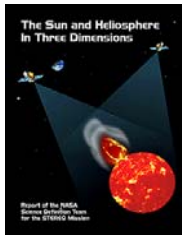
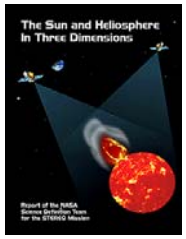


Study of CME Propagation in the Inner Heliosphere

D. Webb[1,2], T. Howard[2,4], T. Kuchar[1,2], J. Morrill[5], D. Odstrcil[3] , R. Harrison[6], C. Eyles[6,7,8], R. Howard[5], B. Jackson[9] & J. Johnston[2]

1 Institute for Scientific Research, Boston College, Chestnut Hill, MA, USA
2 Air Force Research Laboratory, Space Vehicles Directorate, USA
3 NOAA SWPC & CIRES, Univ. of Colorado, Boulder, CO, USA
4 Physics Department, Montana State University, Bozeman, MT, USA
5 Space Science Div., Naval Research Laboratory, Washington, D.C., USA
6 Space Science and Technology Dept., RAL, Chilton, UK
7 Astrophysics and Space Research, University of Birmingham, Birmingham, UK
8 Grupo de Astronomía y Ciencias del Espacio, ICMUV, Universidad de Valencia, Spain
9 CASS, University of California – San Diego, La Jolla, CA, USA

- **Overview**
  - **Understand CME propagation & kinematics to large distances**
  - **Instruments: LASCO, STEREO SECCHI Heliospheric Imagers, SMEI**
- **Late January 2007 east limb events**
  - **Overlap of fields of view; CME Structure/Geometry**
  - **Kinematics over 100˚ range of elongation from Sun**
- **CME Propagation Modeling; Work in Progress**
- **Conclusions/Future Work**

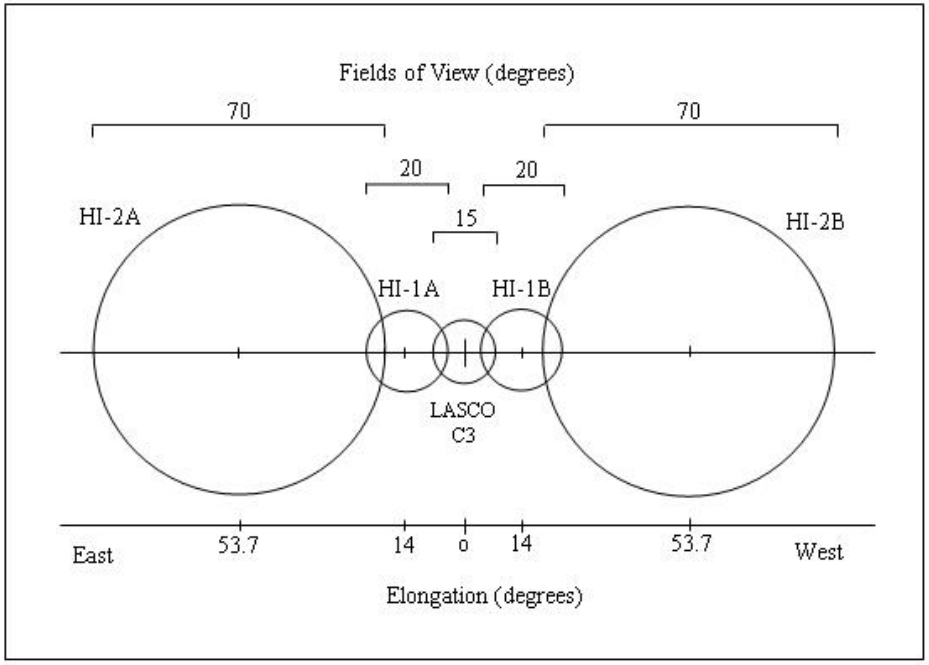


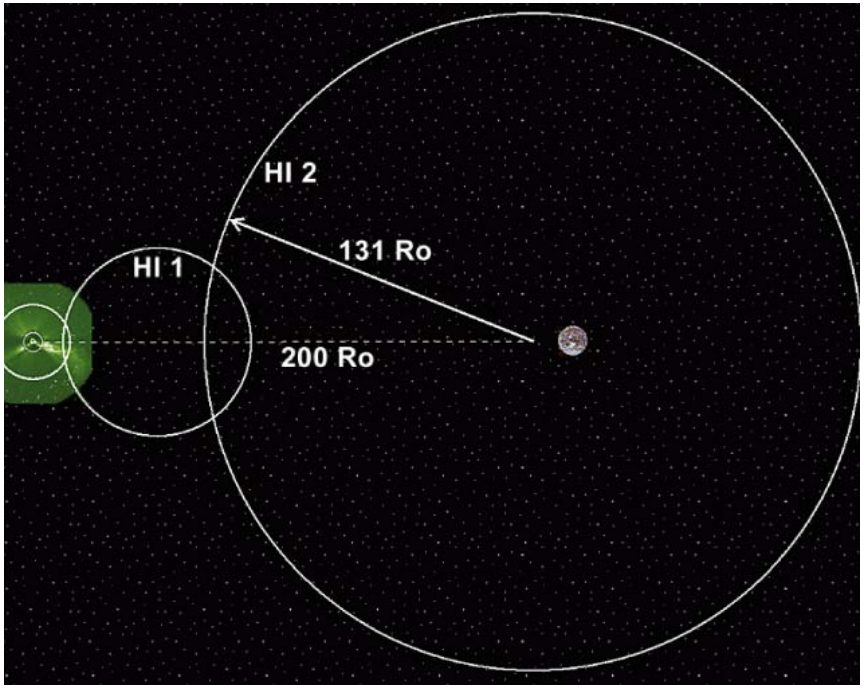
SECCHI HI Fields of View

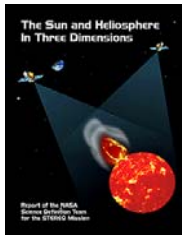
Two of primary science objectives for STEREO Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI):

1) Determine the 3D properties of CMEs

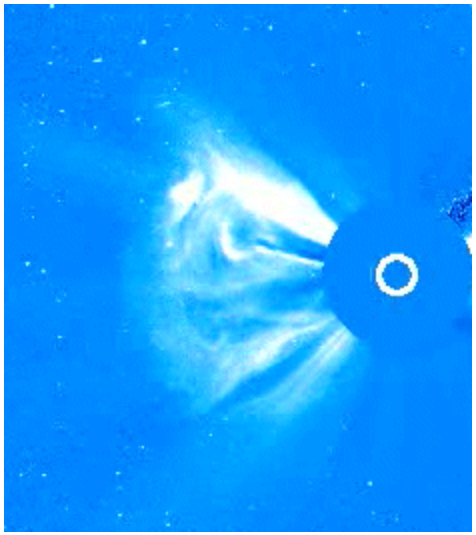
2) Determine the critical forces controlling propagation of CMEs in the corona and interplanetary medium



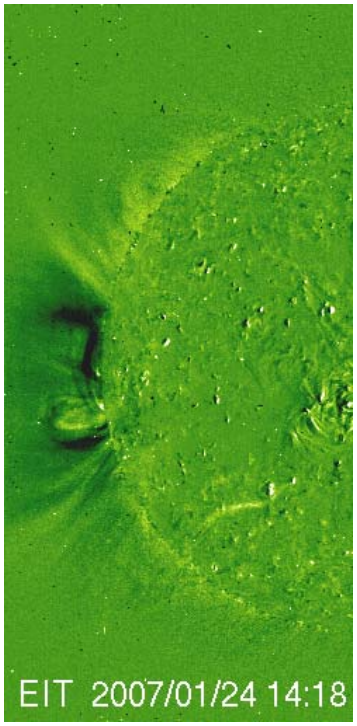




24-25 January 2007 CMEs
SOHO EIT & LASCO C3



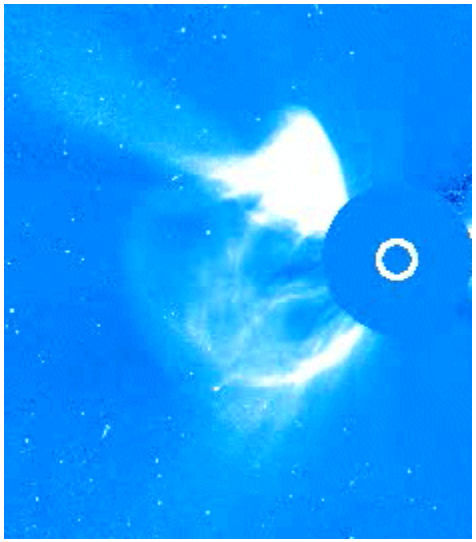
LASCO C3
24, 18:18



EIT Diff.
24, 14:18

B9 flare, wave
CME speed ~700 km/s

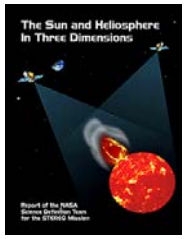
16 hours later



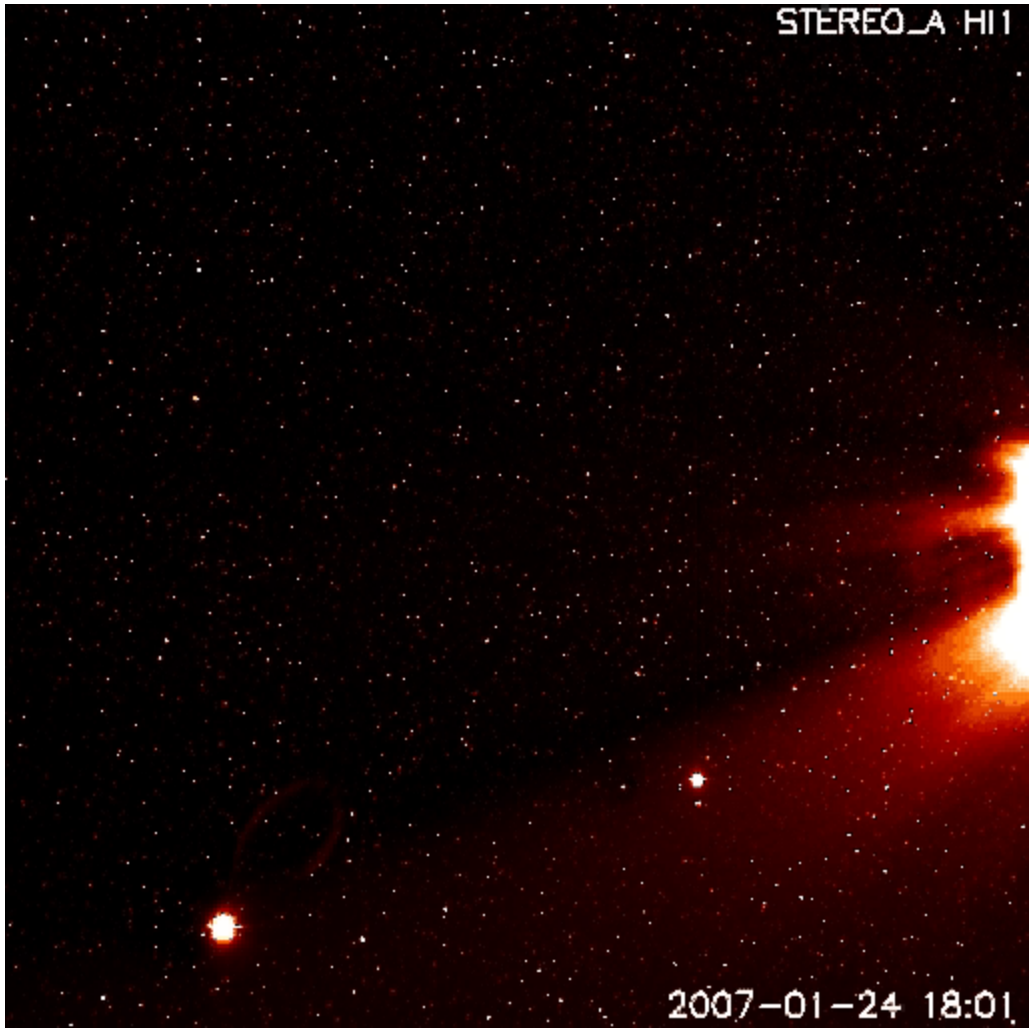
LASCO C3
25, 08:42

EIT Diff.
25, 07:13

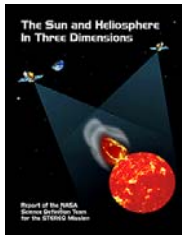
C6 flare, strong wave
CME speed ~1500 km/s, decelerating.
Asymmetric halo



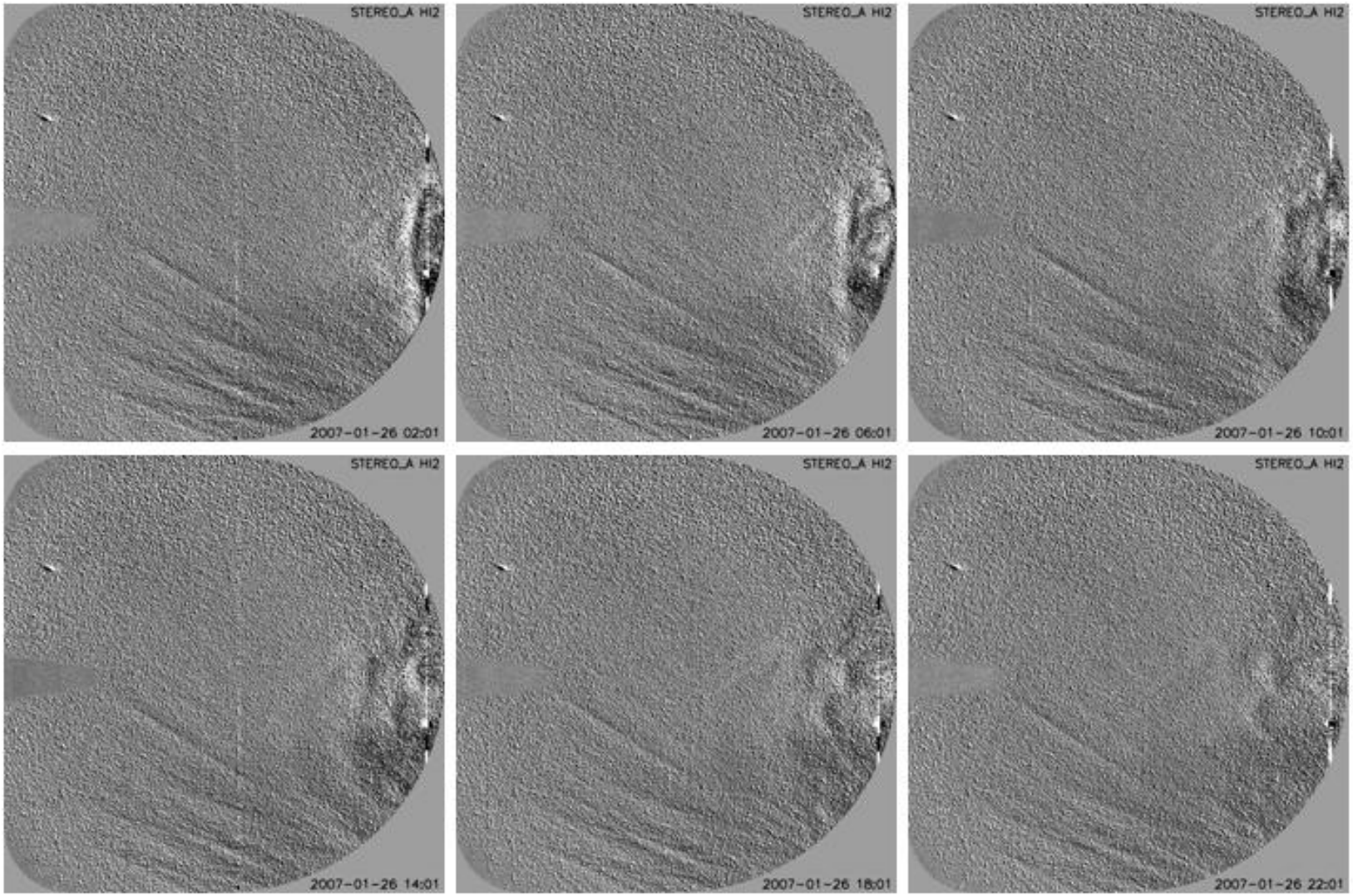
HI-1A CME Movie: 24-25 January



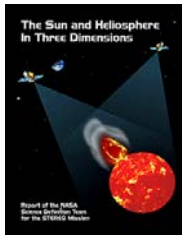
Courtesy:
R. Harrison



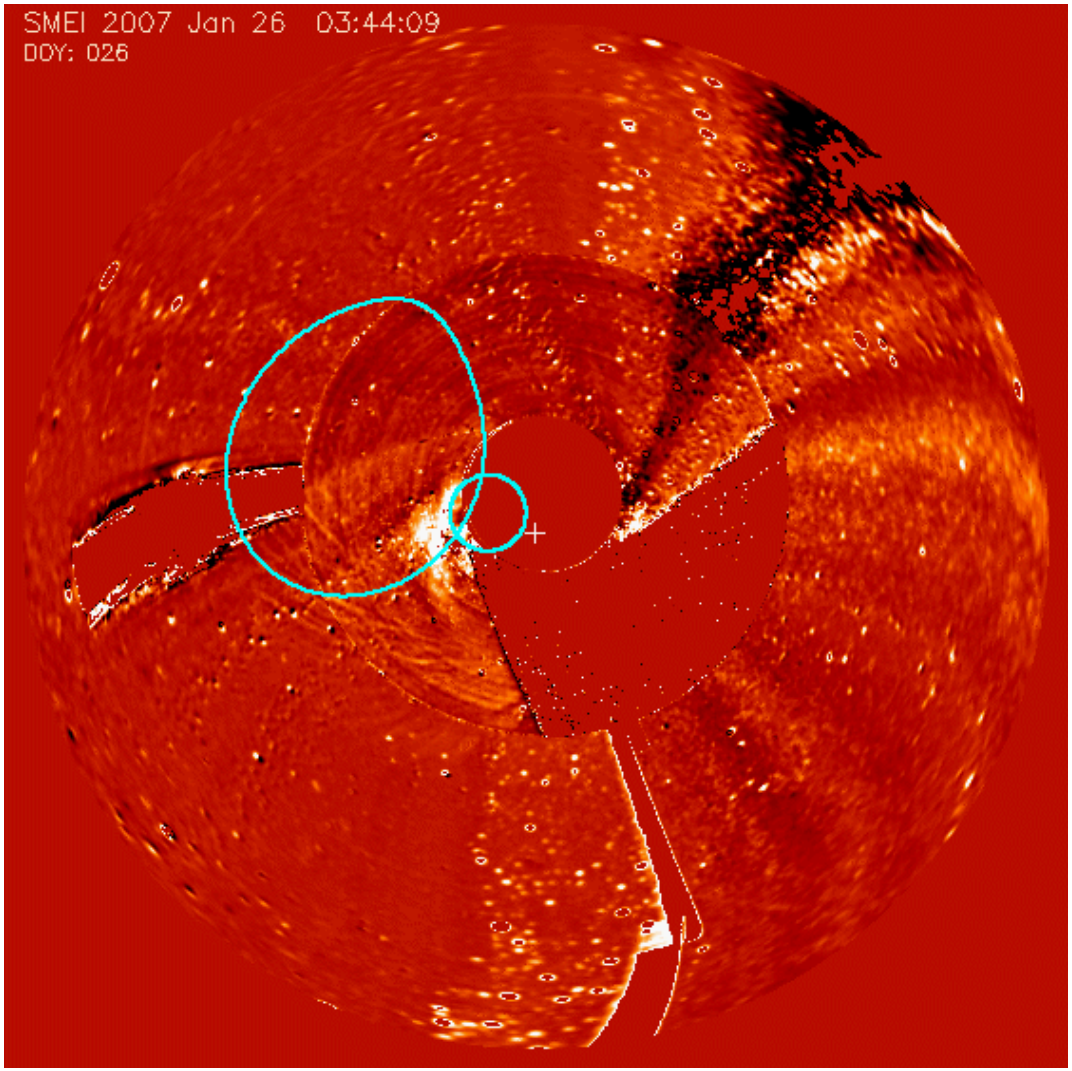
HI-2A CME: 26 January 02:00 – 22:00



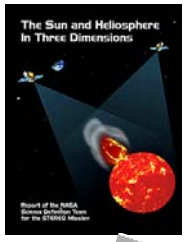
Courtesy: R. Harrison



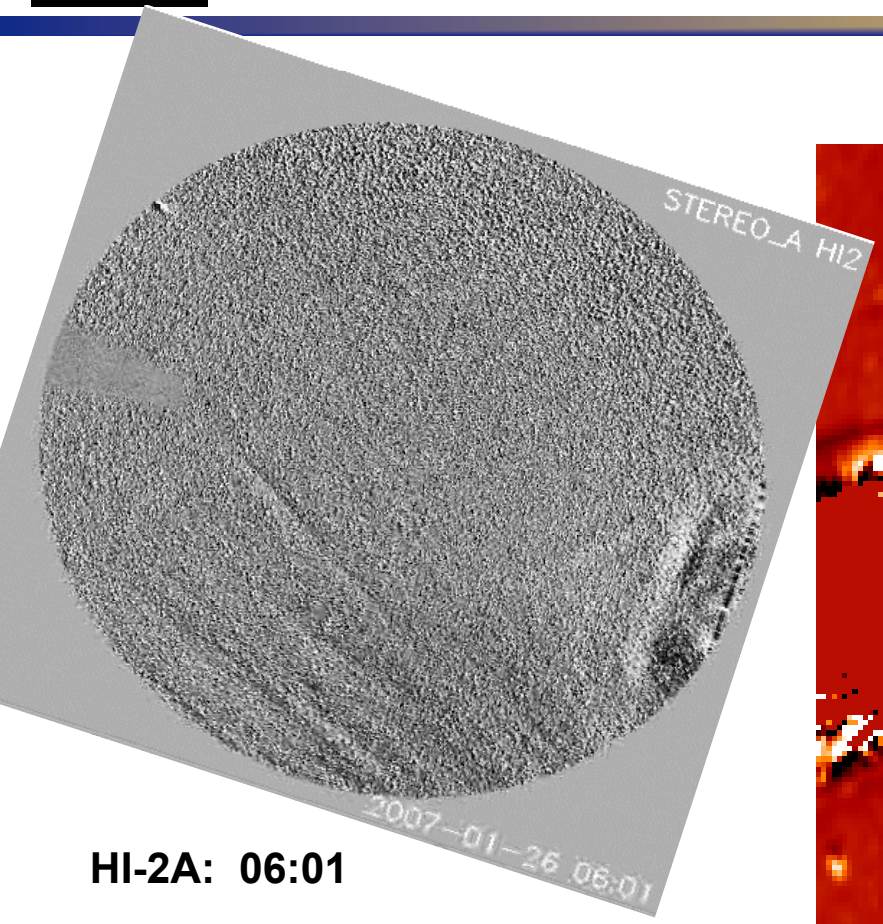
Comparison of HI-As & SMEI Fields of View



SMEI "Fisheye" View to 135° Elongation from Sun (+)

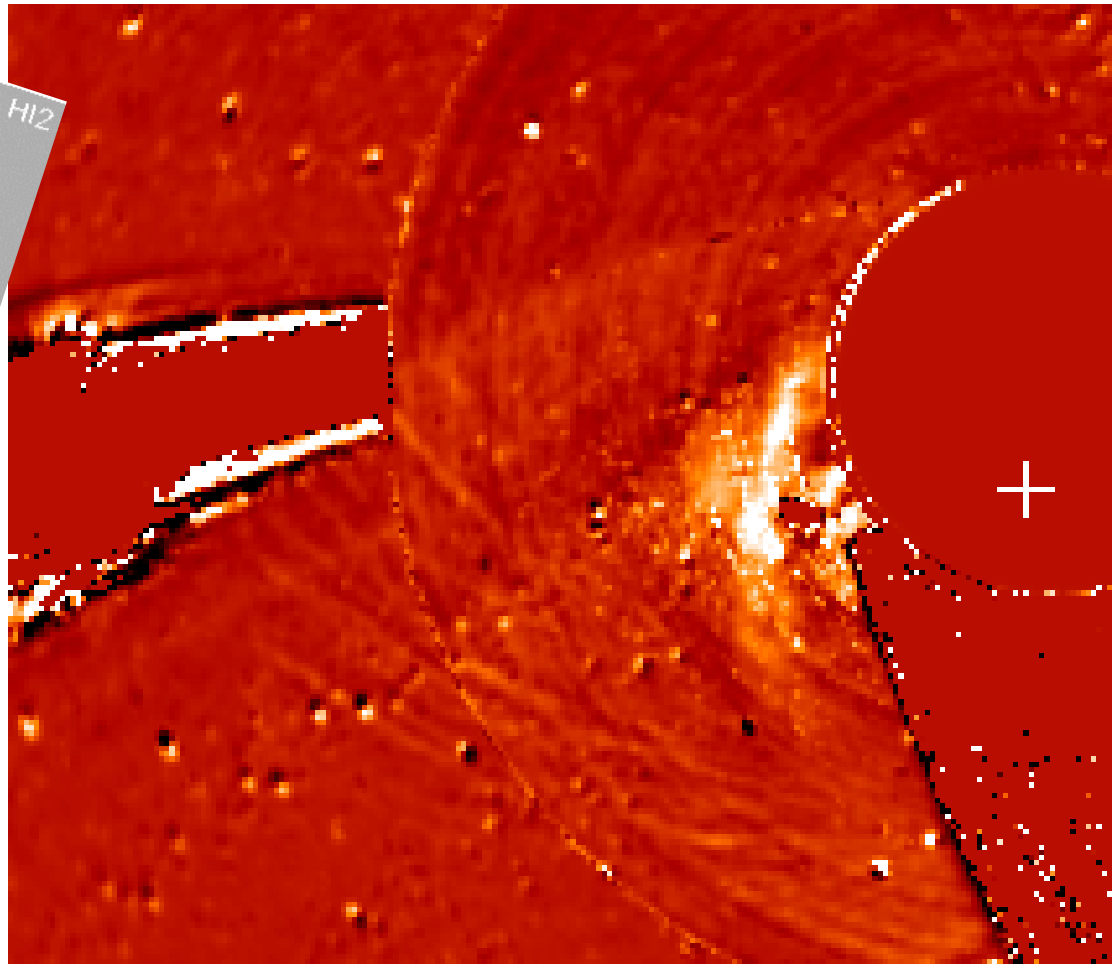


Comparison HI-2A & SMEI: Approx. Same Time & Scale on 26 January

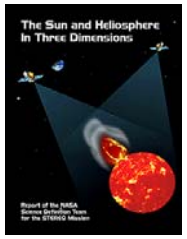


HI-2A: 06:01

SMEI: ~04:00



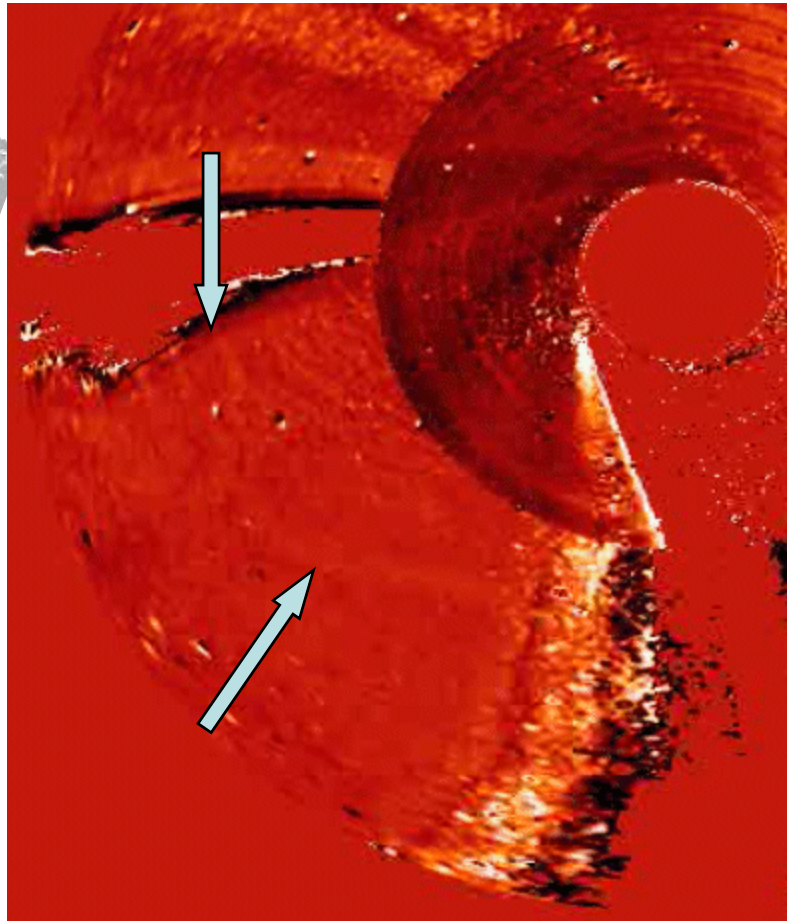
Note similarities in CME & comet (McNaught) tail structures.
Note extension of CME in SMEI - sweeps to SE.

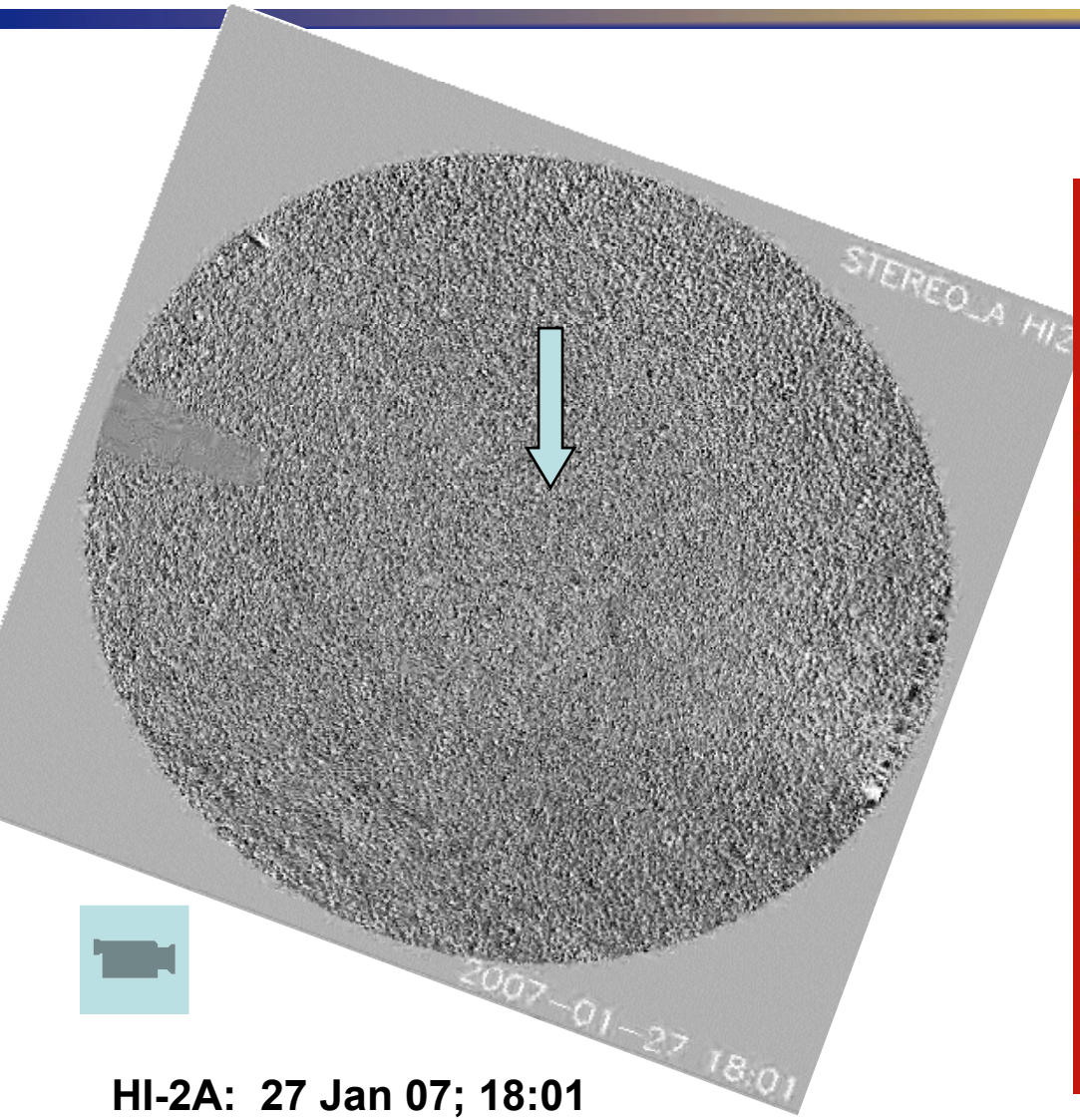


Comparison HIA2 & SMEI Late on 27 January

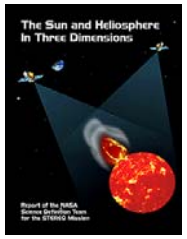
SECCHI

SMEI: 27 Jan 07; ~17:00

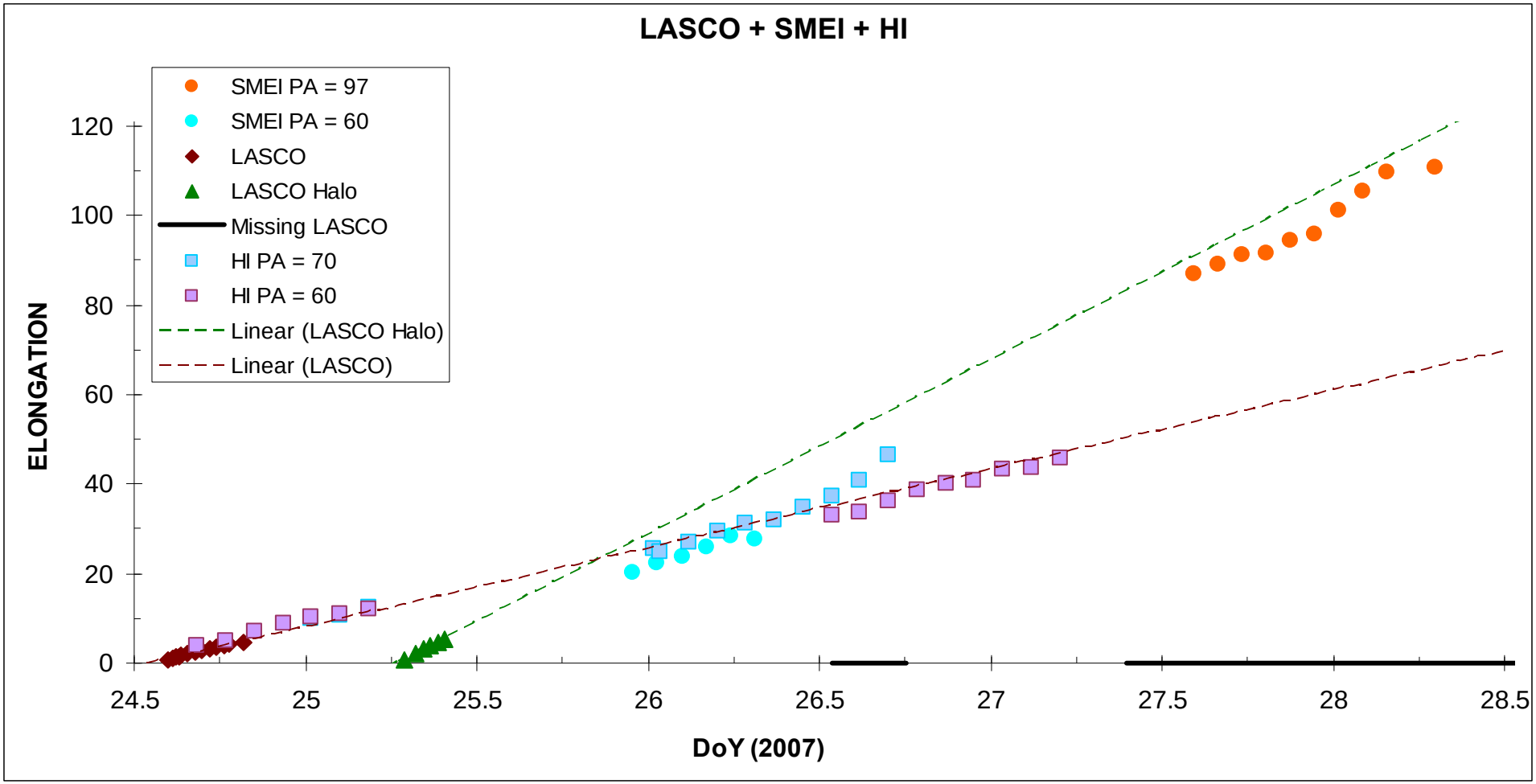


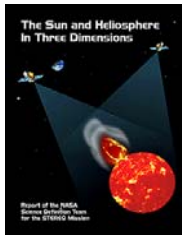


HI-2A: 27 Jan 07; 18:01



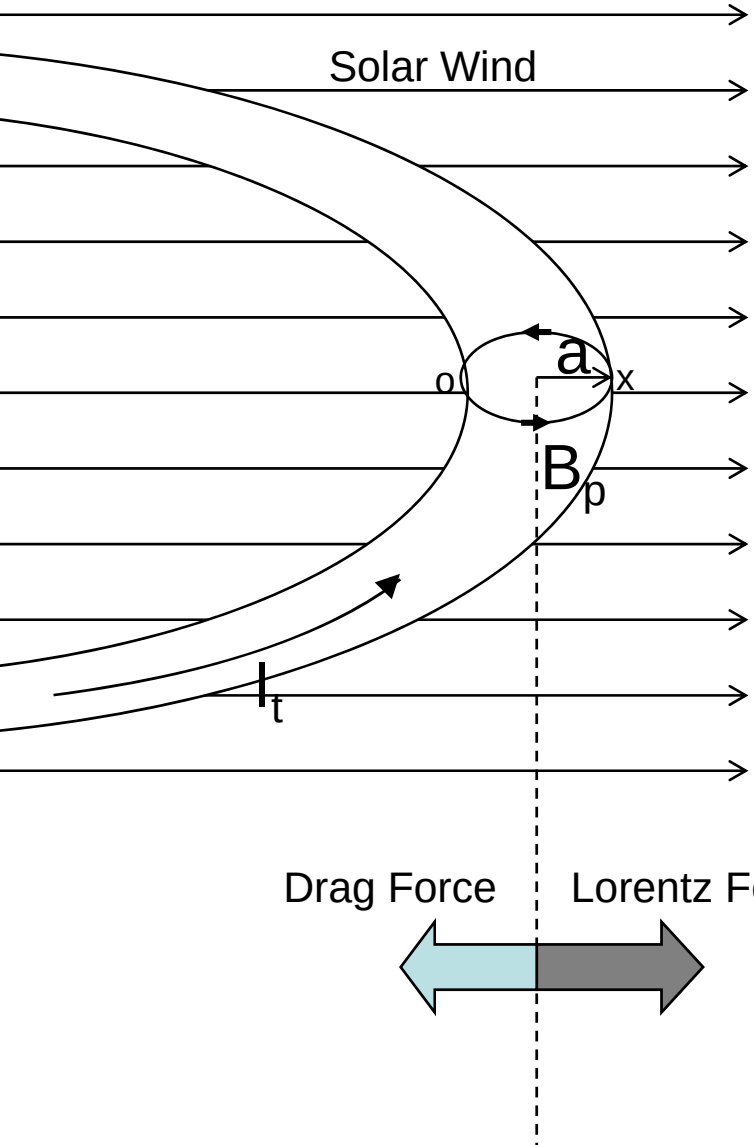
Elongation vs Time Data Along Similar Trajectories





CME Propagation Modeling

1) T. Howard (et al., ApJ, 2007) Model



Driving Mechanism:

Lorentz Force [Chen 1996]:

$$\frac{d^2R}{dt^2} = \frac{I_t^2 \ell}{c^2 R M}\left[\ln\left(\frac{8R}{a}\right) - \frac{1}{2}\frac{B_t^2}{B_{pa}^2} - 1 + \frac{\xi}{2}\right]$$

Drag Mechanism: 2 Models

1. "Snowplow" [Tappin 2006]:

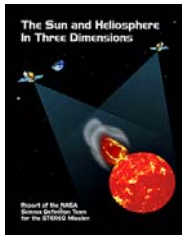
$$\frac{d^2R}{dt^2} = -\frac{dM}{dt}\frac{v_c(R) - v_{sw}(R)}{M(t)}$$

$$\frac{dM}{dt} = \Omega\sigma(R)\left(v_c(R) - v_{sw}(R)\right)$$

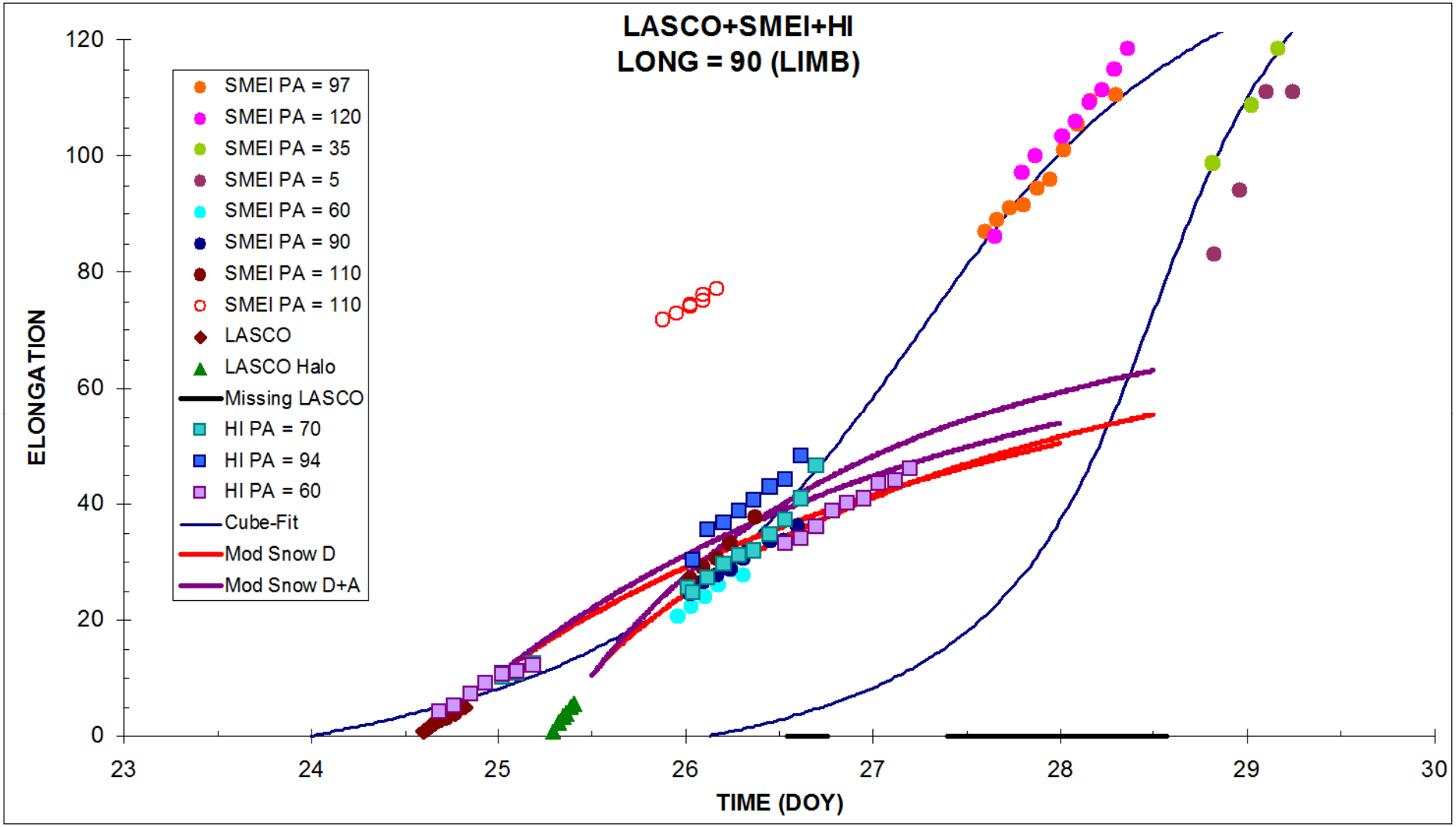
2. Aerodynamic Drag [Cargill 2004]:

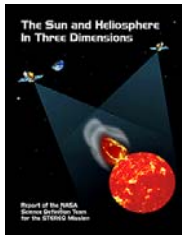
$$\frac{d^2R}{dt^2} = -\gamma C_D\left(v_c(R) - v_{sw}(R)\right)^2$$

$$\gamma = \frac{\sigma\Omega}{M + \sigma\Omega a},$$

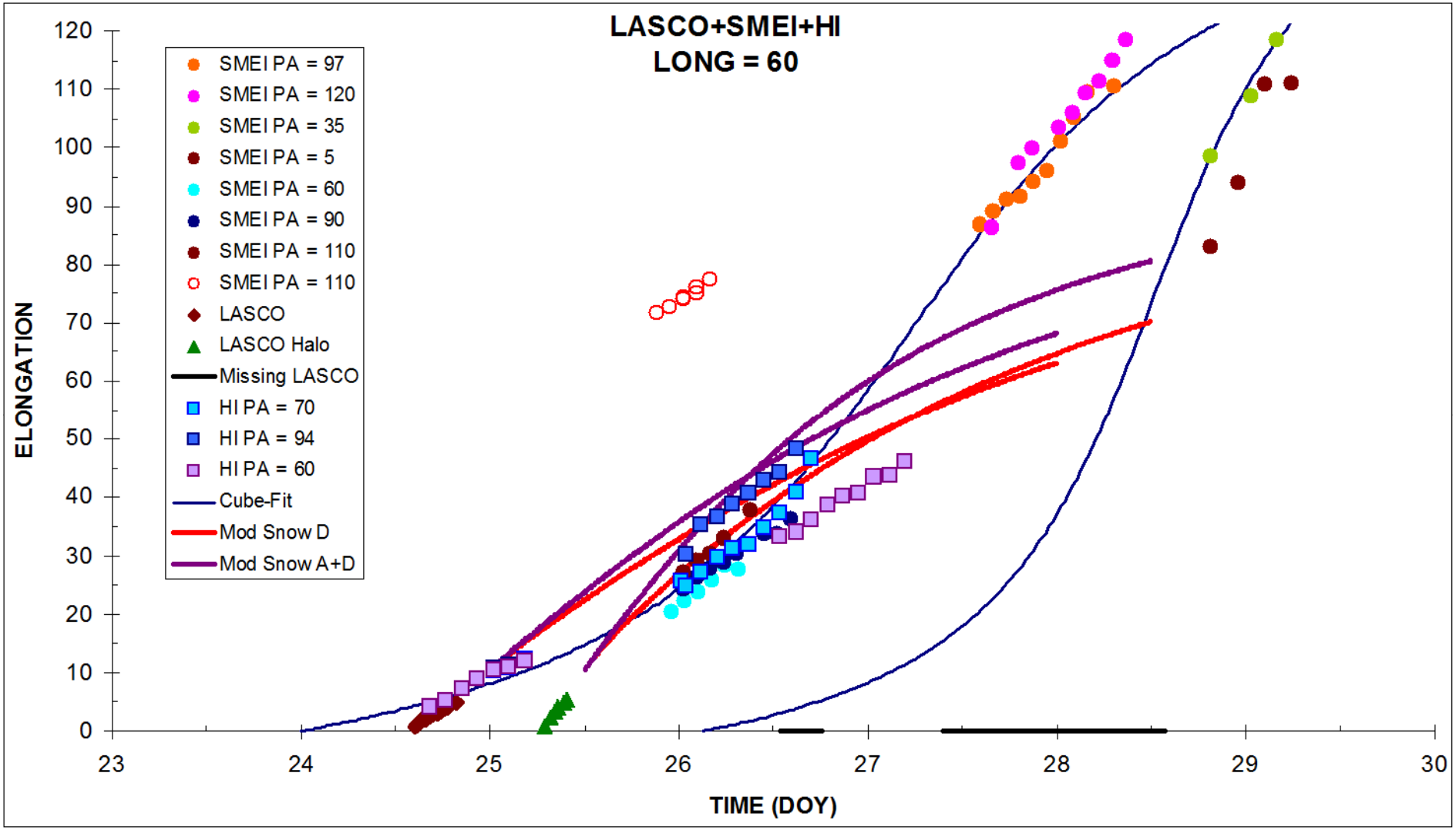


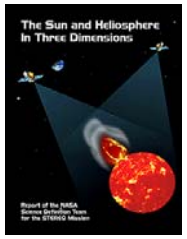
CME Propagation Modeling:
Both Launched from Limb



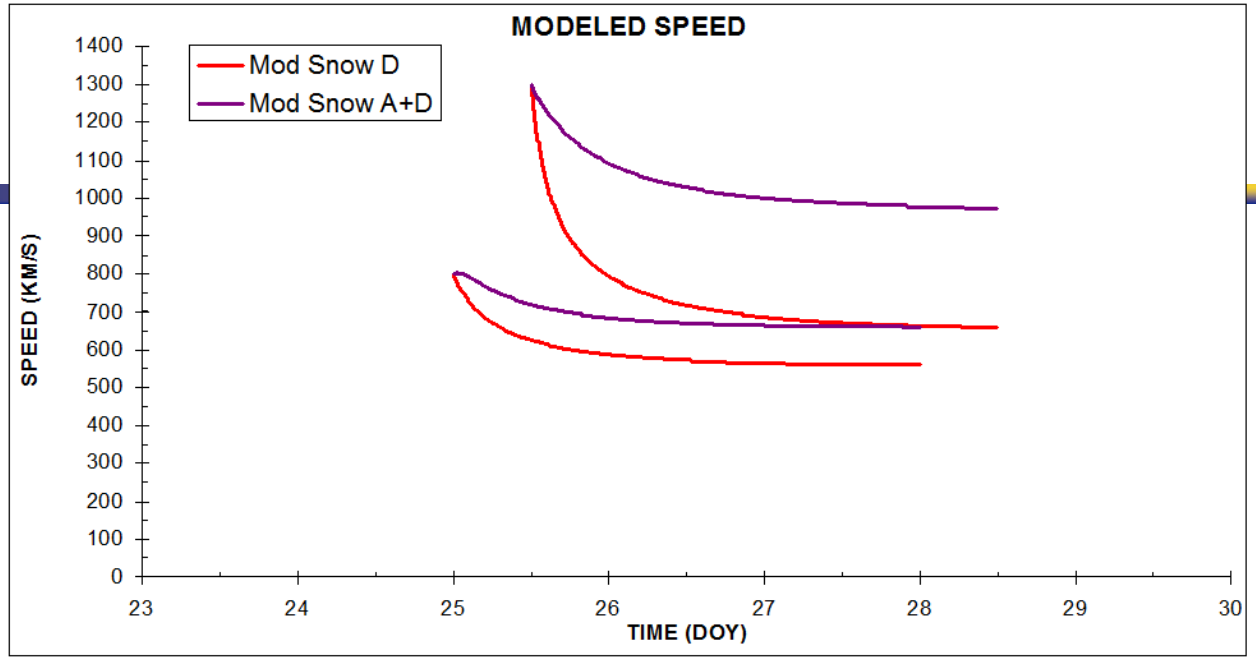


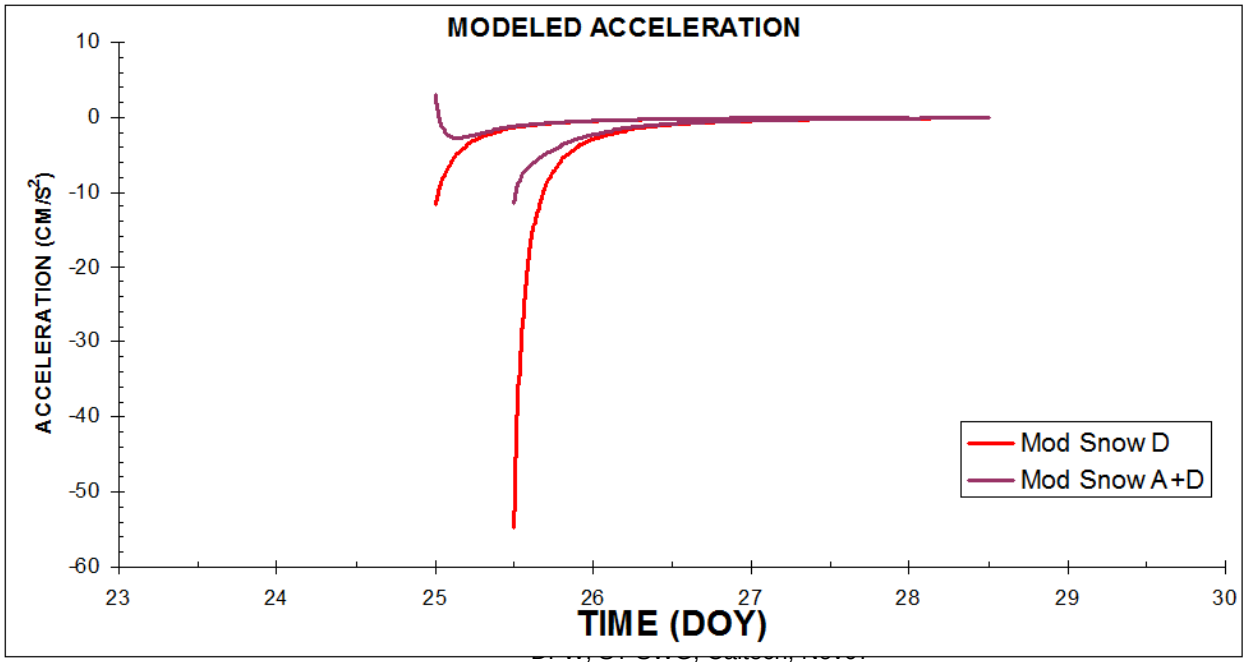
CME Propagation Modeling:
Both Launched 60° from SC

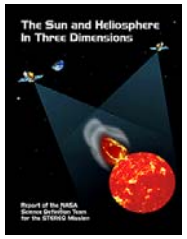



The Sun and Heliosphere
In Three Dimensions

SECCHI


MODELED SPEED
Mod Snow D
Mod Snow A+D
SPEED (KM/S)
TIME (DOY)

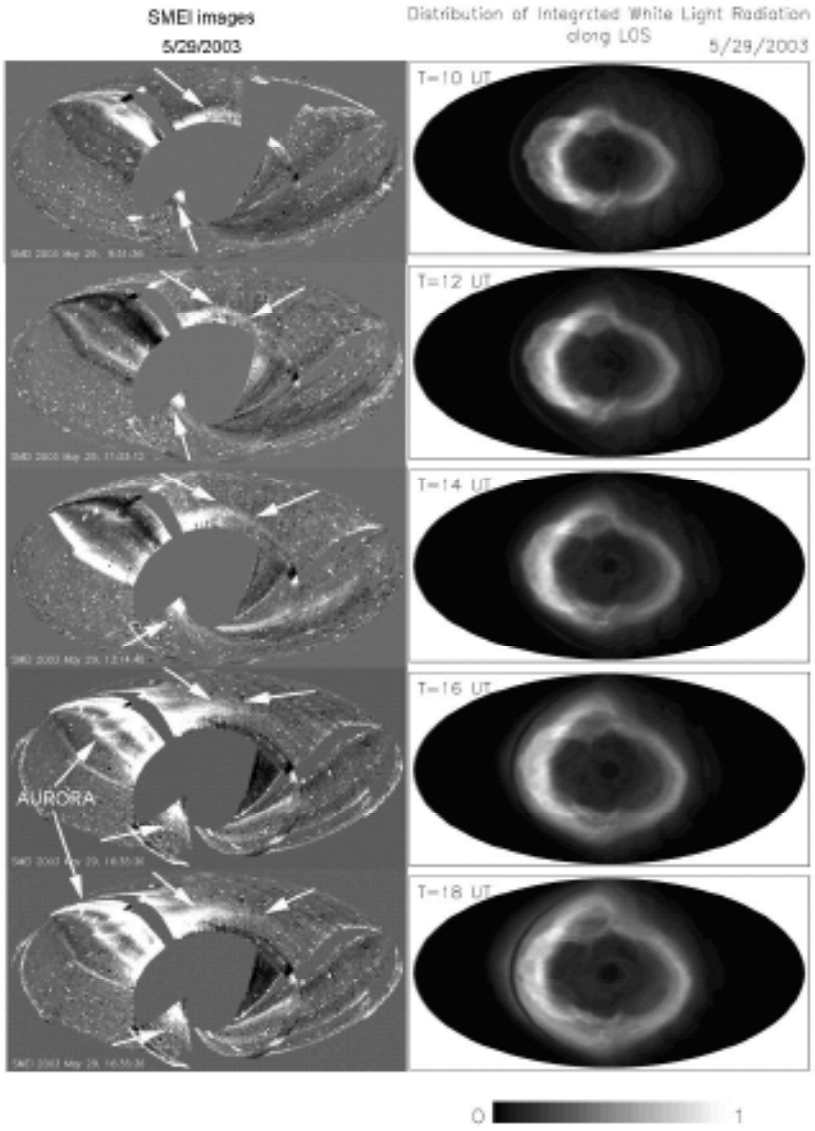

MODELED ACCELERATION
Mod Snow D
Mod Snow A+D
ACCELERATION (CM/S2)
TIME (DOY)

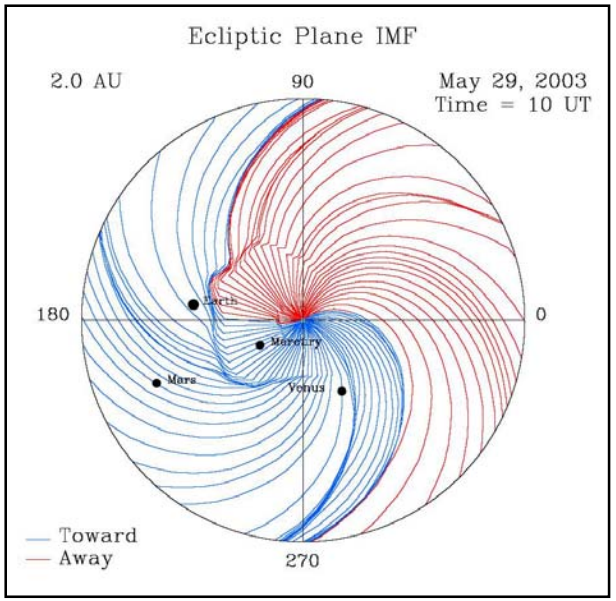


CME Propagation Modeling

2) Hakamada-Akasofu-Fry Kinematic Model

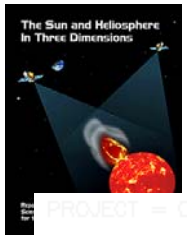
SMEI Aitoff Skymaps; 28-29 May 2003





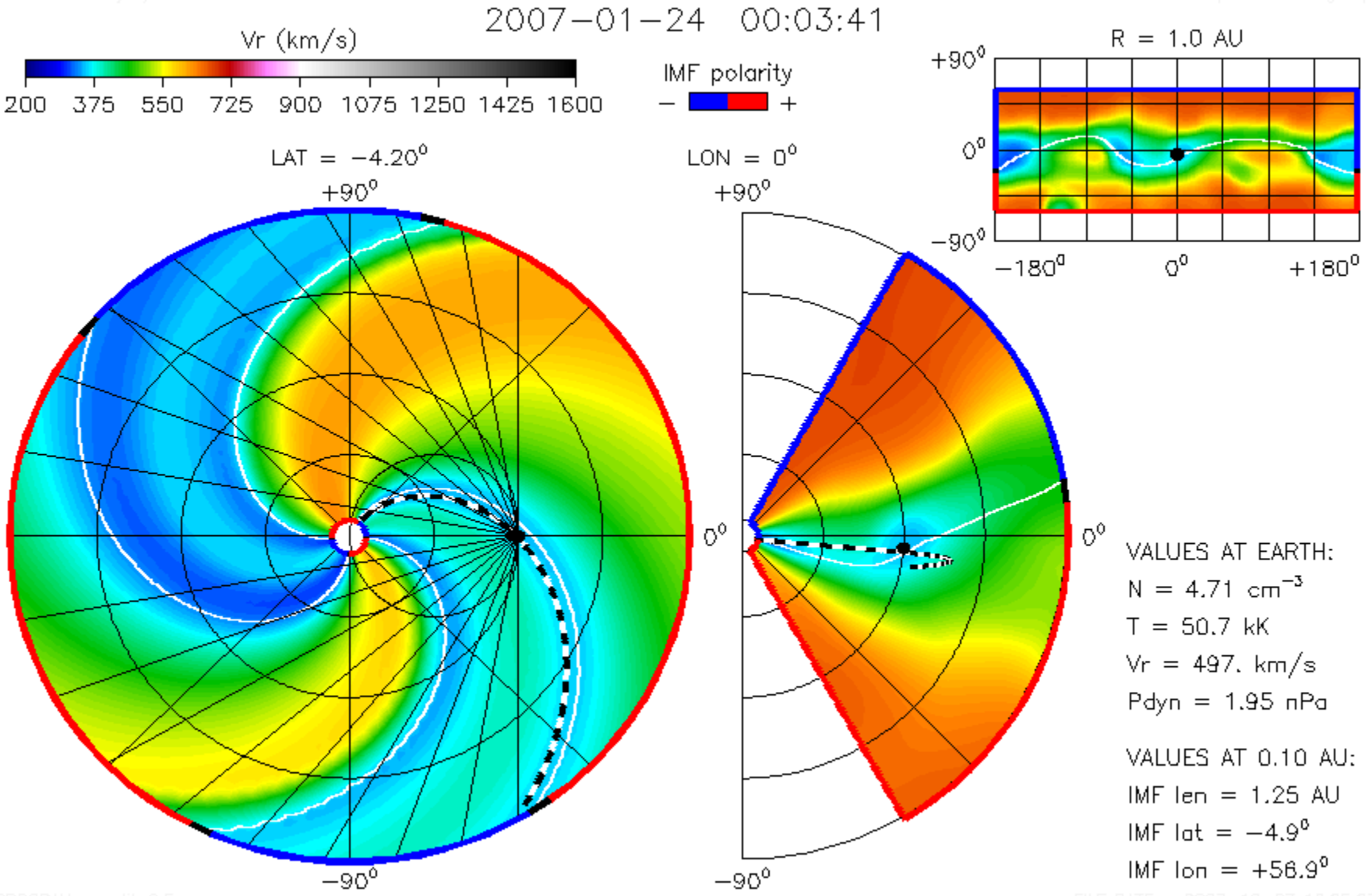
HAFv2 Model Simulation of White Light Emission

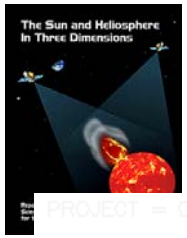
Sun et al., SW, 2007



CME Propagation Modeling

3) ENLIL 3D MHD Model (Odstrcil)





- CME-1: 2007-01-24T18:18, S05E90, R=50^0, V=700 km/s
- CME-2: 2007-01-25T08:42, S05E90, R=60^0, V=1500 km/s

SECCHI

2007−01−24 00:03:41

N (cm−3)

0 10 20 30 40 50 60 70 80

IMF polarity

− +

R = 1.0 AU

+90^0

0^0

−90^0

−180^0 0^0 +180^0

LAT = −4.20^0

+90^0

−90^0

LON = 0^0

+90^0

0^0

−90^0

0^0

VALUES AT EARTH:

N = 4.71 cm^{-3}

T = 50.7 kK

Vr = 497. km/s

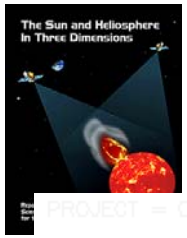
Pdyn = 1.95 nPa

VALUES AT 0.10 AU:

IMF len = 1.25 AU

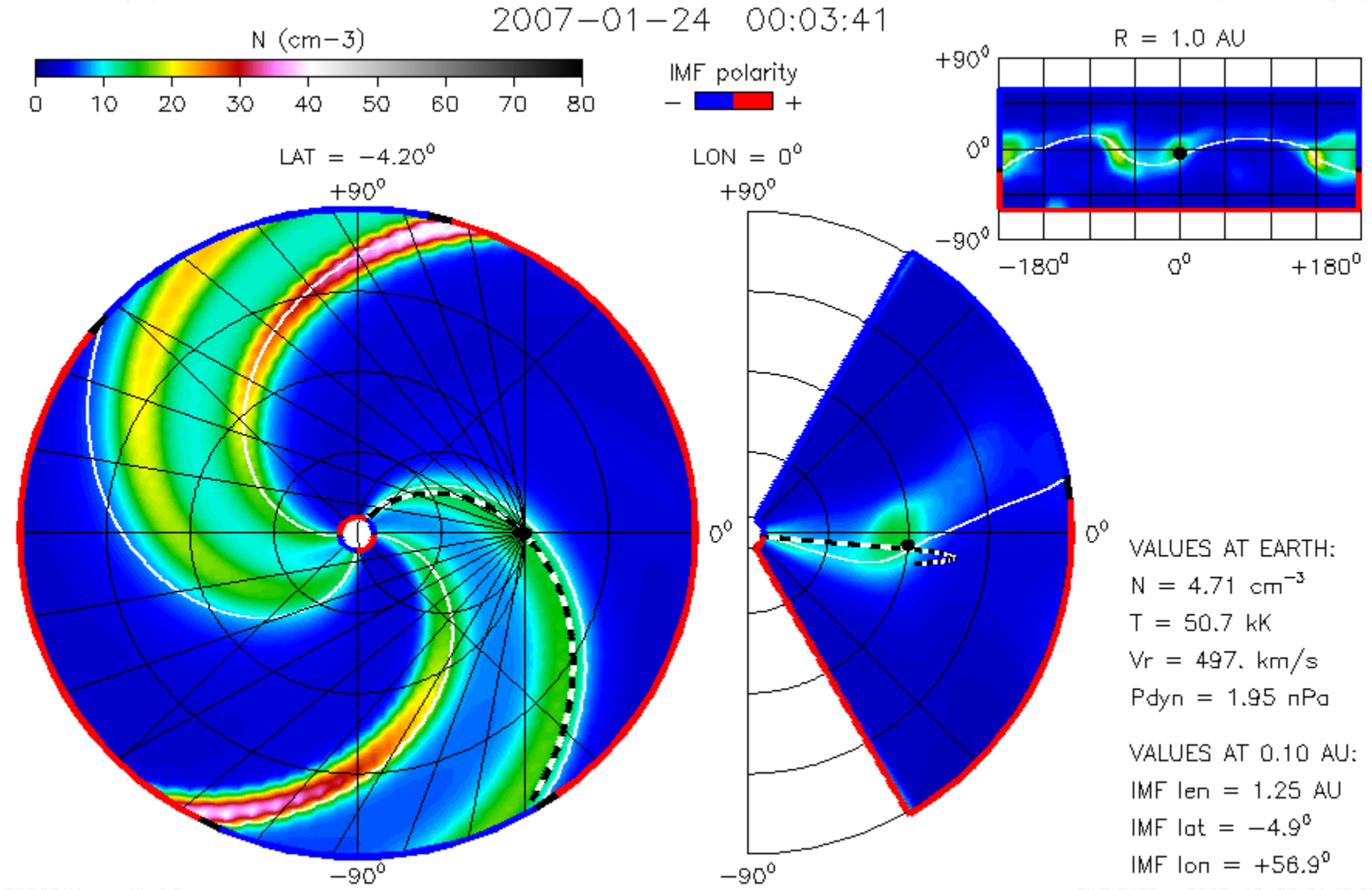
IMF lat = −4.9^0

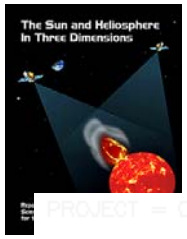
IMF lon = +56.9^0



- CME-1: 2007-01-24T18:18, S05E90, R=50^0, V=700 km/s
- CME-2: 2007-01-25T08:42, S05E90, R=60^0, V=1000 km/s

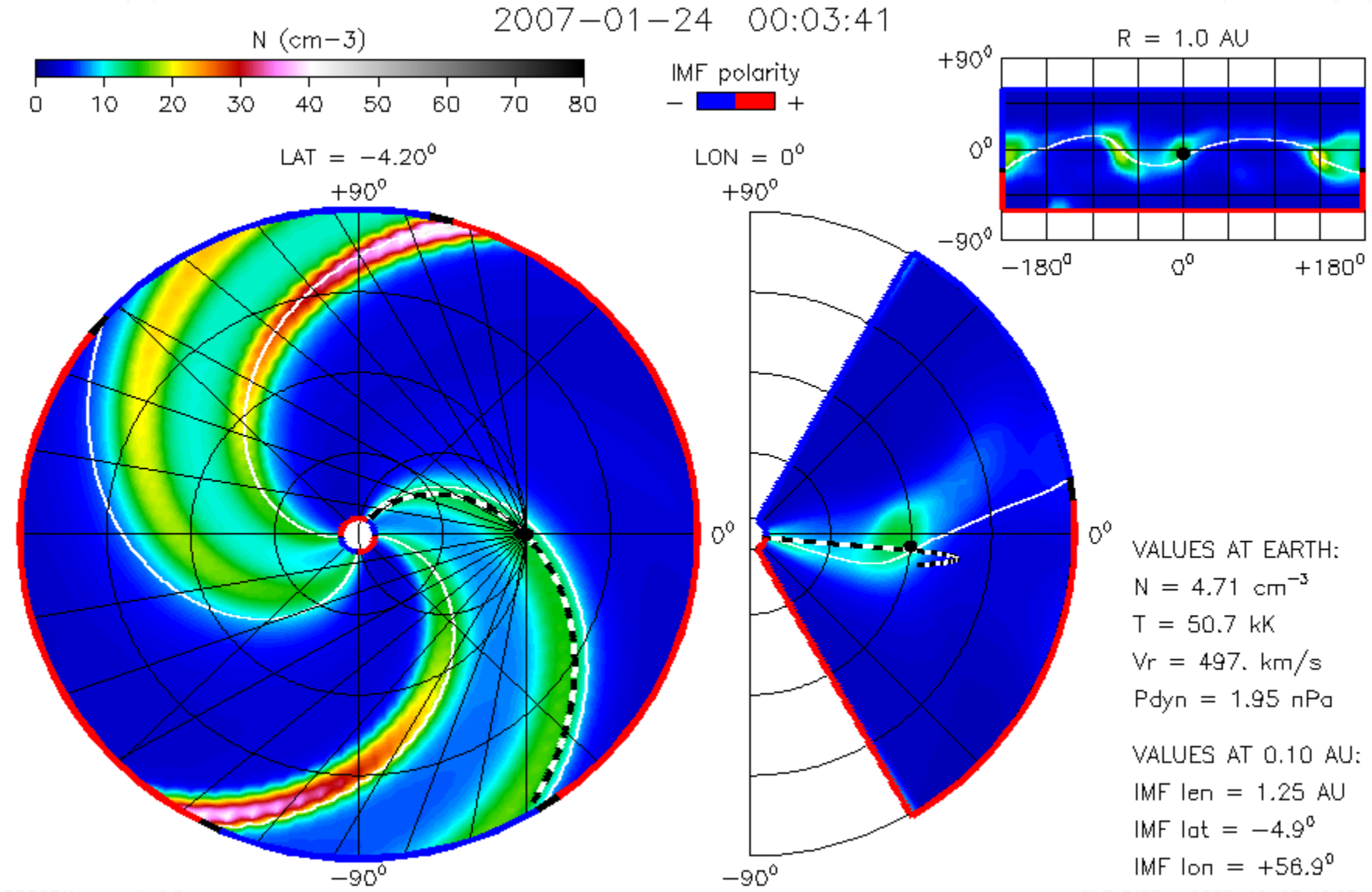
SECCHI





- CME-1: 2007-01-24T18:18, S05E90, R=50^0, V=700 km/s
- CME-2: 2007-01-25T08:42, S05E45, R=60^0, V=1500 km/s

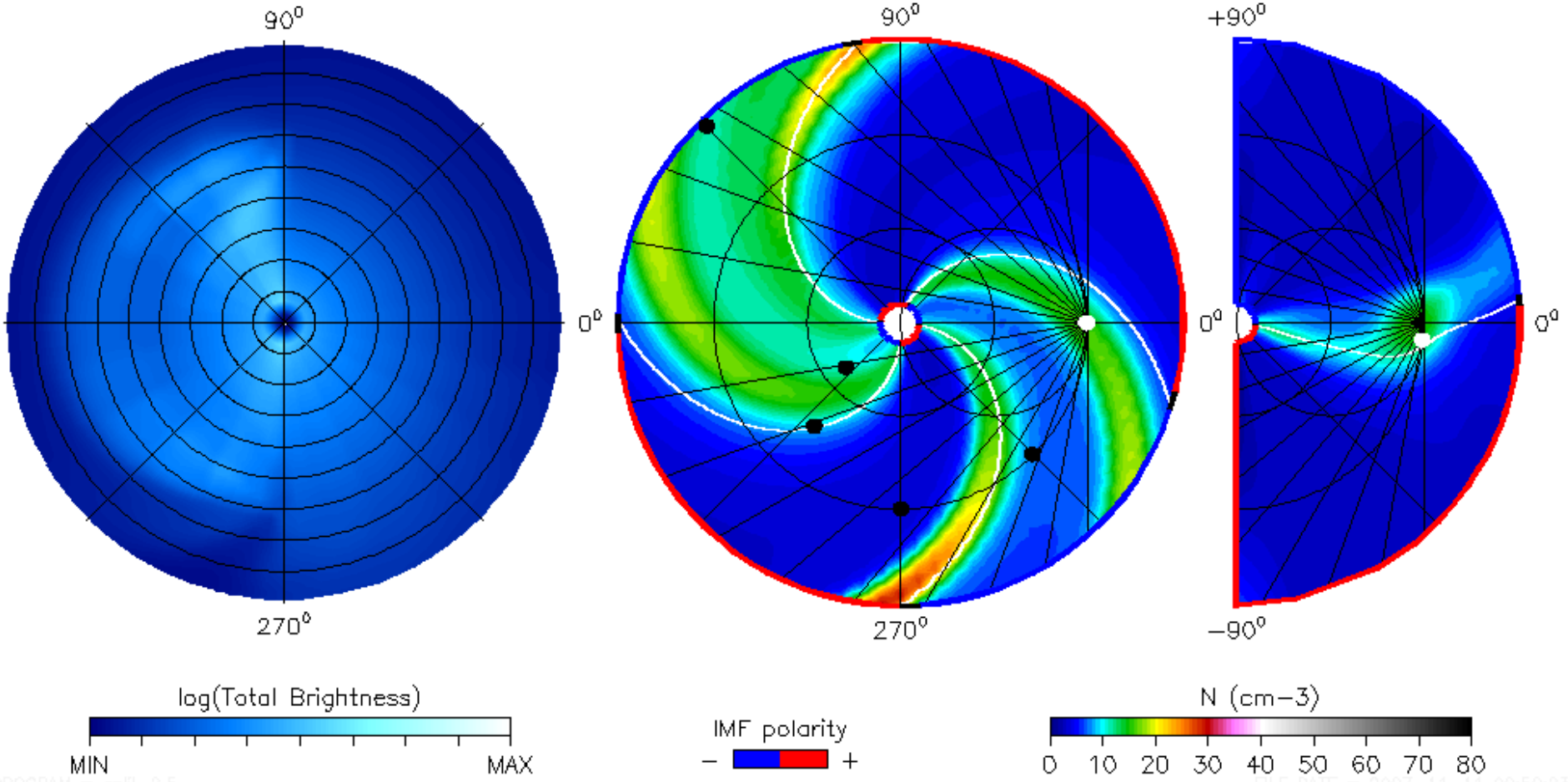
SECCHI



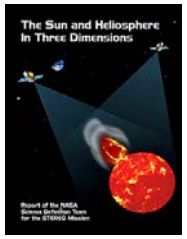
View from Earth

PROJECT = 07jan/wsafr-cld RUN = 2052-a1b2a-sa4.256x36x90.1-mcp1um1mt-1.g15q0

2007-01-24 00:02:21

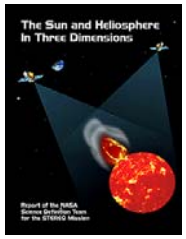


PROGRAM = enlil-2.5 FILE DATE = 2007-11-11 00:50:23



Preliminary Results

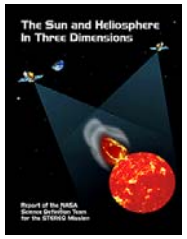
- Can observe and track CME fronts from near-Sun to ~100°
- Similar structure & orientation observed in all instruments out to ~40°
  - LASCO C2/C3, HI-1A + 2A, SMEI
- In January events, HI-1A & SMEI observe single structures/CMEs
  - Slow CME followed by faster CME: superposition in LoS or merging?
  - At large elongation-times SMEI observes front likely near Earth; Second, fast, halo CME or part of merged event?
- Assumptions:
  - Material moves radially from Sun; Make measurements along same PAs
  - How material is observed by given instrument along LoS depends on distance from Sun, distance from the instrument, & Thomson sphere
- HI and SMEI observations are complimentary
  - HI-1 fills gap between LASCO/COR & SMEI inner camera
  - HI-2 overlaps with SMEI over 10's of degrees – improved resolution
  - Despite areal gaps, SMEI observes entire sky; HI fields centered on ecliptic.



FUTURE WORK

- **Compare CME detection capabilities for more events → SMEI vs HIs**
- **Compare e-t plots with kinematic models → CME propagation over large distances**
  Include drag effects, acceleration vs constant speed, launch location, etc.
- **Compare CME structure & propagation with ENLIL MHD model**
- **Determine flow of density & mass over large distances**
- **Space weather: Use HIA + HIB + SMEI observations to model (3D) propagation to Earth & estimate timing and size characteristics**

THE END



Putting All the A-Telescopes Together

4R ≈ 1º

90º
360 R

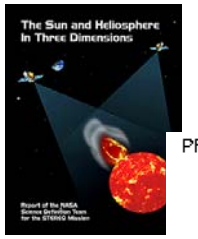
65º
260 R

24º
96 R

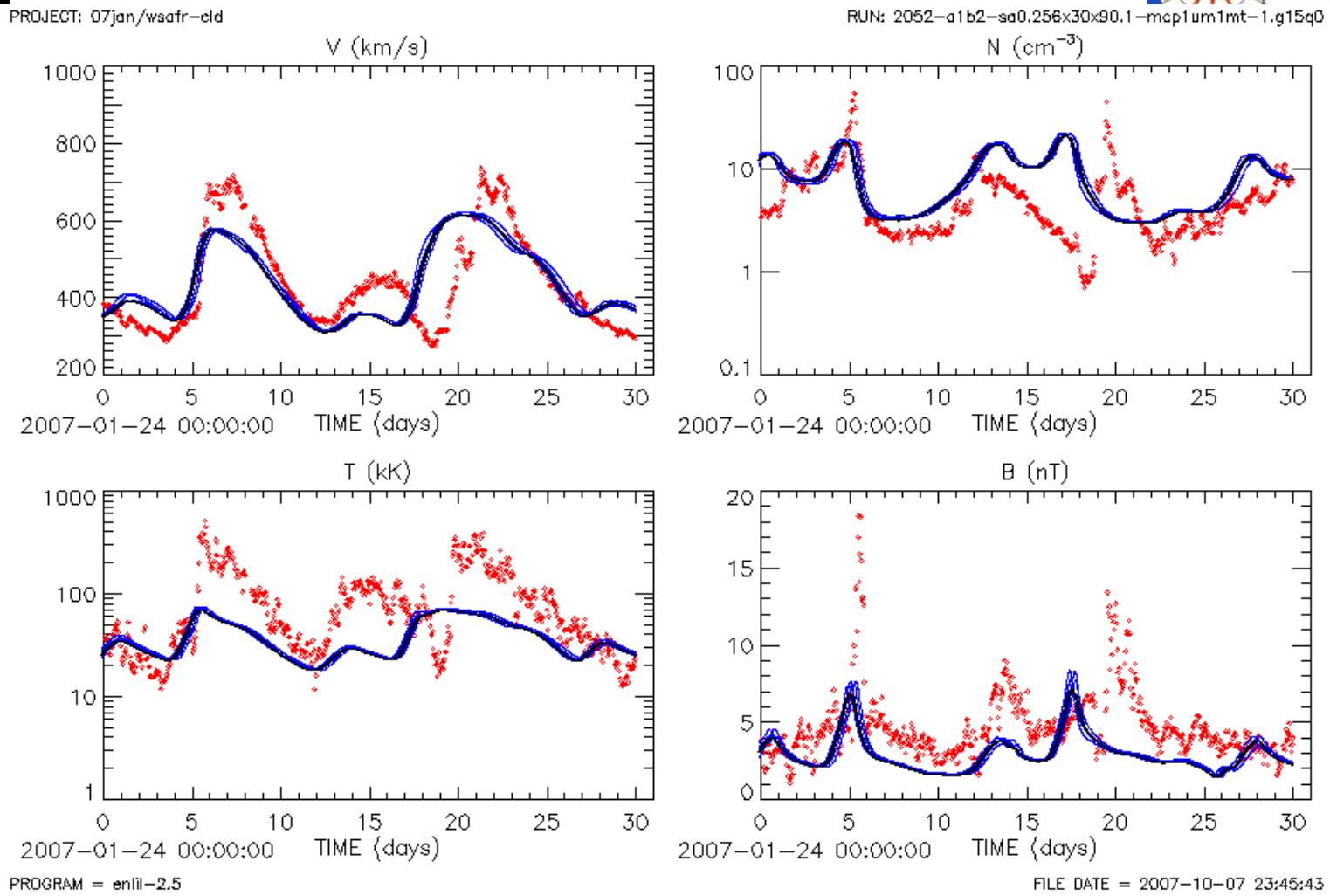
4º
15 R

0

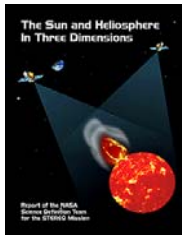
Courtesy:
R. Howard



Background Solar Wind at Earth



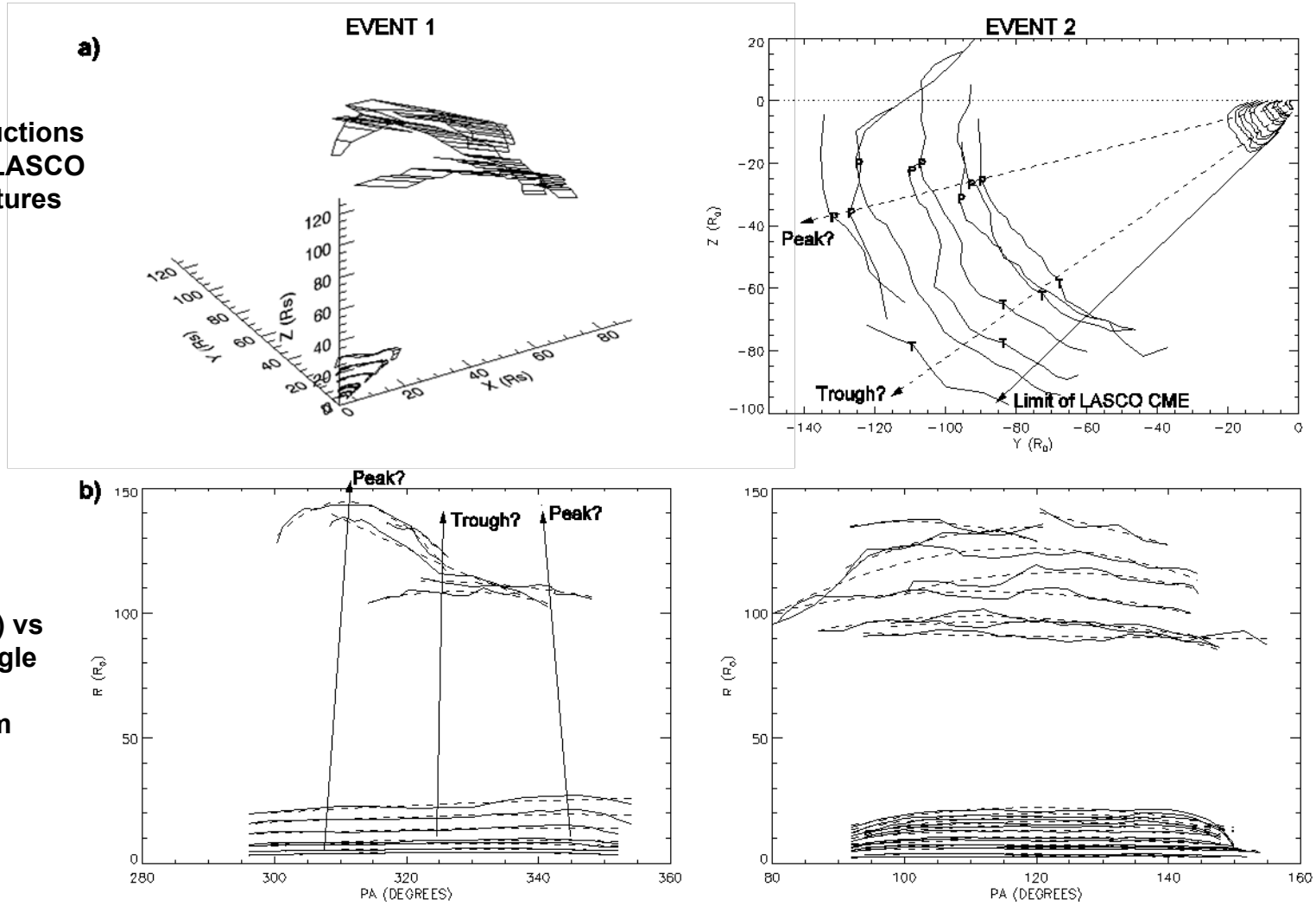
Low-resolution computations driven by WSA/NSO full rotation maps (blue) and observation at Earth (red dots). Contrast between slow and fast streams will be increased in higher-resolution runs; however, general match is good.

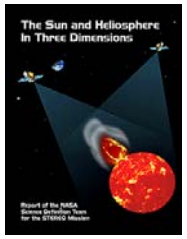


Model Fits to 2 Prior LASCO/SMEI Events

3D Reconstructions of observed LASCO & SMEI structures

Distance (R) vs Position Angle (PA) plots derived from above





Model Fits to 2 Prior LASCO/SMEI Events

Model with only Drag

Event 1 shows net deceleration; Well fit by either Drag model

Model with both Lorentz Force + Drag

Event 2 shows constant speed; Well fit by Lorentz driver + Drag