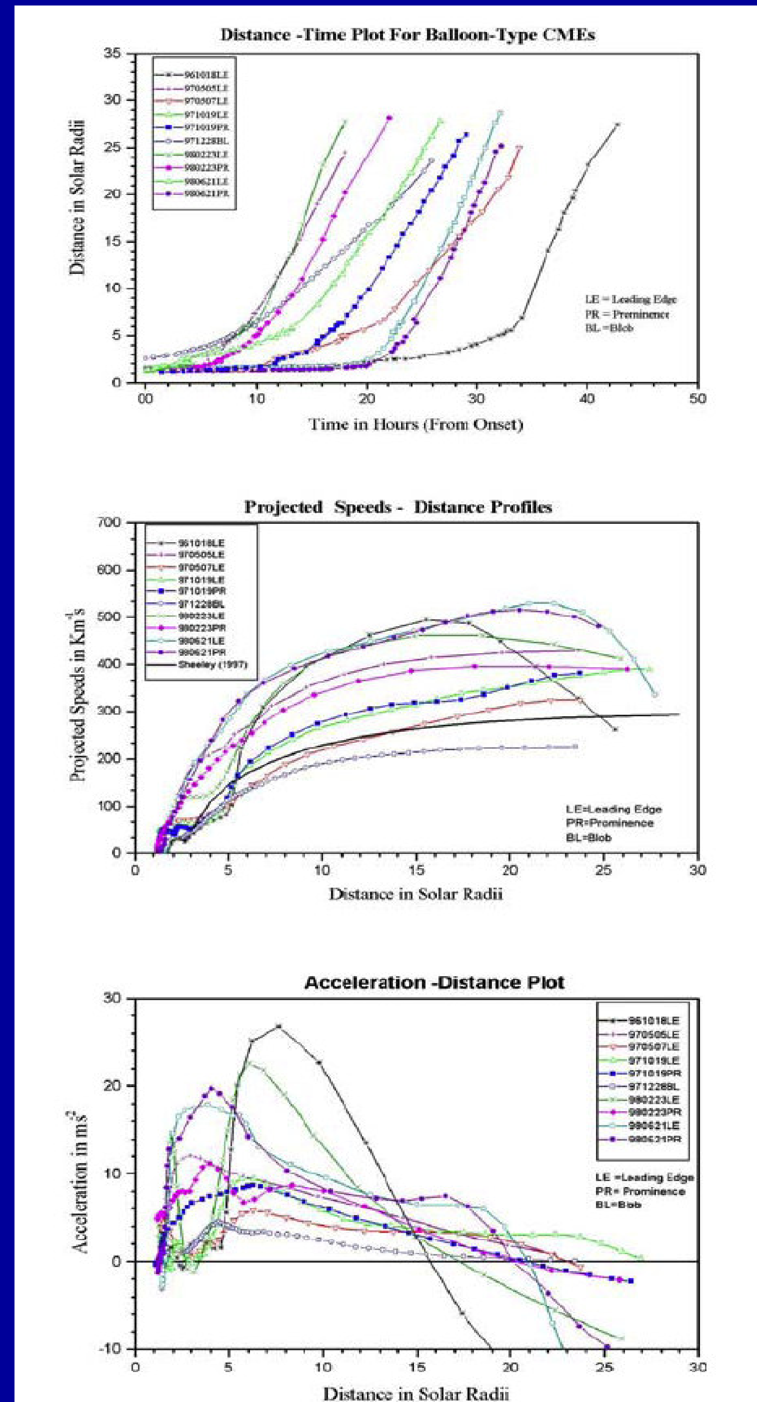
Slow CMEs (<1000 km s^{-1} have higher values of acceleration (0-80 cms^{-2})

Height -Time profiles

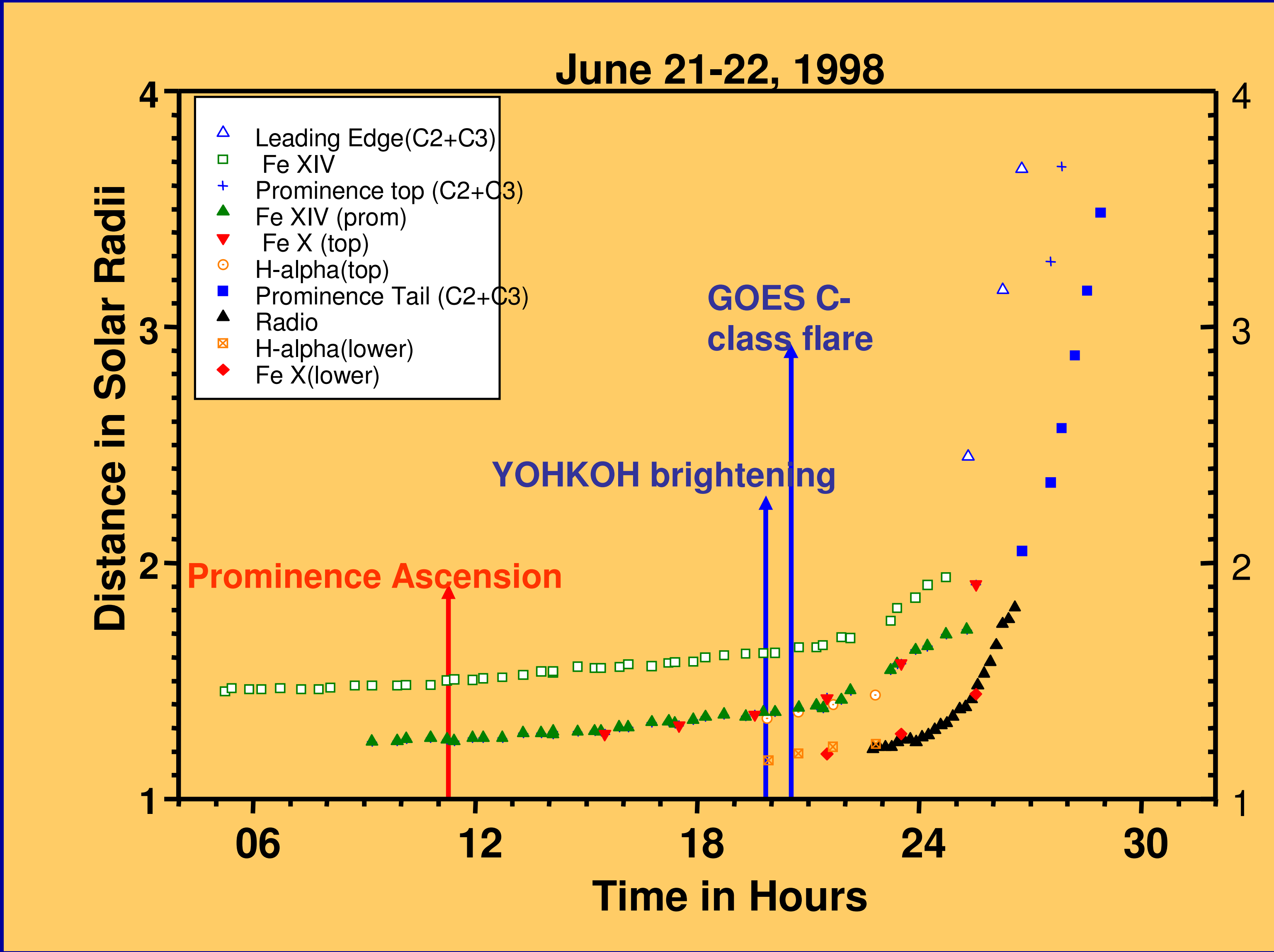


Zhang et al. 2004

Srivastava et al. (1999)

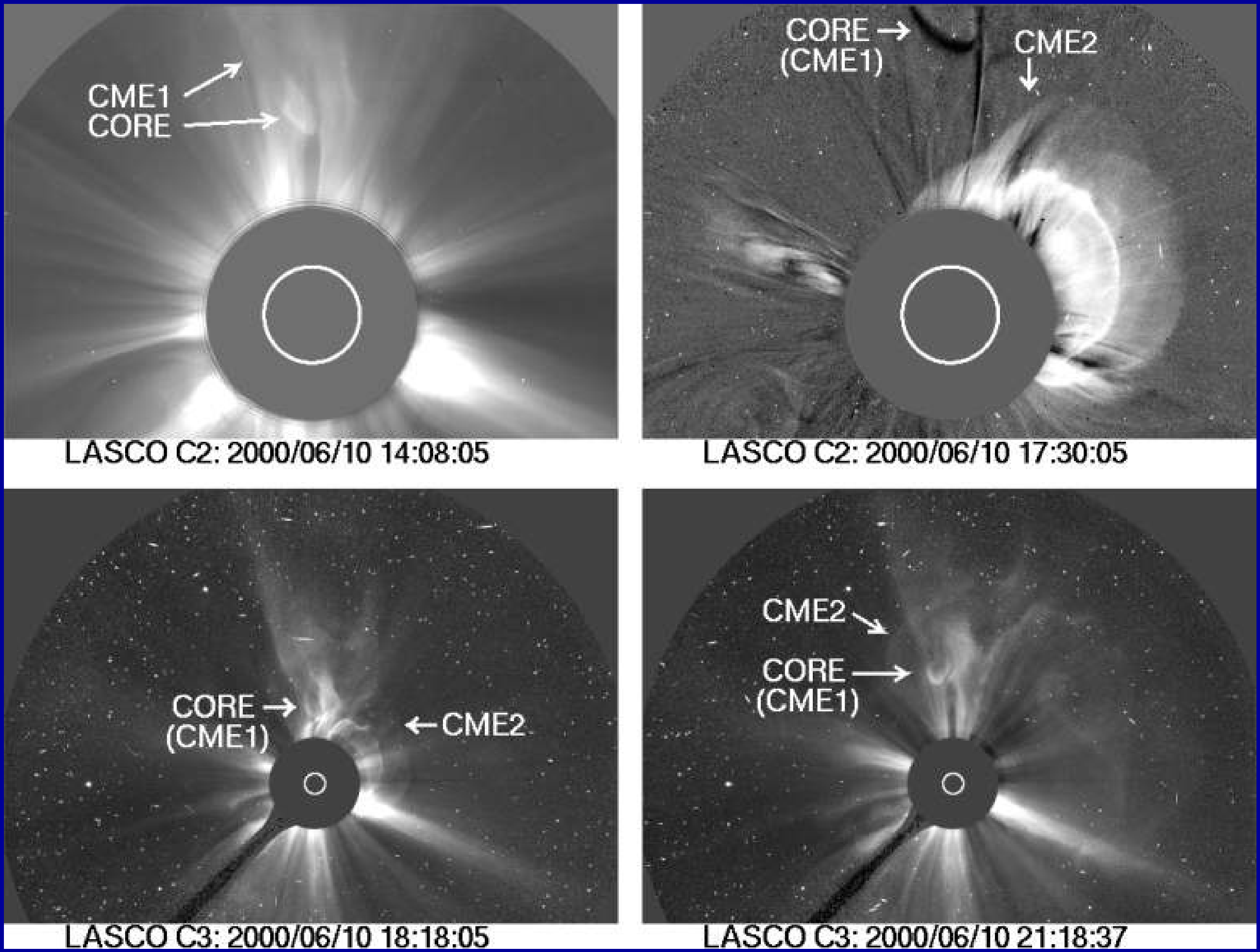


CME INITIATION : Lower Corona

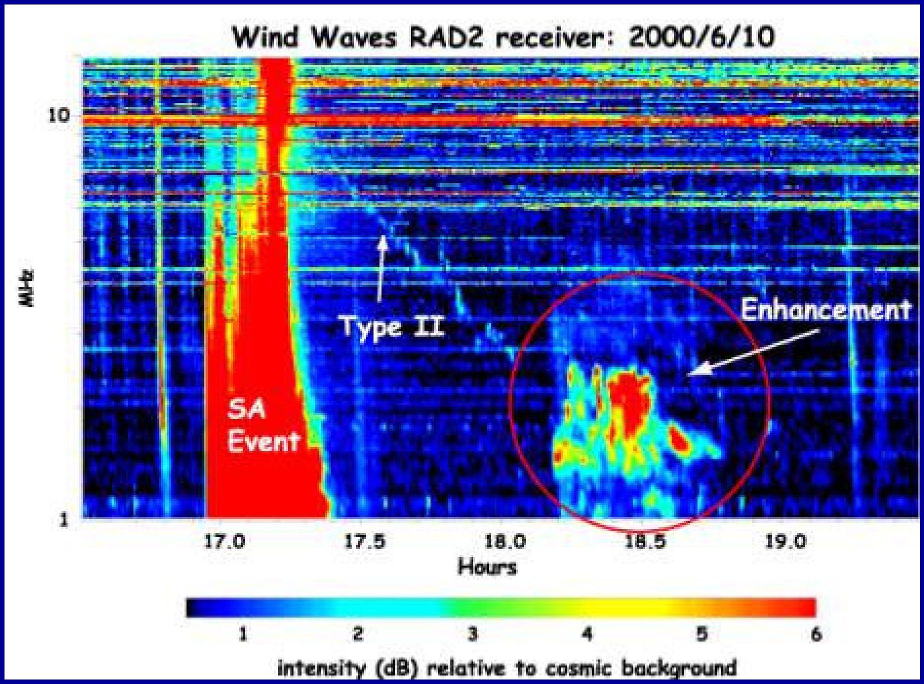


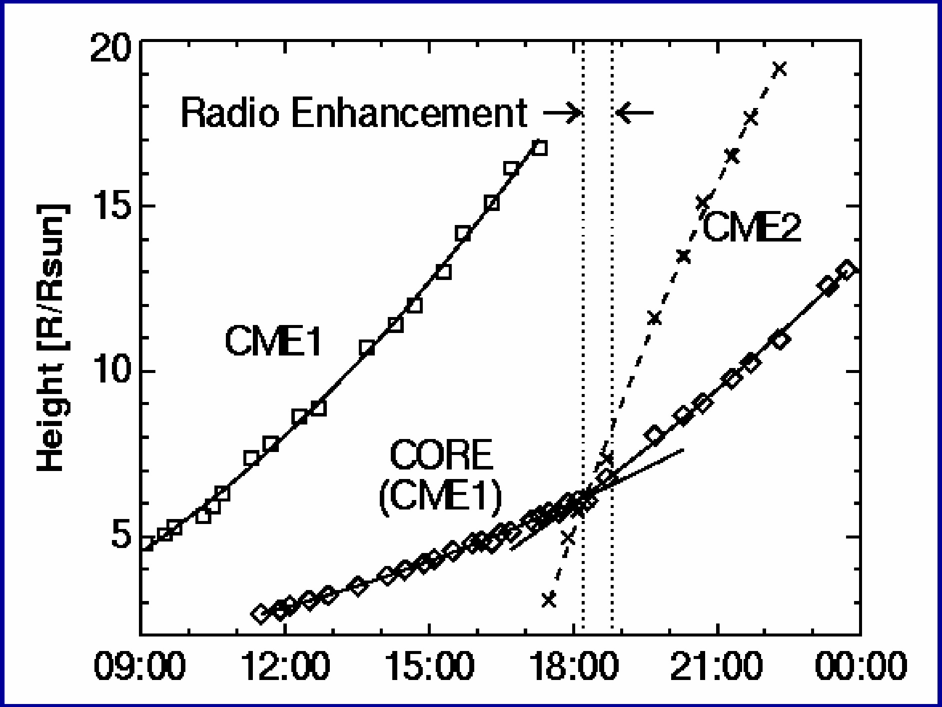
Exact Onset Time ~ Difficult to define

CMEs can interact with each other



Radio signs of CME interaction



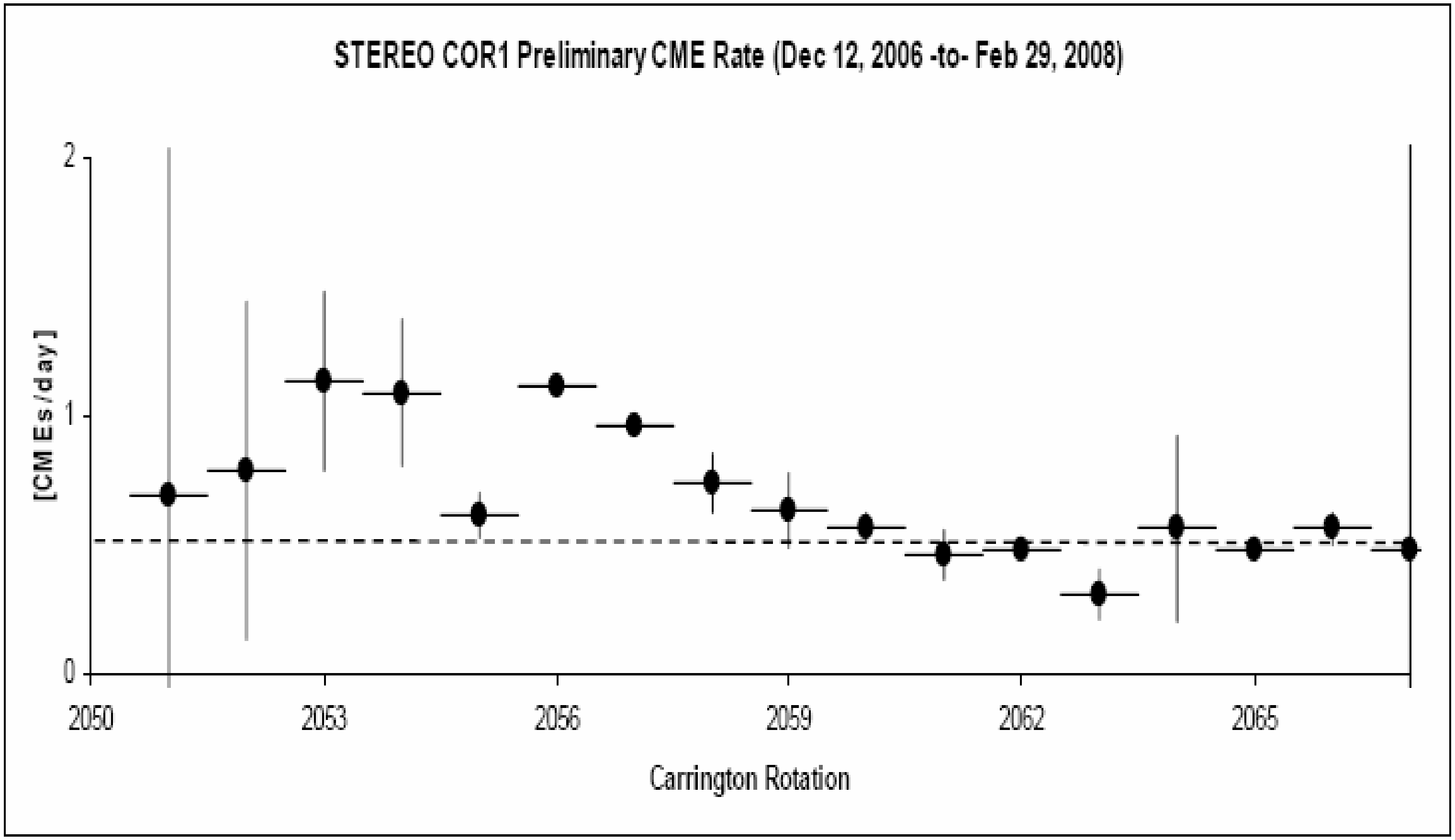


Gopalswamy et al. 2001

Coronal Mass Ejections: New Views from STEREO

Space –based Coronagraphy

Coronagraph	Year	FOV	Resolution
OSO-7	1971-1973	3.0-10 Rs	3 arc-min
Skylab	1973-1974	2.0-6.0 Rs	5 arc-sec
Solwind/P78-I	1979-1985	3.0-10 Rs	Same as OSO
SMM	1980, 1984-1989	1.6-6 Rs	30 arc-sec
LASCO	1995-1998 1995-	1.1-3.0, (E-corona) 2.0-6.0, 3.7-32 Rs	11.2 arc-sec 23 arc-sec 112 arc-sec
SECCHI	2006-	1.4-4.0, 2.0-15 Rs	7.5 arc-sec 29 arc-sec



SOHO LASCO CME Rate in 1996-1997 was ~0.5 CMEs/day

Courtesy St. Cyr. (2008), presentation at SECCHI meeting

3d Reconstruction of CME Leading Edge using COR1 and COR2 images

Collaborators:

Marilena Mierla, Royal Observatory of Belgium

Bernd Inhester, Max-Planck Institute for Solar System Research

1. Motivation of the study
2. Reconstruction Techniques
   (a) Tie Pointing (b) Height-Time
3. Data from COR1 and COR2 coronagraphs
4. Application of reconstruction techniques to data
5. Results

MOTIVATION

1. 3-D reconstruction of leading edge or front of the CME to give the true speed and direction of the CME

2. Understand the initiation and propagation of CMEs

3. Important input to space weather prediction

COR1 Instrument

FOV: 1.1-4.0 R_{sun}

Resolution: white light 7.5 arc-sec

Cadence: one image every 5 min

Sequence of images taken with polarizer at 3 positions 0, 120 and 240

COR2 Instrument

FOV: 2.0-15 R_{sun}

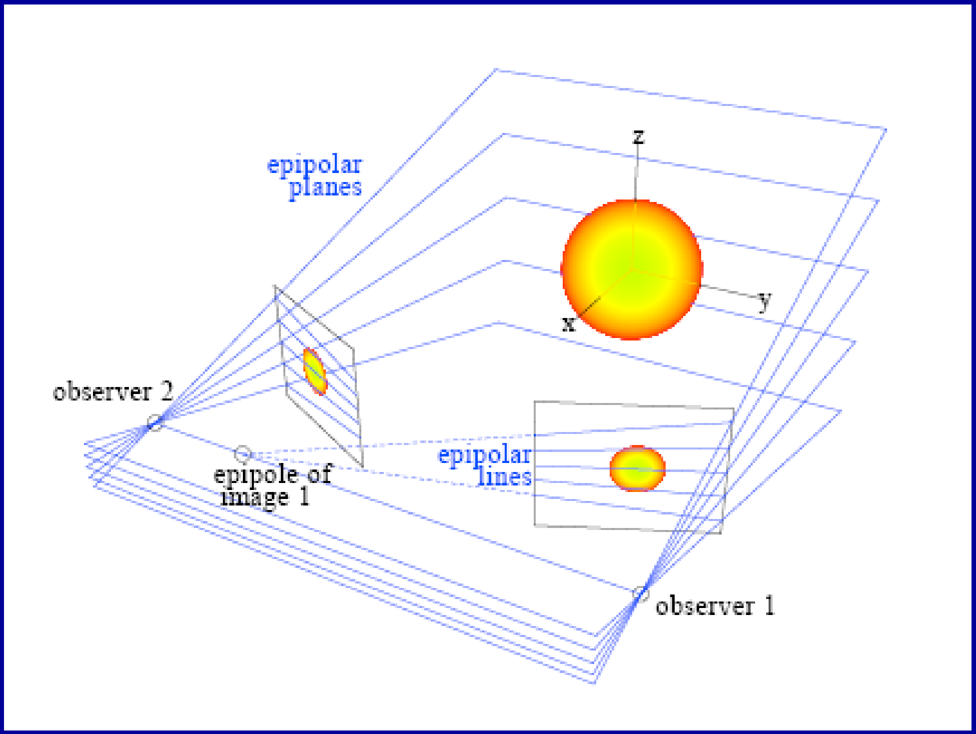
Resolution: white light 29.4 arc-sec

Cadence: one image every 20-30 min

Sequence of images taken with polarizer at 3 positions 0, 120 and 240

Reconstruction Technique

Tie pointing

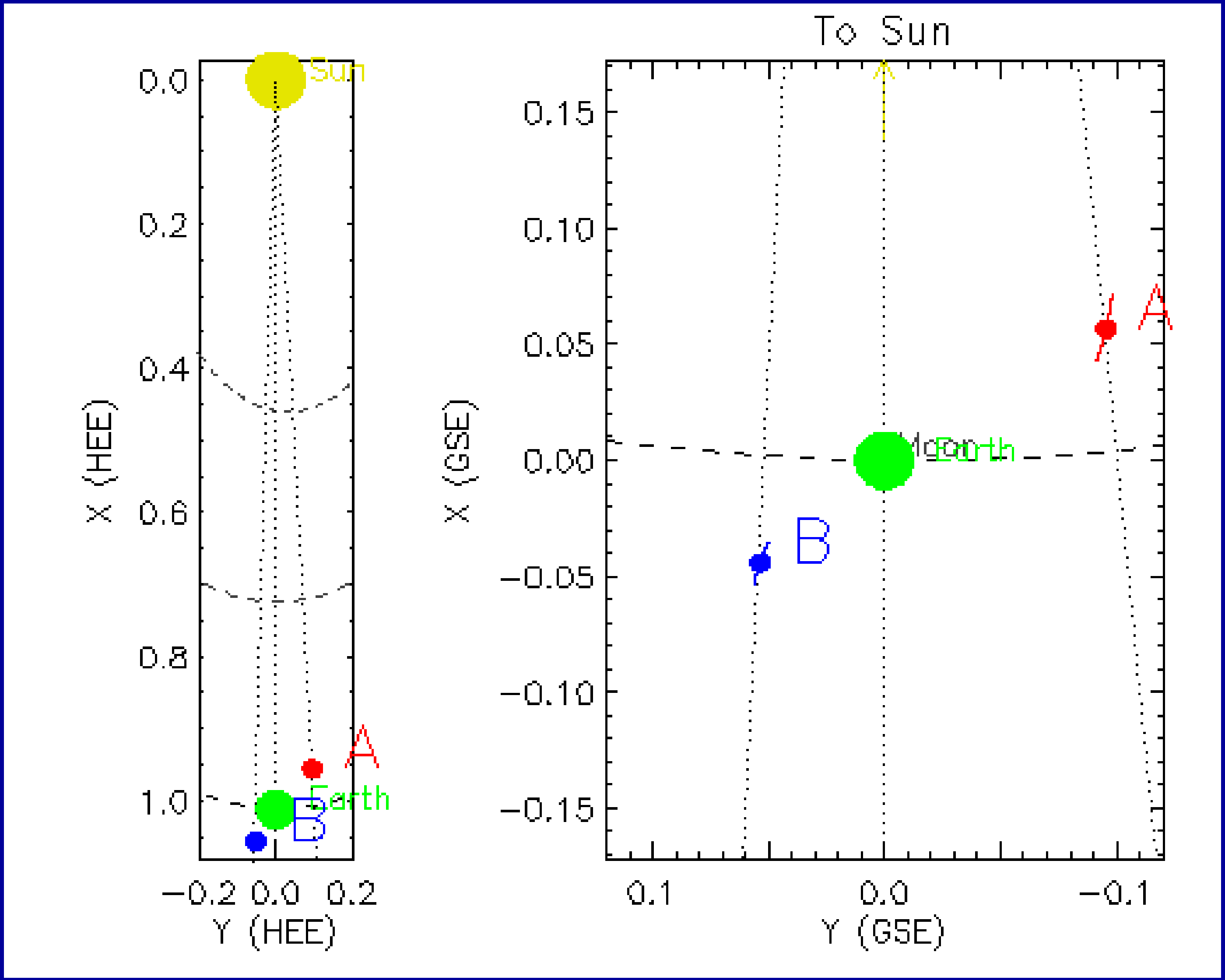


Determine 3-d location of a feature which can be identified in both images of a STEREO pair.

The tie-pointing computes 3-d coordinates in a fixed coordinate system of a point by determining the intersection of the line-of-sights of the projected points in the image plane

Position of STEREO: 19 May 2007 12:00 UT

Separation angle=8.628

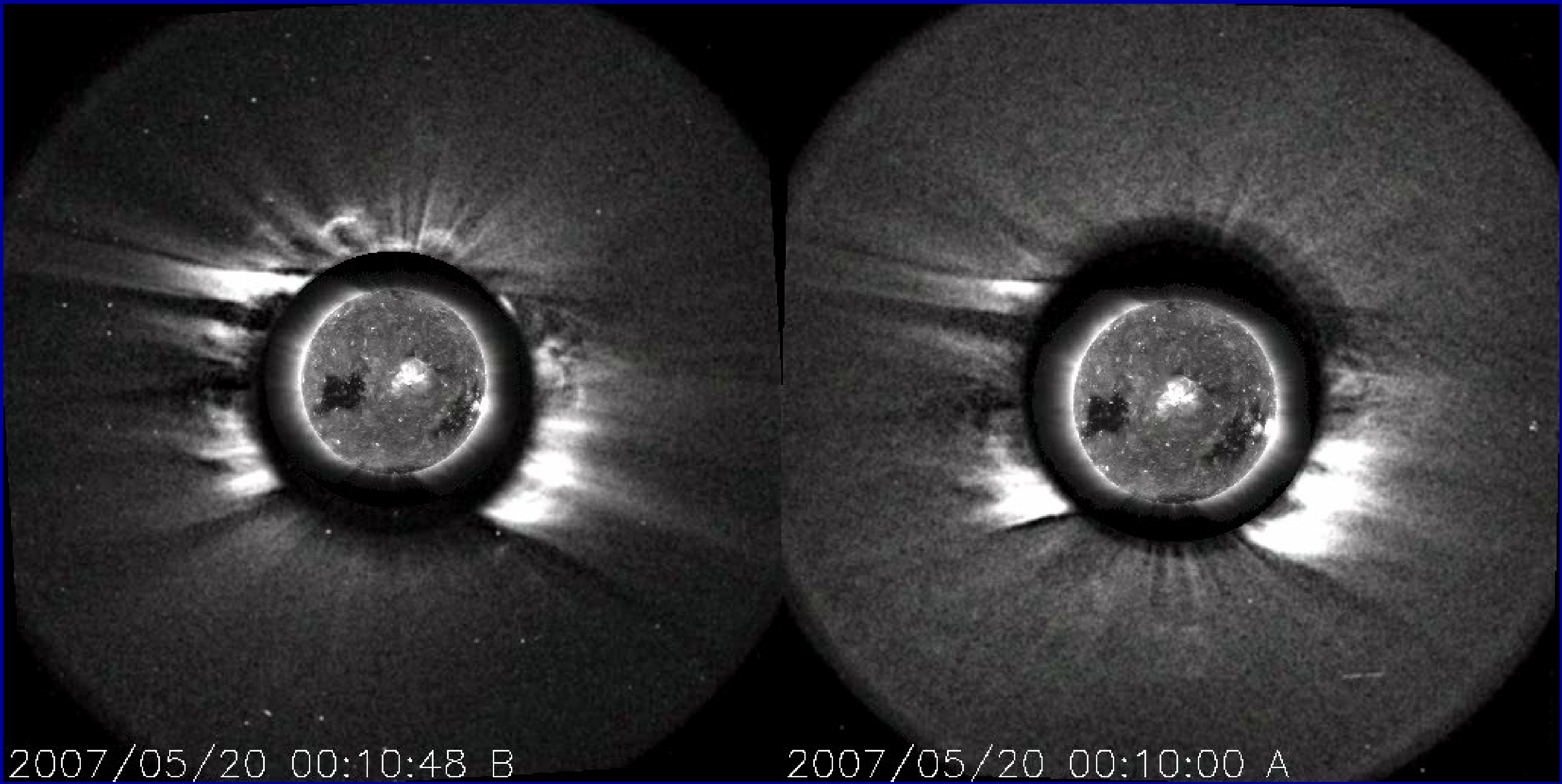


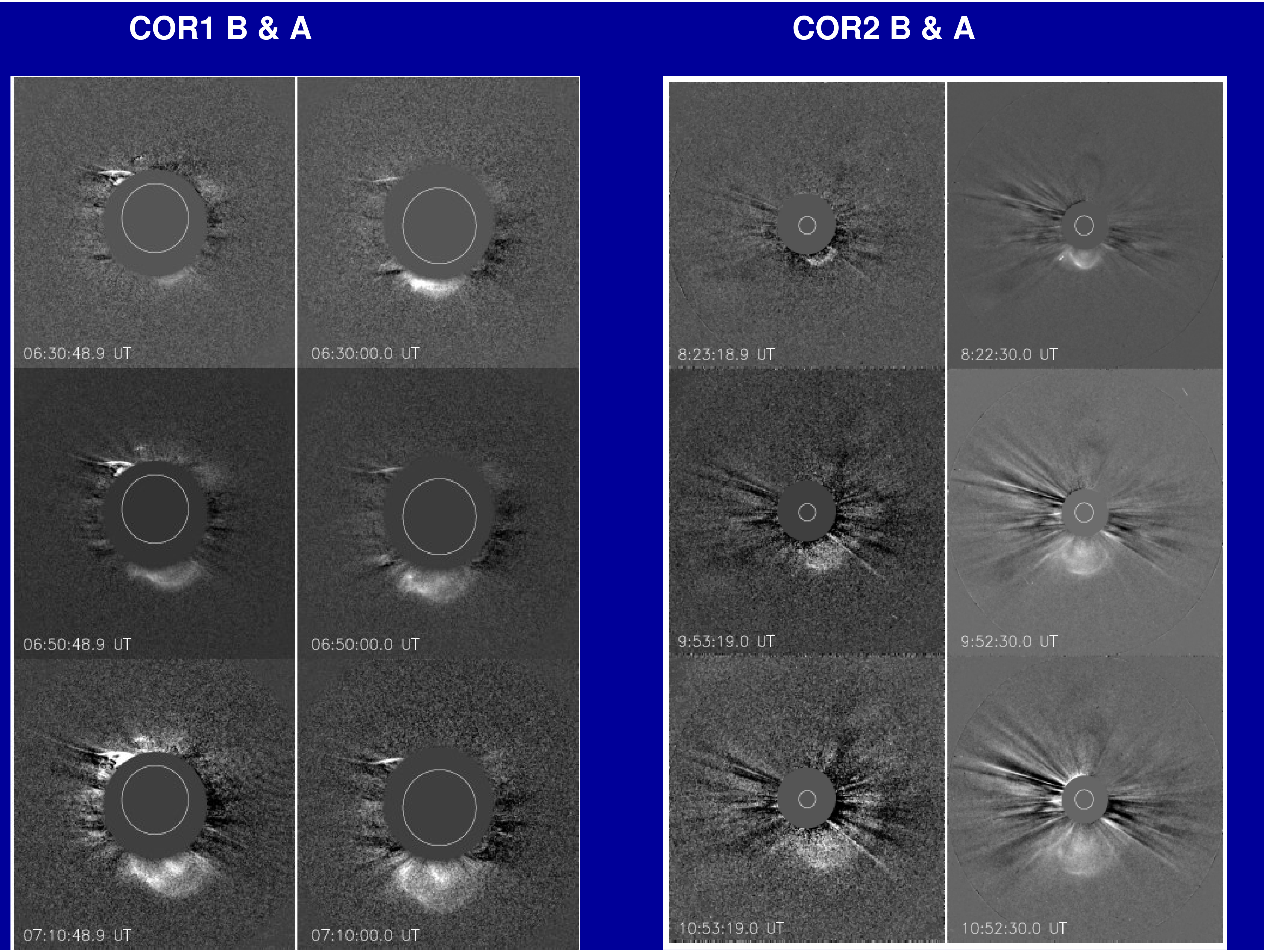
Distance A= 0.959685 AU

Distance B=1.056906 AU

Distance E=1.011707 AU

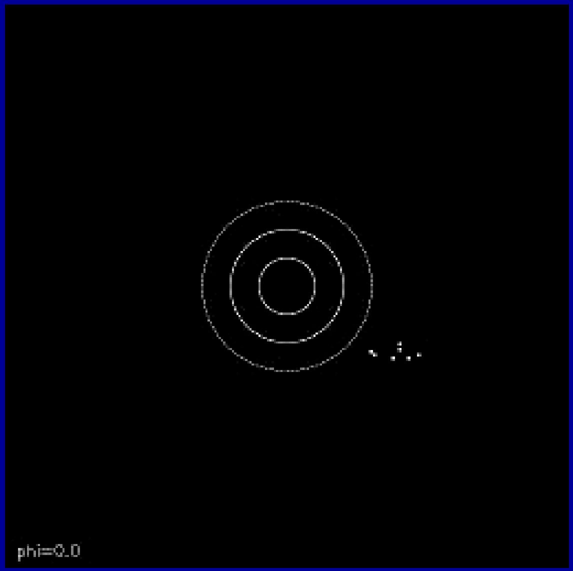
20 May 2007 CME



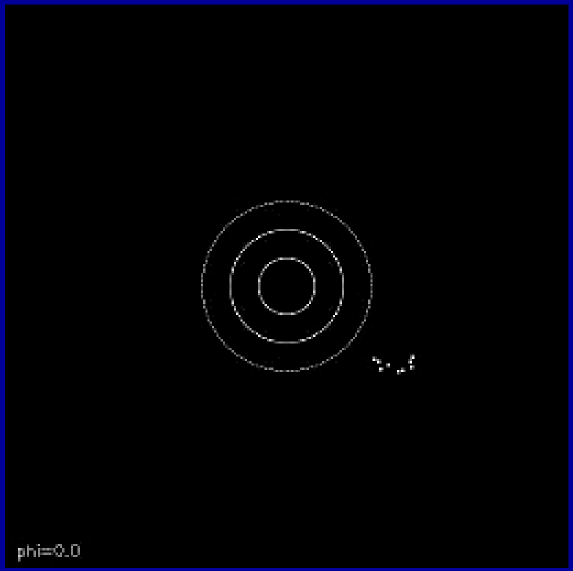


COR1 B & A
COR2 B & A
06:30:48.9 UT
06:30:00.0 UT
06:50:48.9 UT
06:50:00.0 UT
07:10:48.9 UT
07:10:00.0 UT
8:23:18.9 UT
8:22:30.0 UT
9:53:19.0 UT
9:52:30.0 UT
10:53:19.0 UT
10:52:30.0 UT

Reconstruction of the leading edge



07:00 UT



07:20 UT

Identification of points along the leading edge.

Seen along the sun-earth line

Latitude is approximately 30 degrees south.

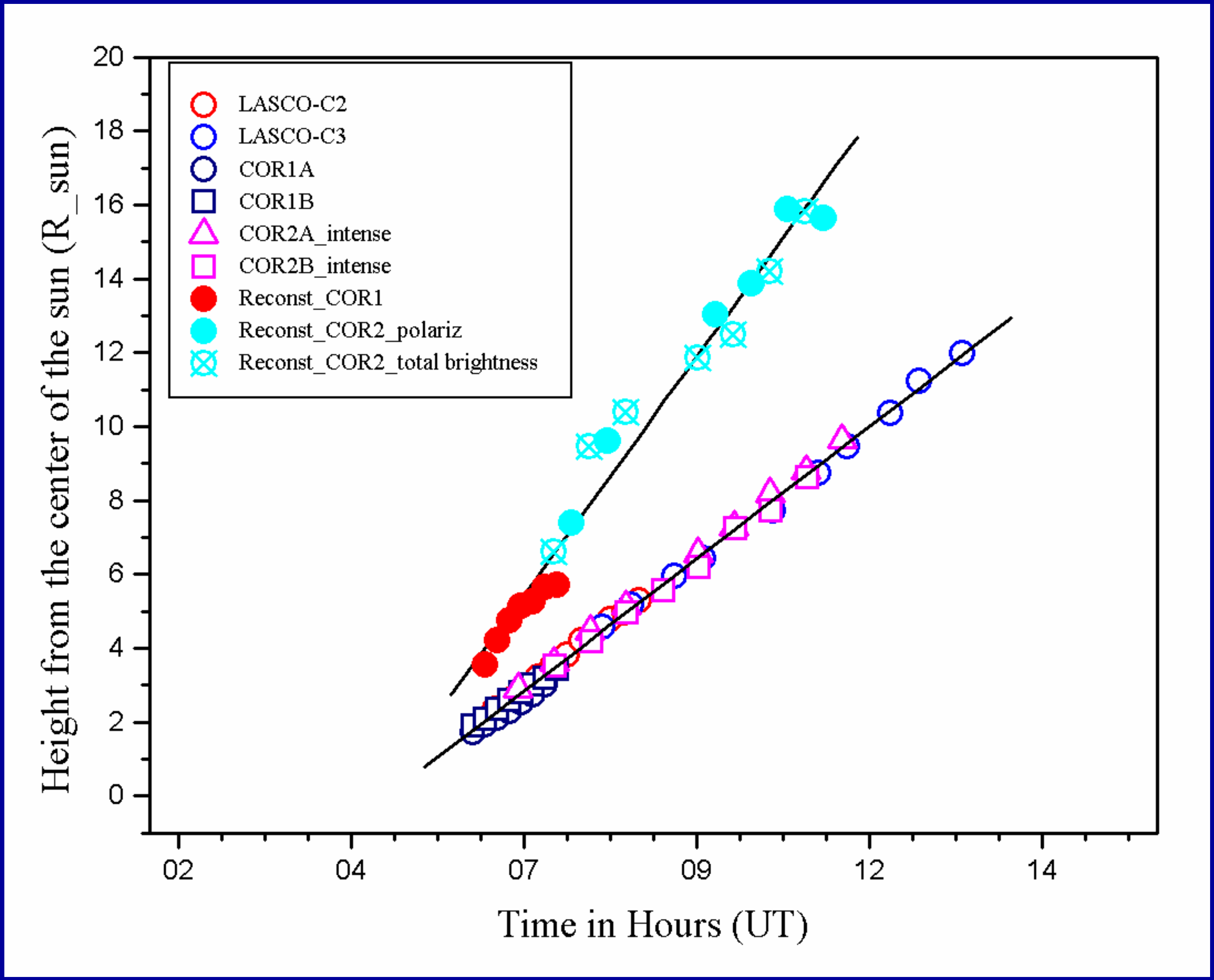
Longitude is expressed in Carrington longitude.

20 May 2007

06:40 UT **06:50 UT** **07:00 UT** **07:10 UT**

07:20UT **07:30UT** **07:40 UT** **07:50 UT**

Comparison of Height Time plots



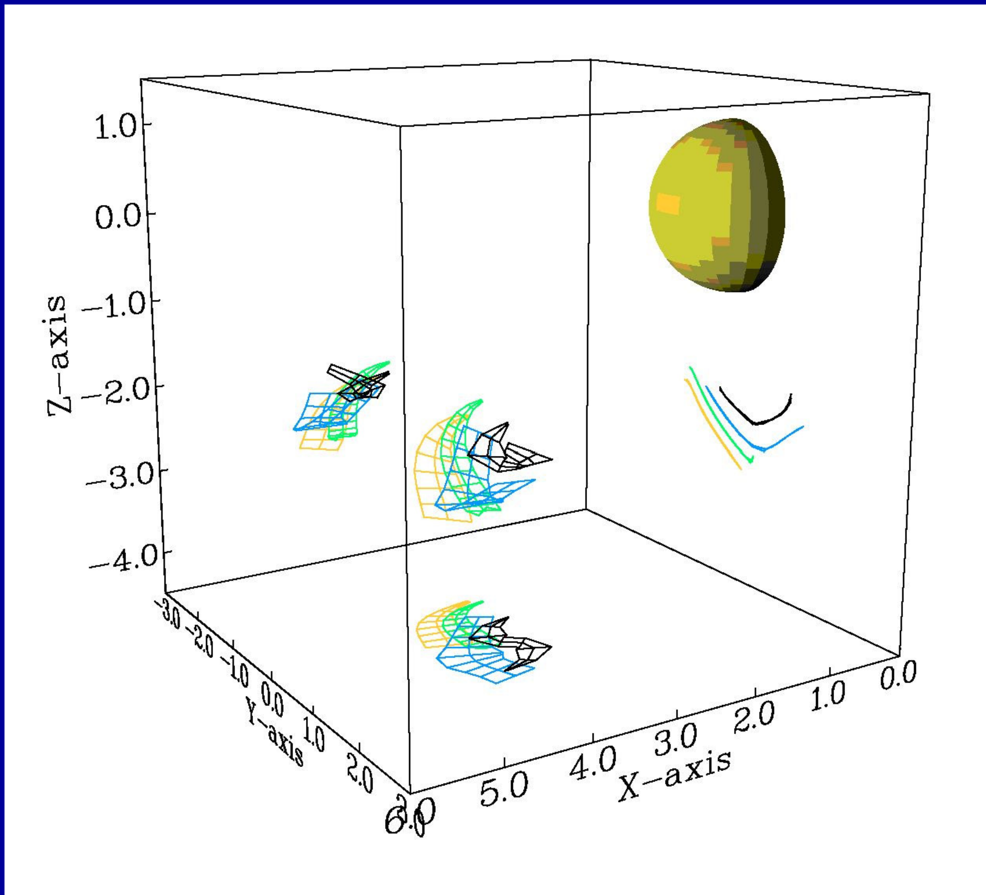
Plane-of-sky speeds

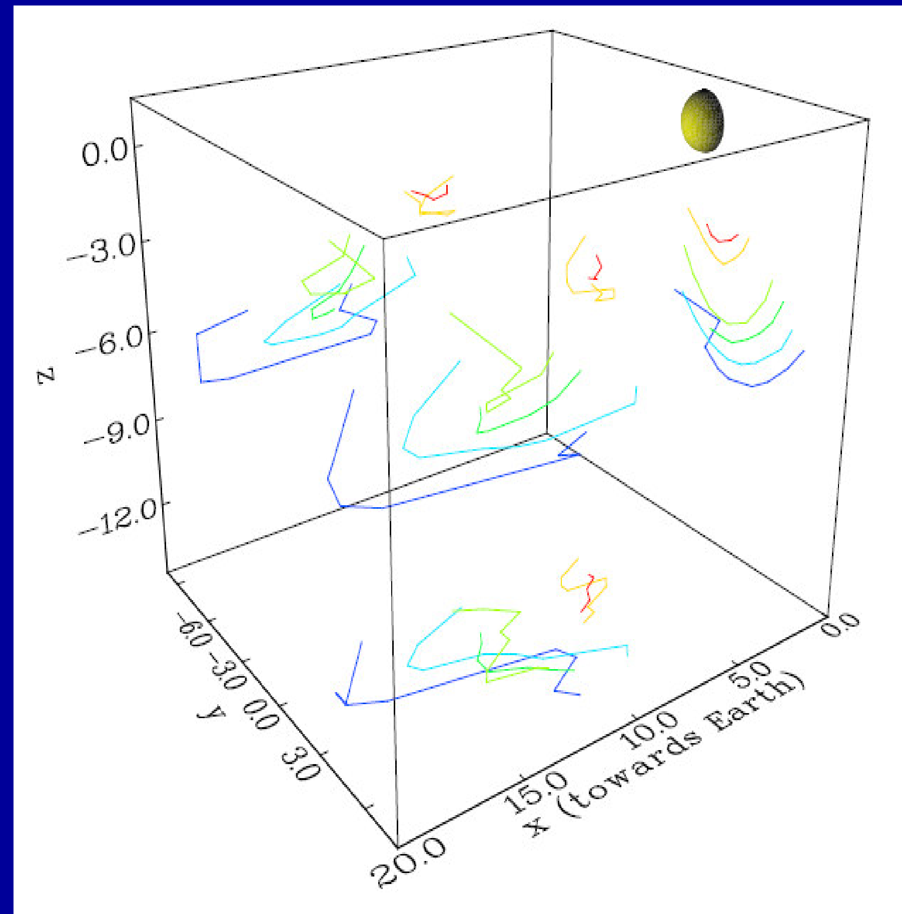
LASCO, STEREO A and B ~ 230 km/s

True radial speed

RECONSTRUCTED ~500 km/s

RECONSTRUCTED LEADING EDGE IN COR1 and COR2 IMAGES

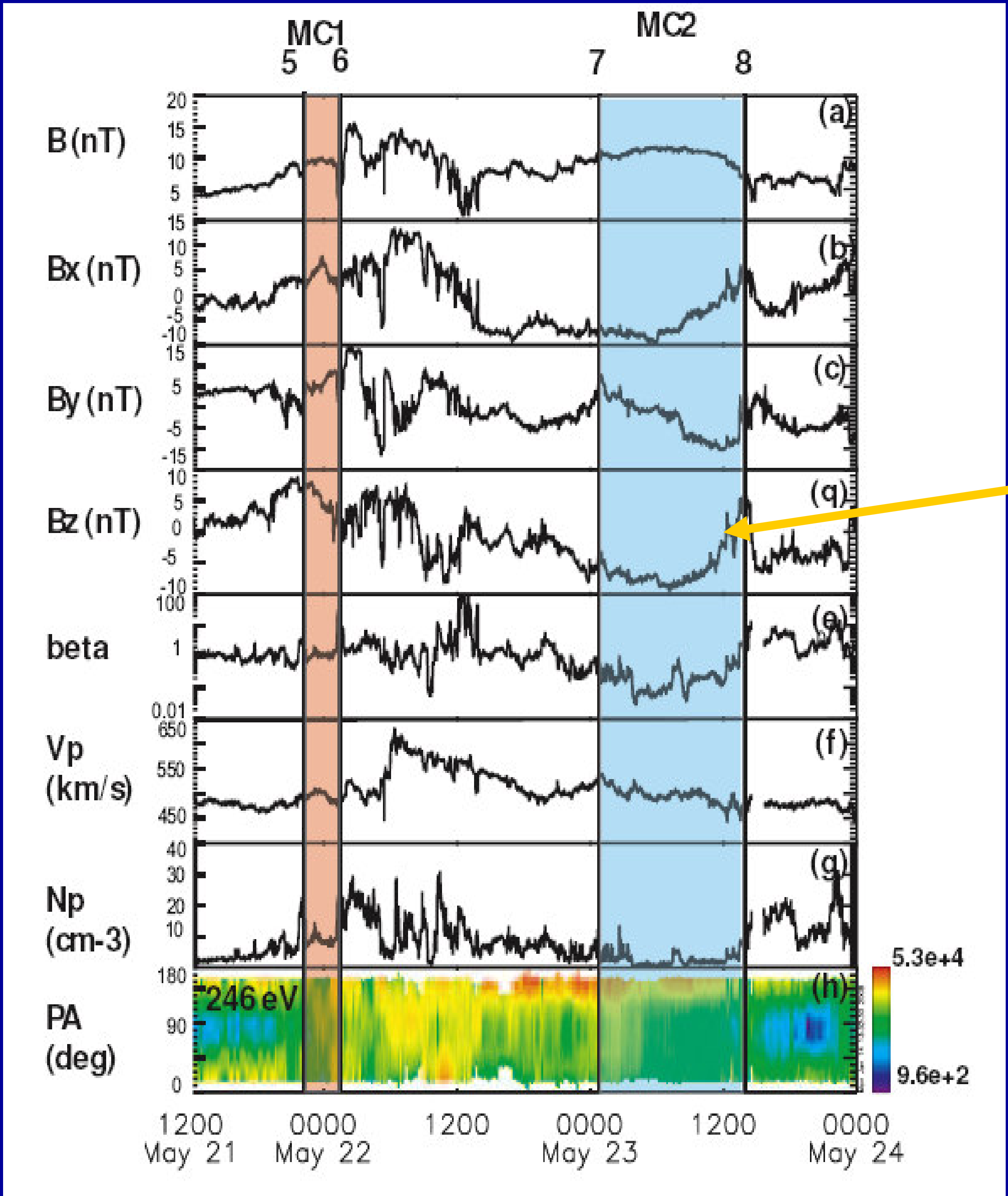




True Speed of the estimated leading edge is approximately 600 Km/s

Srivastava et al. 2008

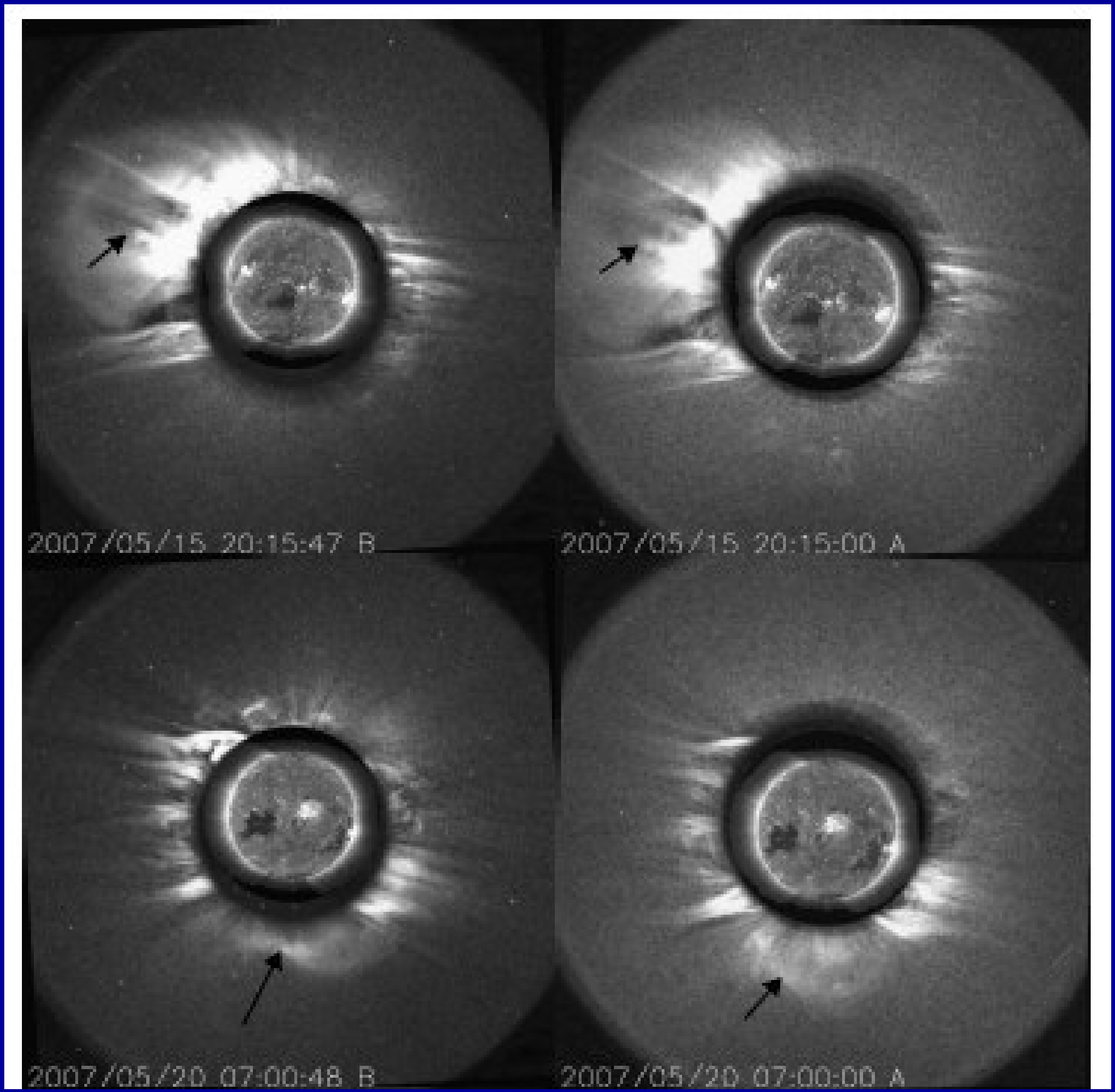
(to be submitted to Topical issue, Solar Physics)



Associated with May 20, 2008 CME

Courtesy: Kilpua et al. 2008, Solar Physics (Accepted)

Height time technique for reconstruction of CME feature in STEREO A & B

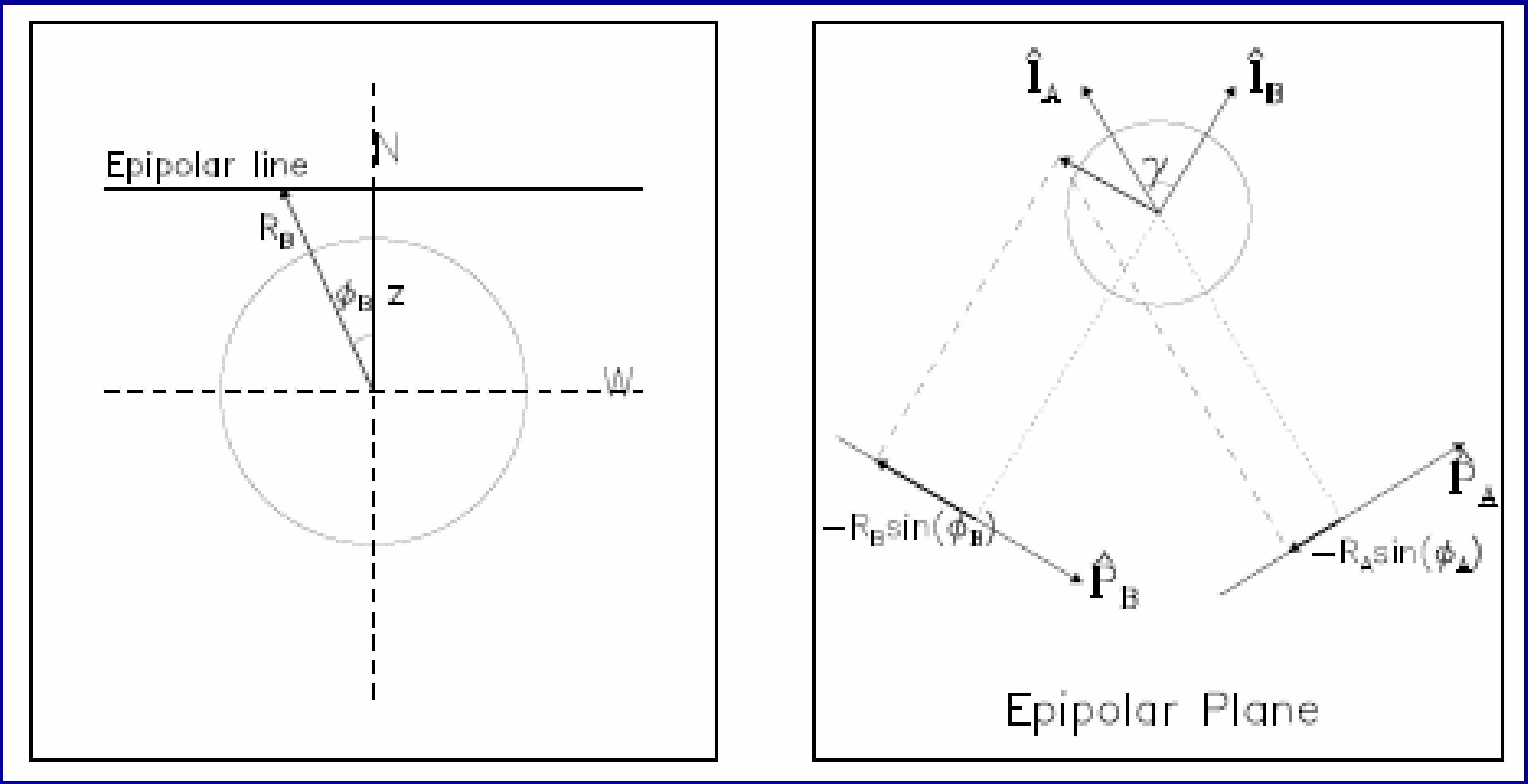


Method:

- Height-Time (HT) plots of the same identified feature in COR1-A and –B images
- - from a simple geometry: 3D coordinates of the coronal feature

Assumption:
- the 2 spacecraft are in the ecliptic plane (errors < 3°)

Geometry



Epipolar line
N
R_B
ϕ_B
Z
W
$\hat{I}_A$
$\hat{I}_B$
γ
$-R_B\sin(\phi_B)$
$\hat{P}_B$
$\hat{P}_A$
$-R_A\sin(\phi_A)$
Epipolar Plane

Geometry CALCULATION

$$long = \arctan\left(\tan\left(\frac{\gamma}{2}\right)\frac{a-b}{a+b}\right),$$

$$lat = \arctan\frac{R_{2d}}{z},$$

Here, γ is the angle between the spacecrafts

$a = -R_A \sin\varphi_A$,

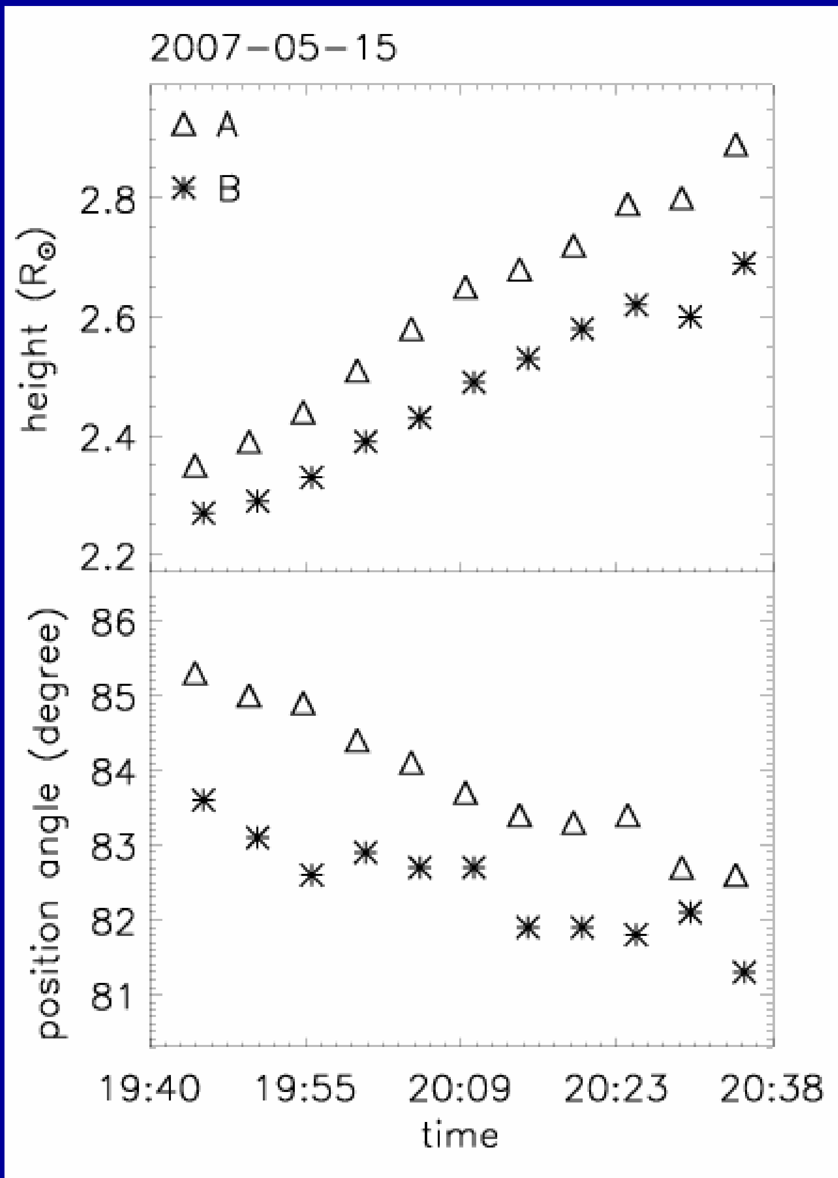
$b = R_B \sin\varphi_B$

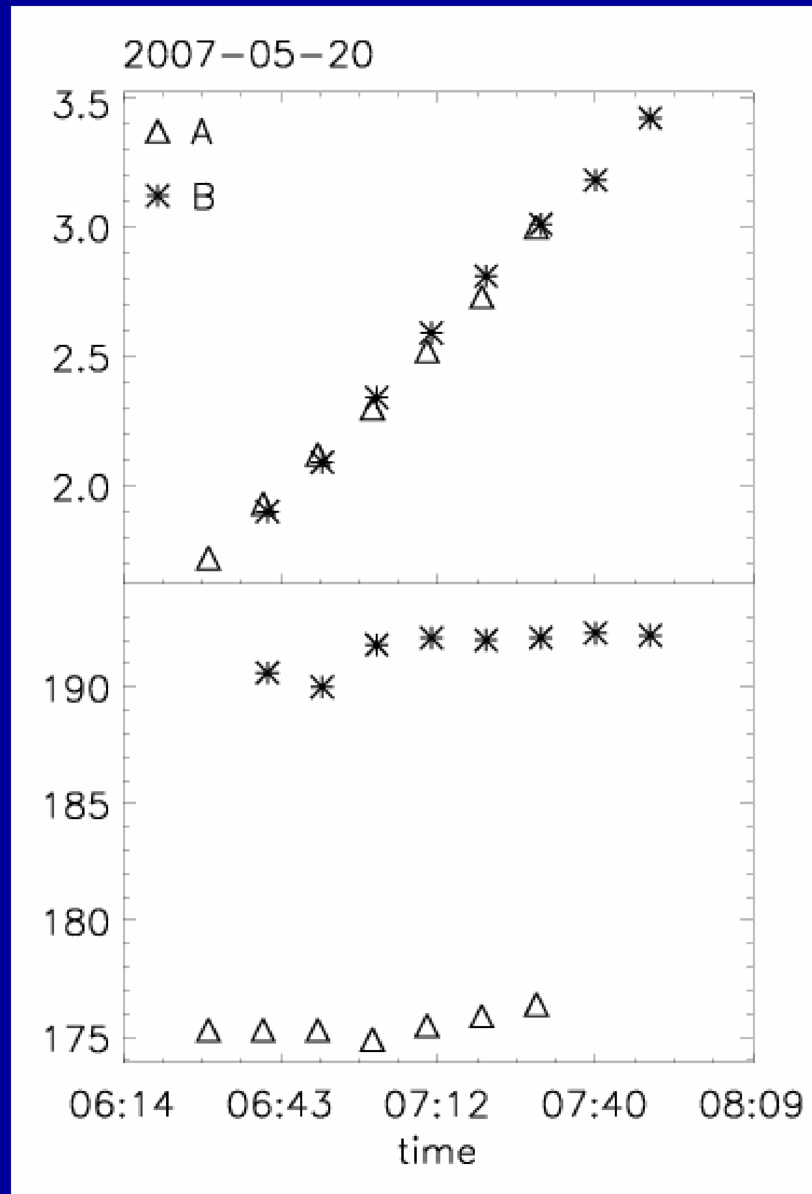
Φ is the position angle measured from the north pole.

R is the height measured in projected plane

$$\vec{R}_{2d} = \frac{R_B \sin\phi_B \hat{l}_A - R_A \sin\phi_A \hat{l}_B}{\sin\gamma},$$

Height-time Plots for a selected feature: INPUT





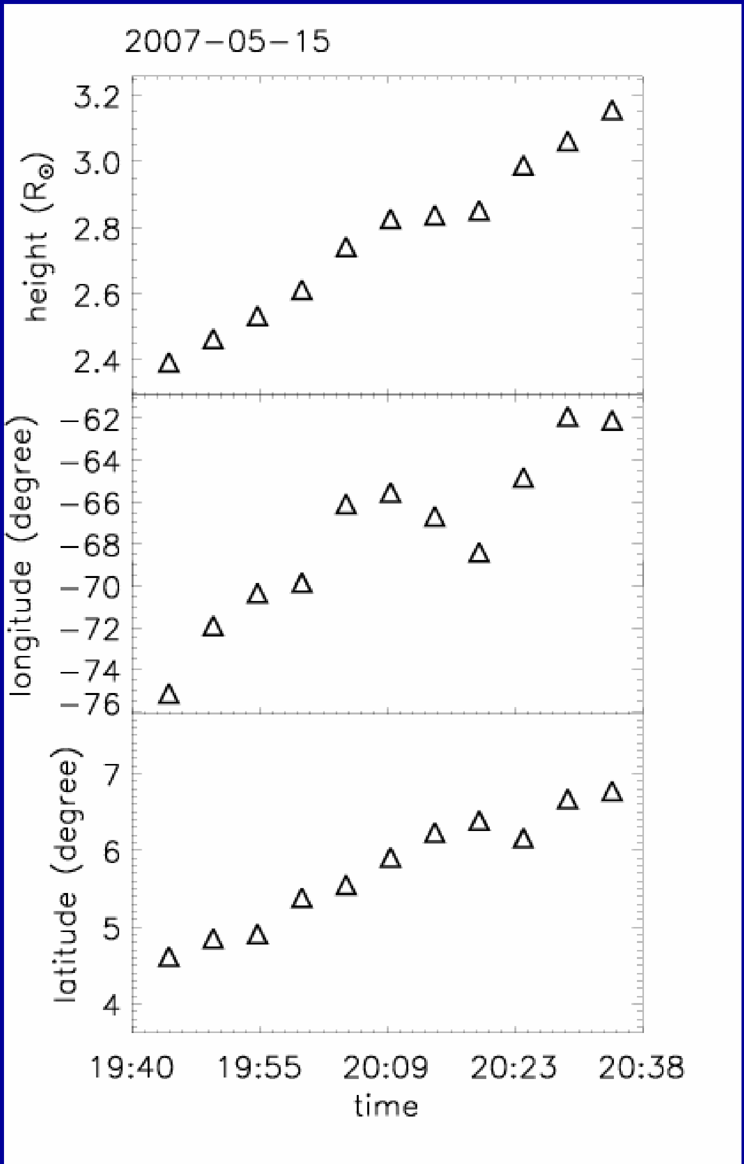
Position angle measured from north (0degree) counter-clockwise

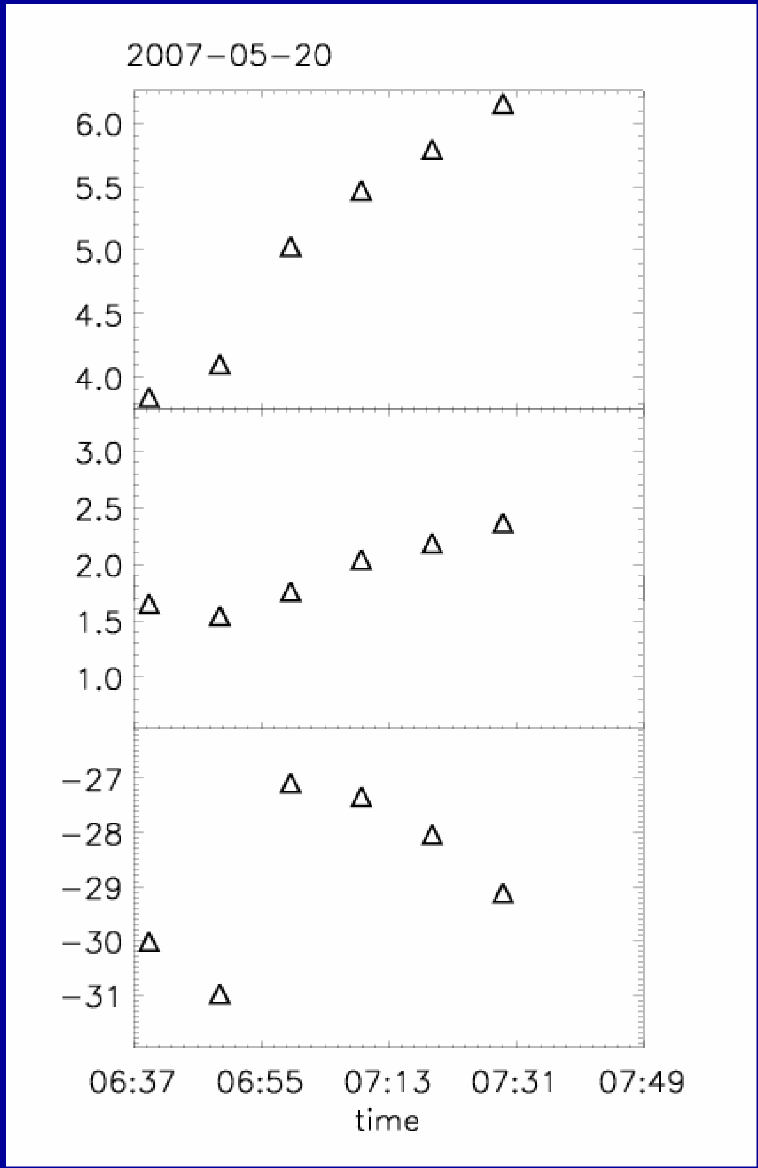
Mierla et al. Solar Physics, 2008

CME at E-limb: 15 May 2007

CME in the South: 20 May 2007

Diagram 3-d coordinates of the leading edge: Output





Va = 125 km/s
Vb = 99 km/s
V = 169 km/s

Va = 242 km/s
Vb = 253 km/s
V = 548 km/s

SUMMARY

1. Reconstruction techniques applied to May 20, 2007 CME: Tie-pointing and Height-time,Time techniques
2. Results obtained from both the techniques yield similar results
3. The values of true speeds are higher than the projected speeds (as measured individually by any spacecraft)
4. These techniques are Effective tools to get true or radial speeds of leading edge.
5. major implications on arrival time and magnitude of geomagnetic storms (Space weather prediction models can be improved!)