Propagation of an Earth-Directed CME Front in Three-Dimensions

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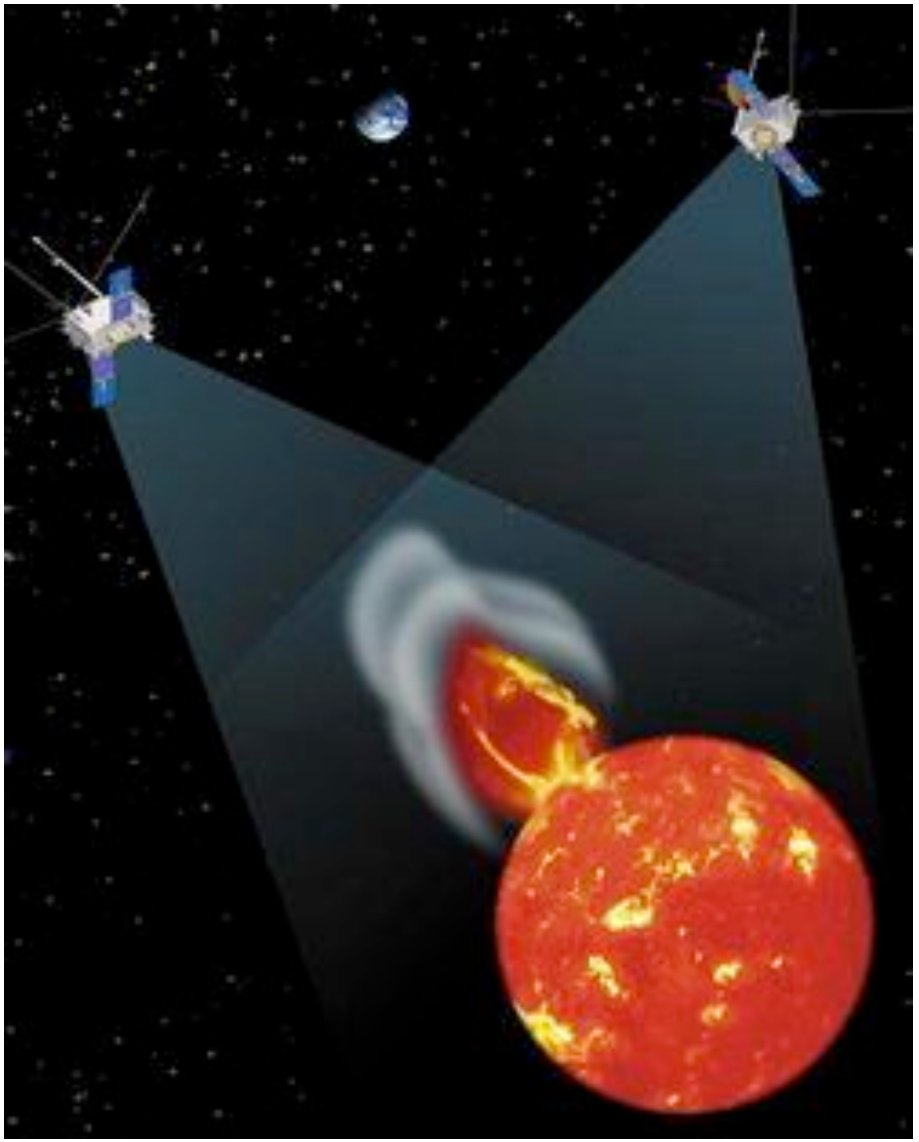
Overview

1) CME Theory
   - Dynamics - morphology - POS
   - CME models & analysis

2) The STEREO Mission
   - Tie-pointing
   - Forward modeling
   - Multiscale edges + ellipse fits

3) Results
   - Reconstruction: 12-Dec-2008
   - Kinematics & morphology
   - Drag model
   - Arrival time (ACE)
   - 3D visualization



STEREO illustration

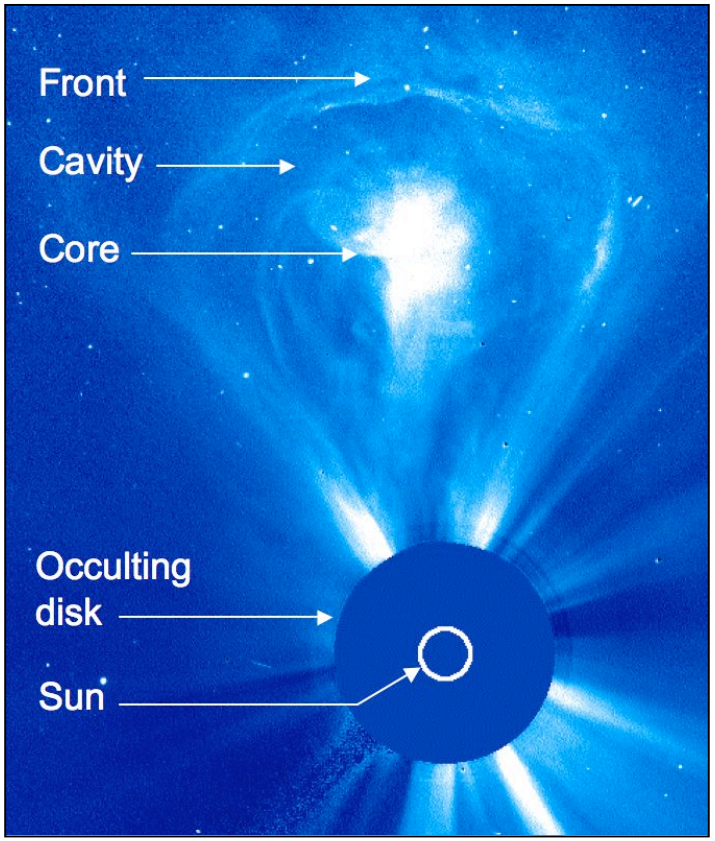
CME Dynamics

Equation of motion:

$$\sum F = F_B + F_P + F_G + F_D$$

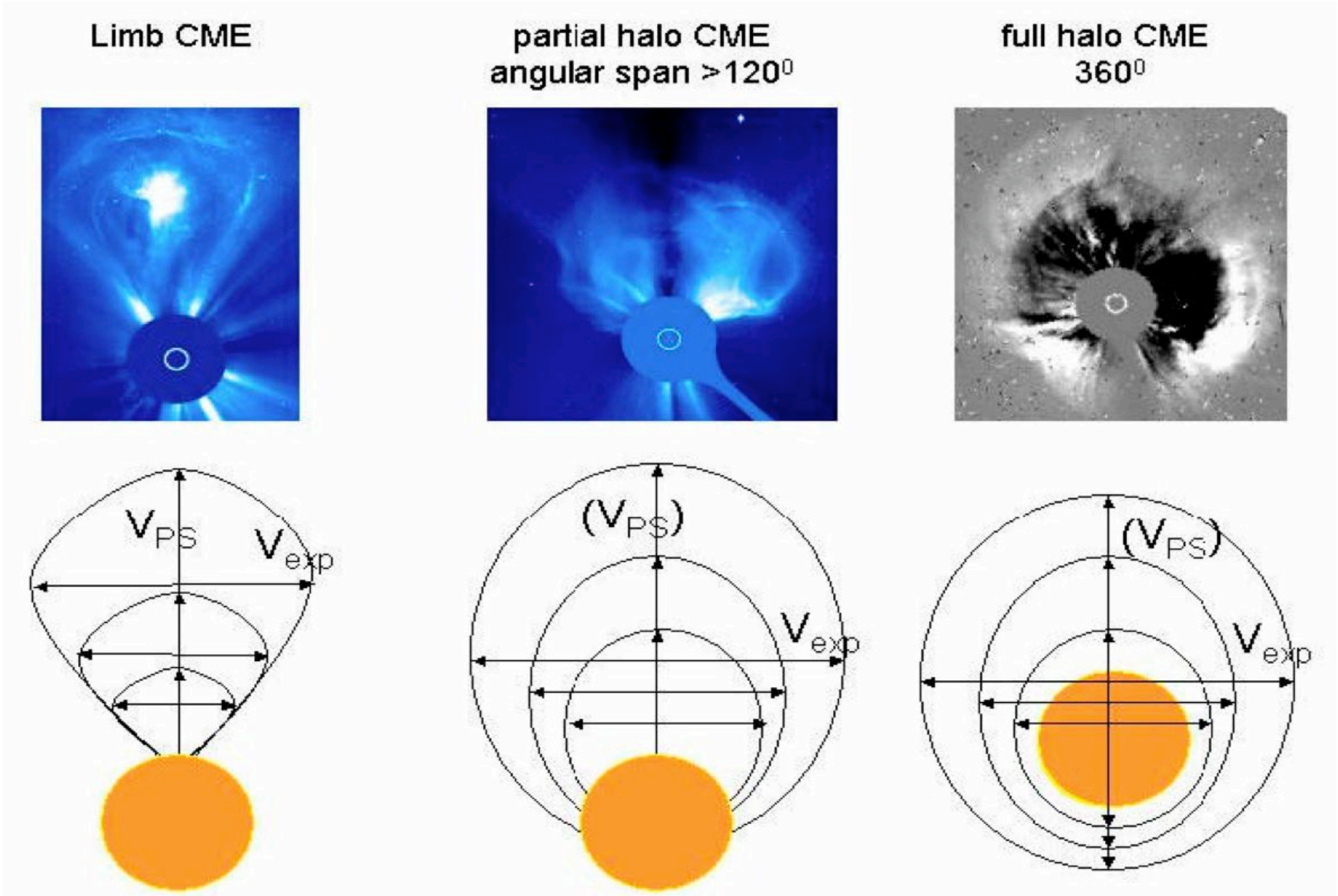
$$\rho \frac{D\vec{v}}{Dt} = \vec{j} \times \vec{B} - \nabla P - \rho \vec{g} - \frac{1}{2} \rho \vec{v}^2$$

Density
Lorentz force
Pressure gradient
Gravitational force
Drag force



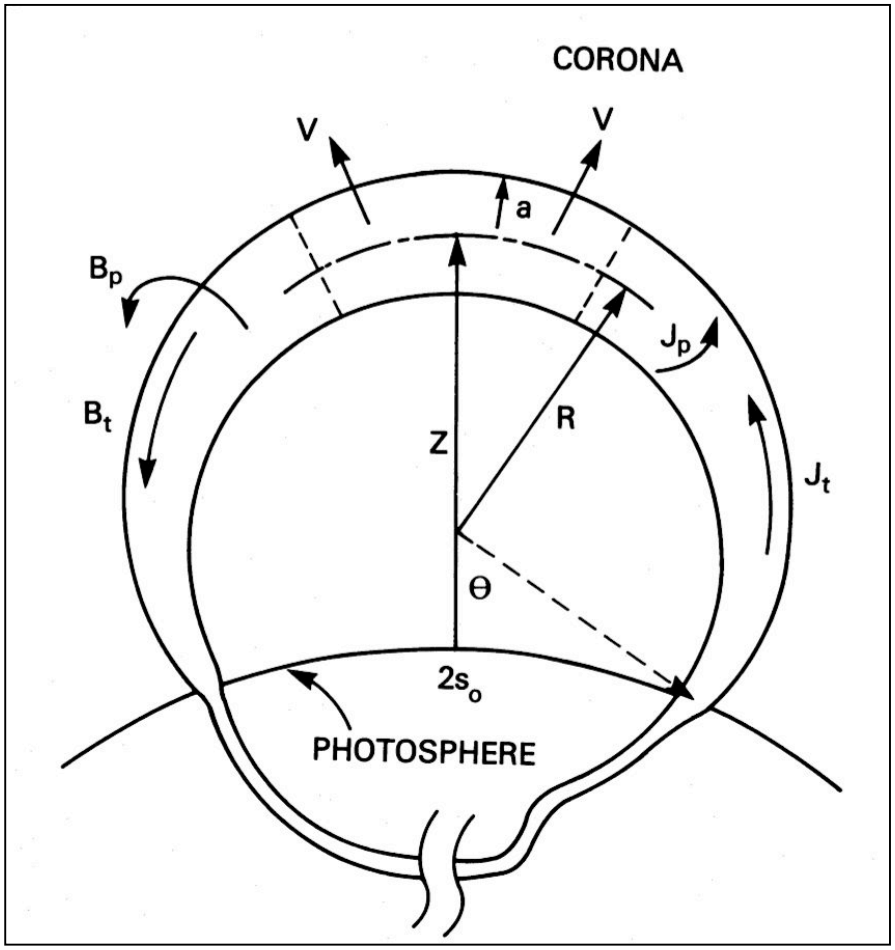
SOHO

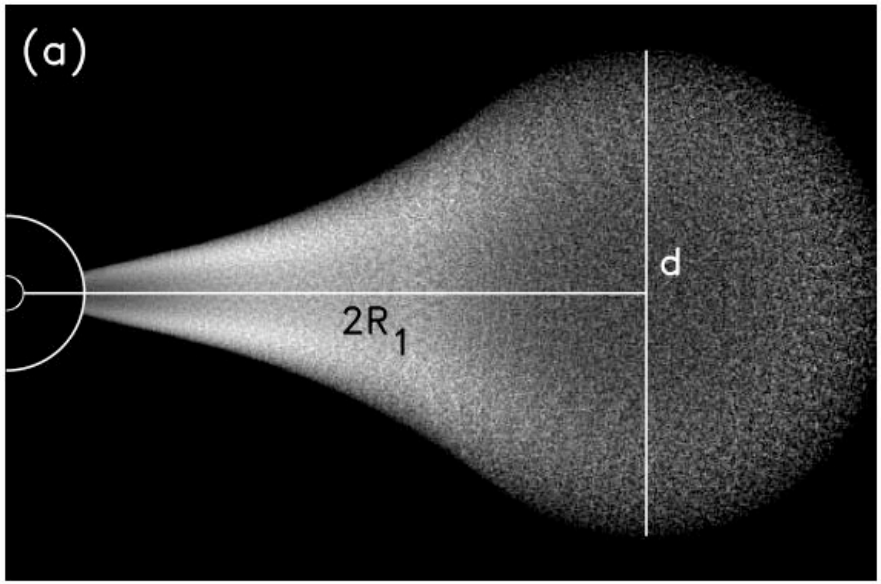
CME Morphology

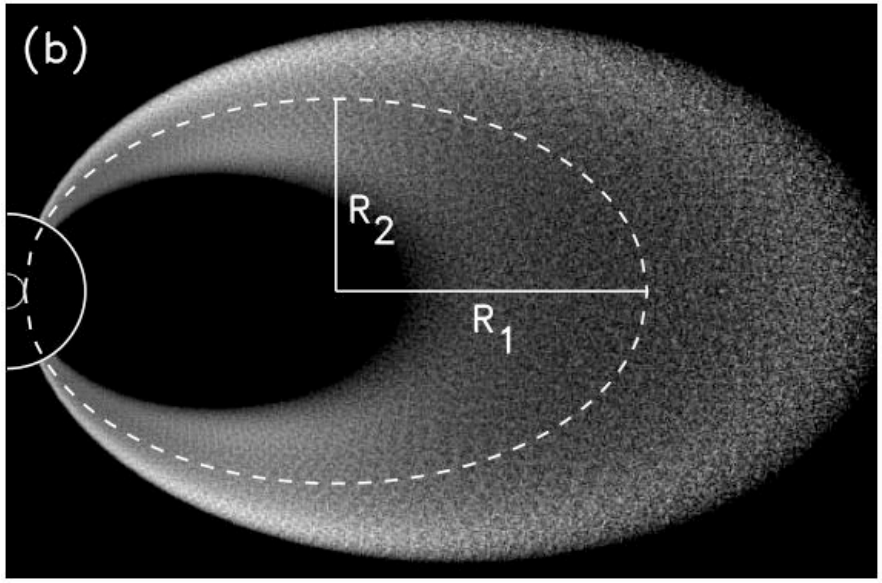


CME Morphology

1) 3D Flux Rope (Krall & Chen)

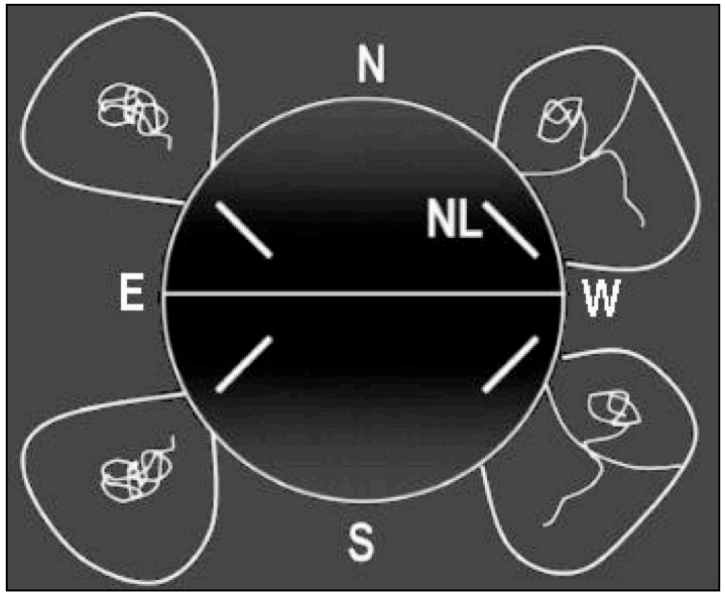


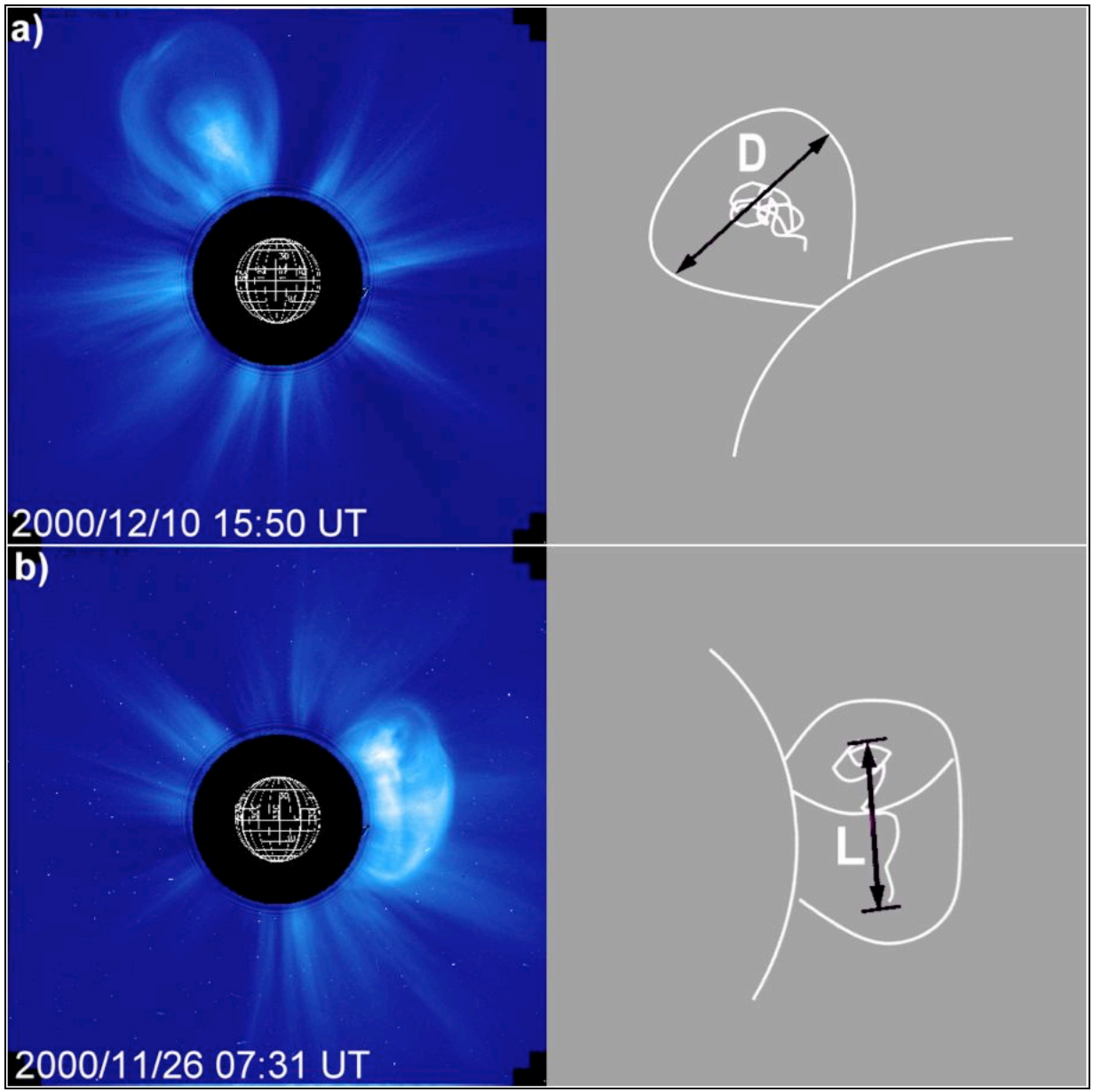




CME Morphology

2) Cylindrical Model
(Cremades & Bothmer)

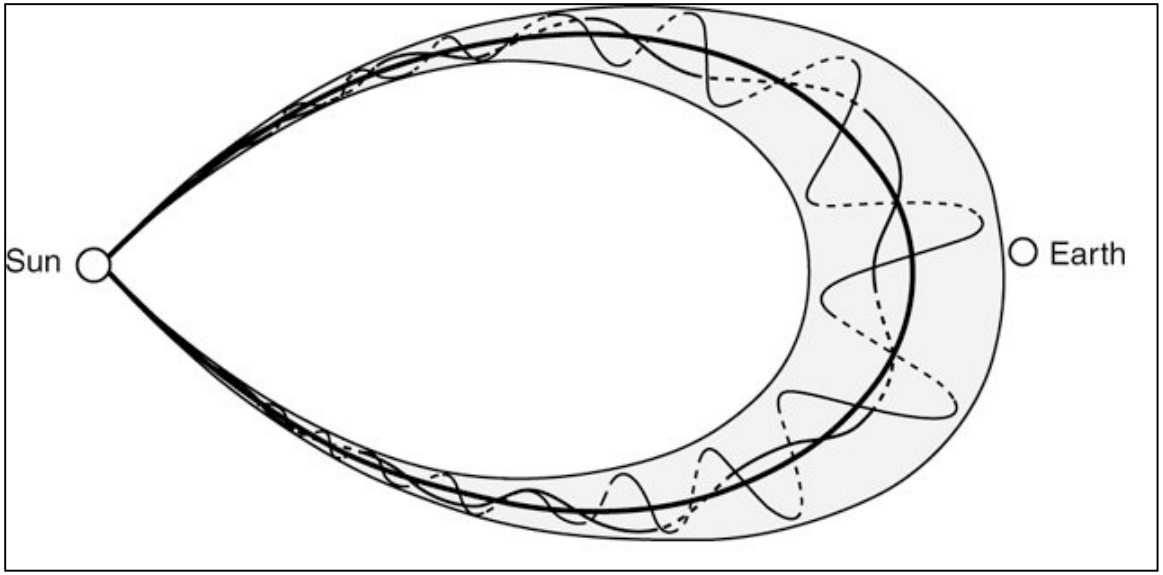


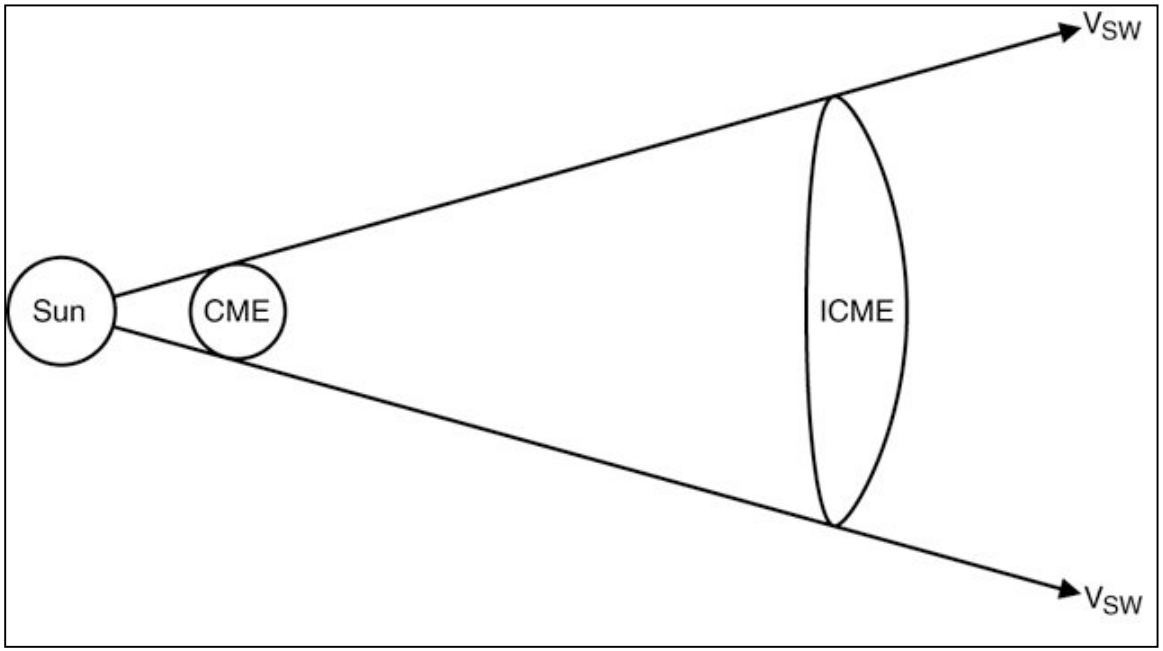


CME Morphology

3) CME Flattening (Russell & Milligan)

Near the Sun the CME has a circular cross section but the spreading of the solar wind flow lines stretches the ICME.

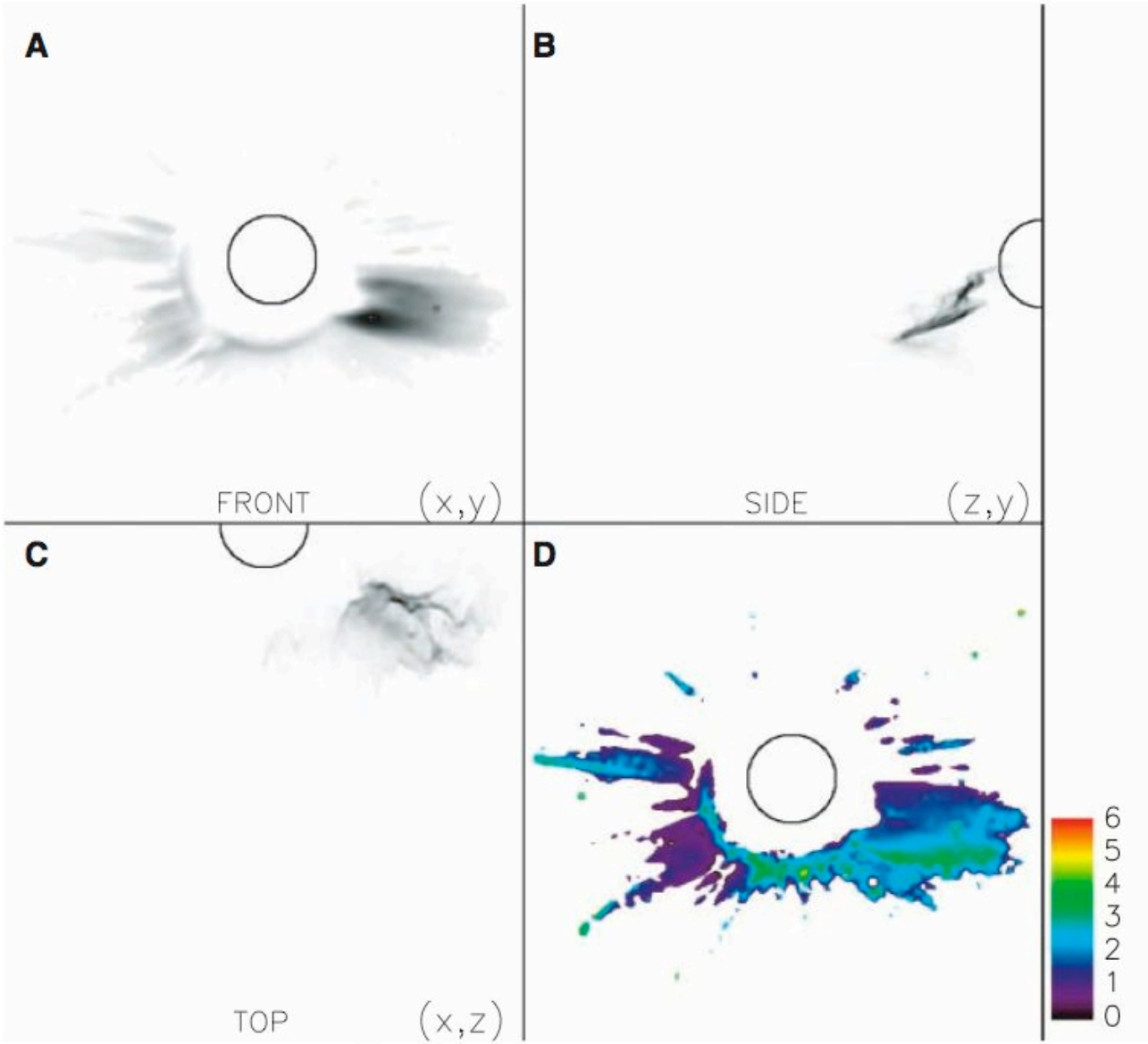




CME Morphology

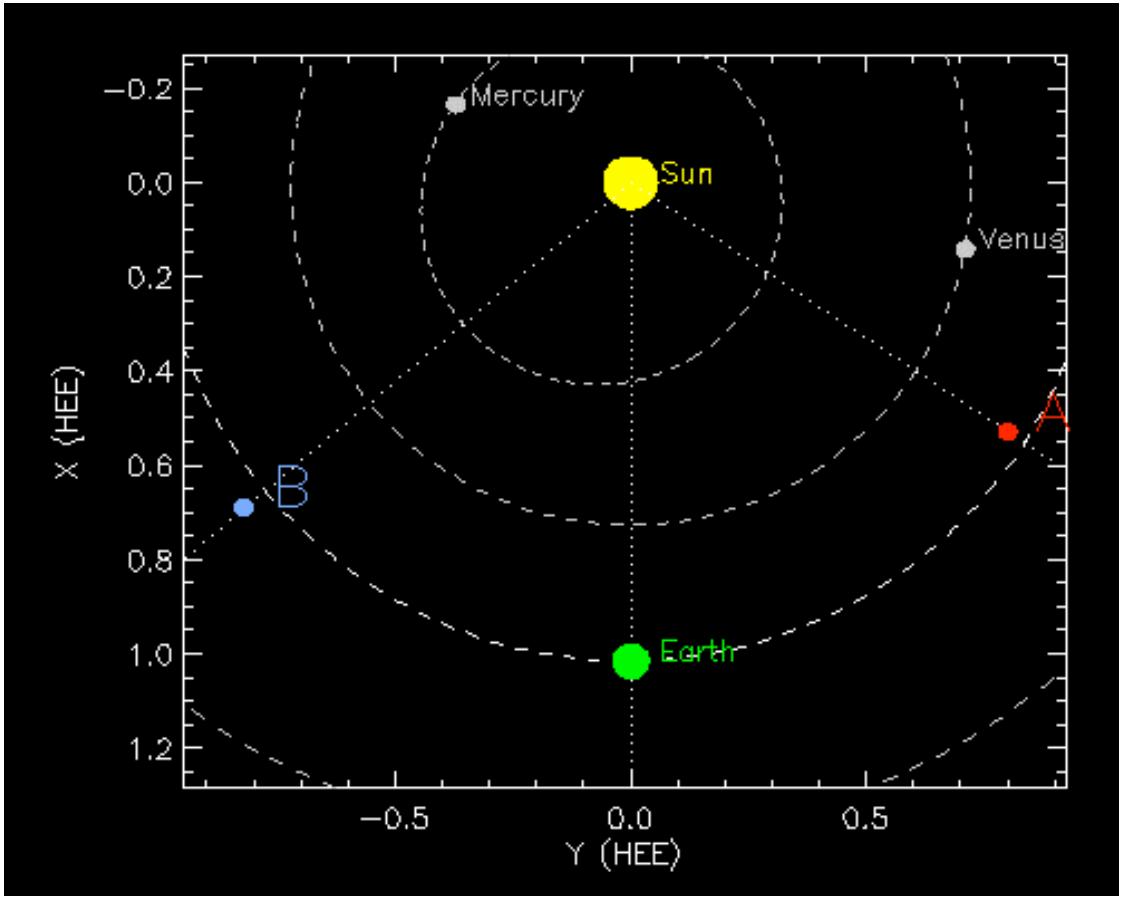
4) Polarization Analysis (Moran & Davilla)

"The line-of-sight averaged distances from the plane of the sky are computed from measurements of the ratio of polarized-to-unpolarized brightness"



The STEREO Mission

- Launched Oct. 2006
- Separation ± 22°/yr.
- SECCHI
  - EUVI
  - COR1 / 2
  - HI1 / 2



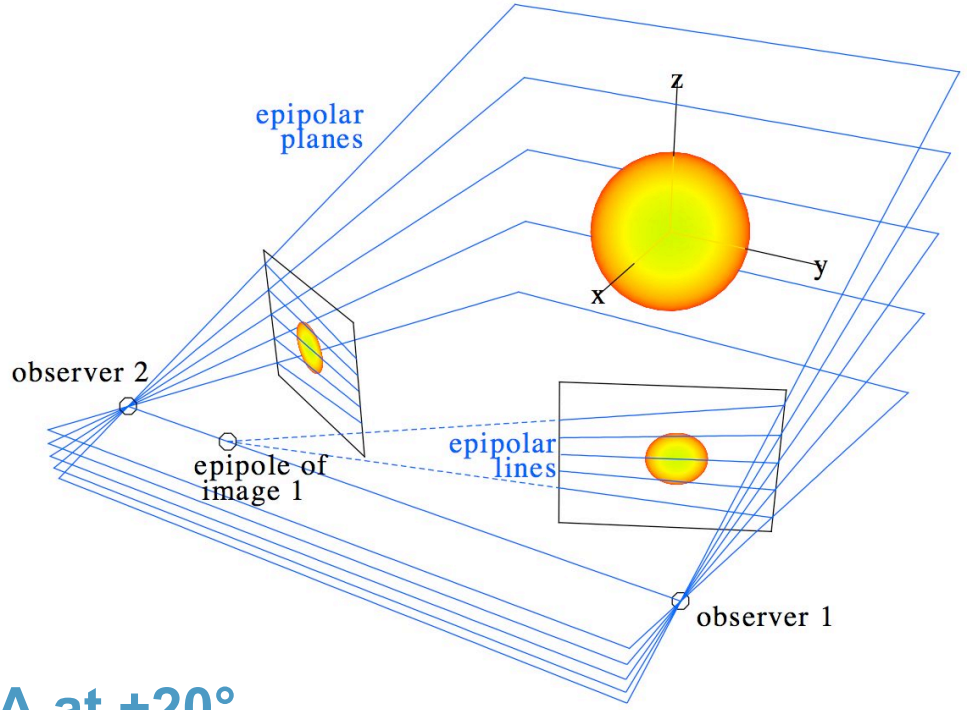
Two of STEREO's scientific objectives:

"Understand the causes and mechanisms of CME initiation."

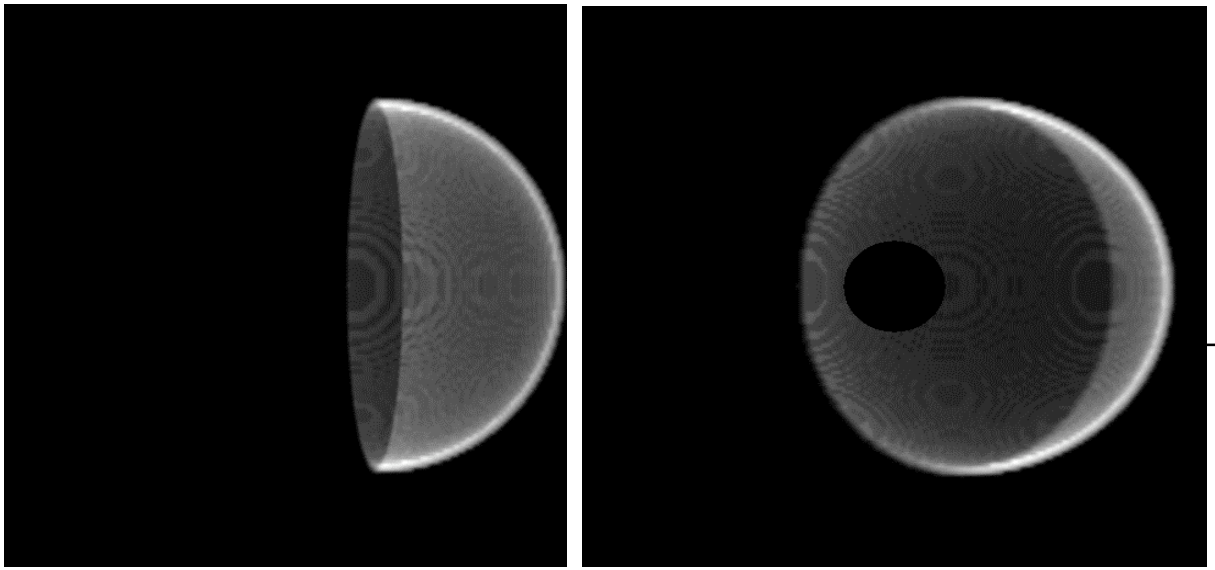
"Characterize the propagation of CMEs through the Heliosphere."

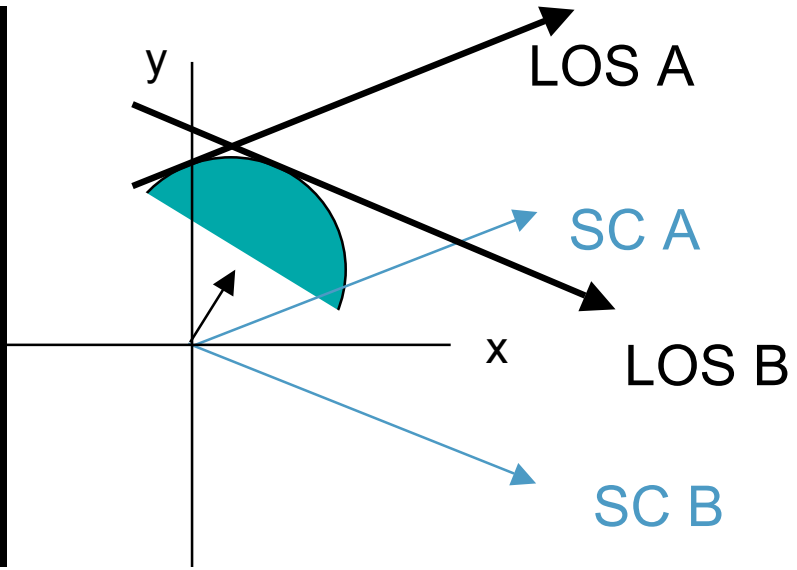
Stereoscopic Analysis

1) Tie-pointing techniques
   - Liewer et al., 2009
   - Srivastava, 2009
   - Temmer et al., 2009
   - Mierla et al., 2008



COR2 - SC B at -20° **COR2 - SC A at +20°**

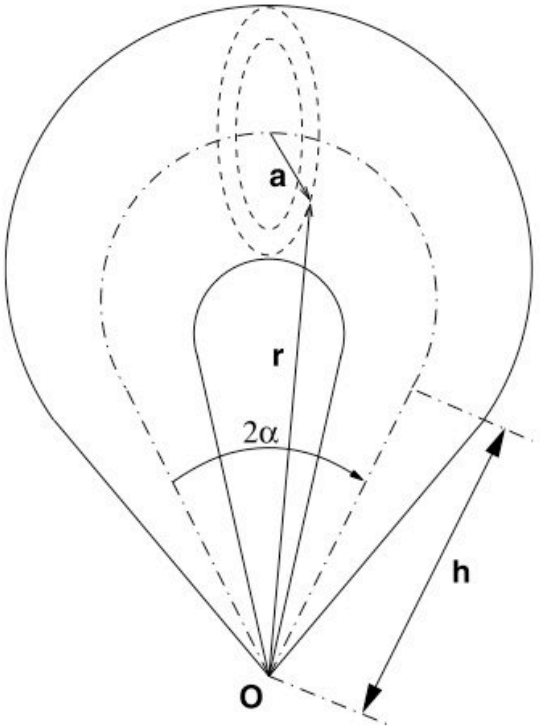


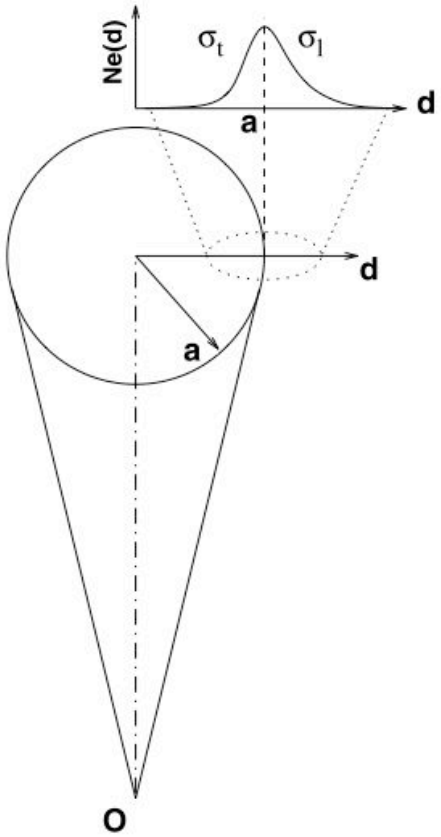


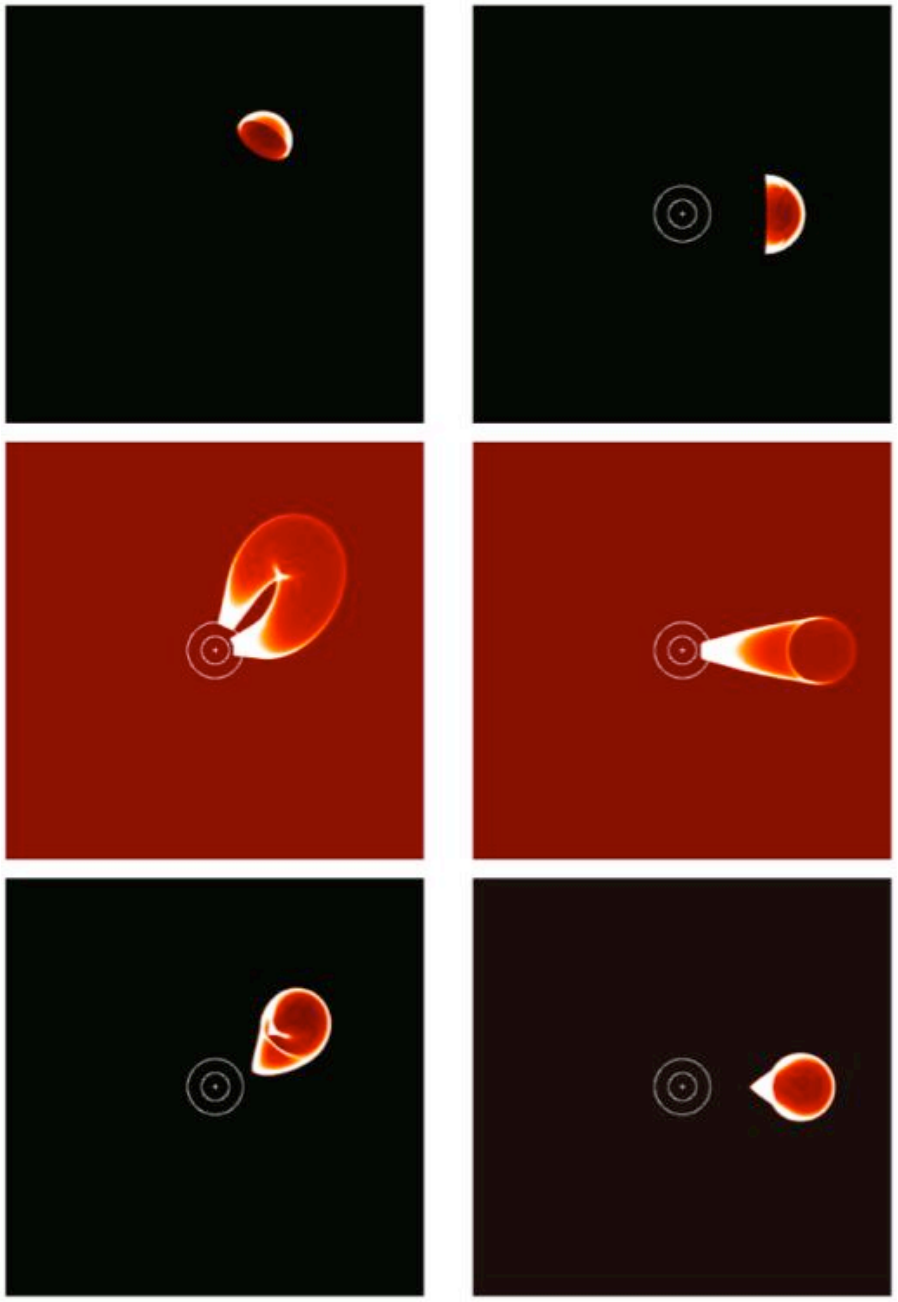
Stereoscopic Analysis

2) Forward-modeling techniques

- Thernisien et al., 2009
- Boursier et al., 2009
- Antunes et al., 2009



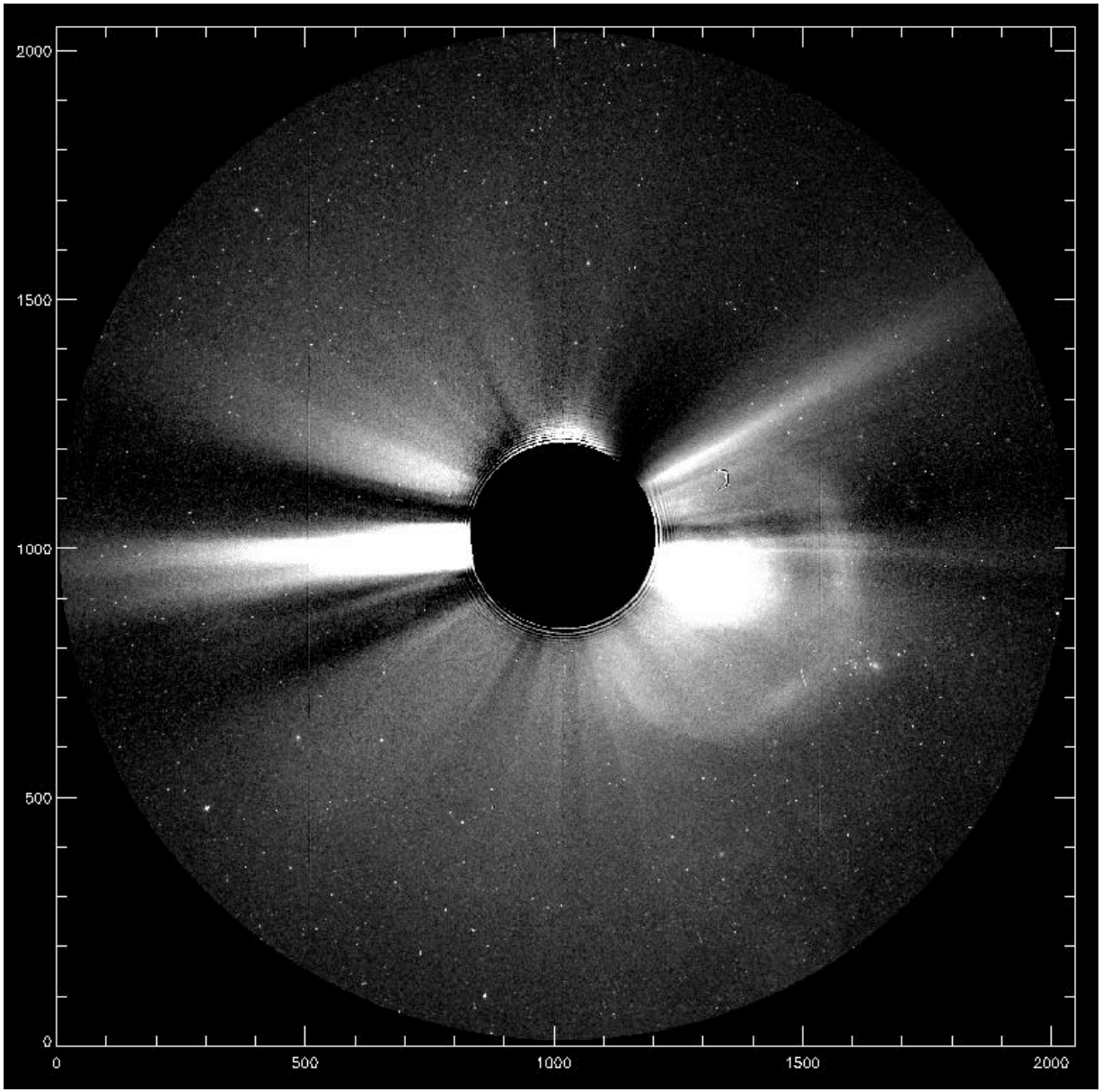




Stereoscopic Analysis

- COR2 (STEREO-A)
- FOV 2-15 R_{Sun}
- Multiscale edge detection
- Ellipse fit
- Plane-of-sky
  - Velocity
  - Acceleration
  - Expansion

(Byrne et al, A&A 2009)



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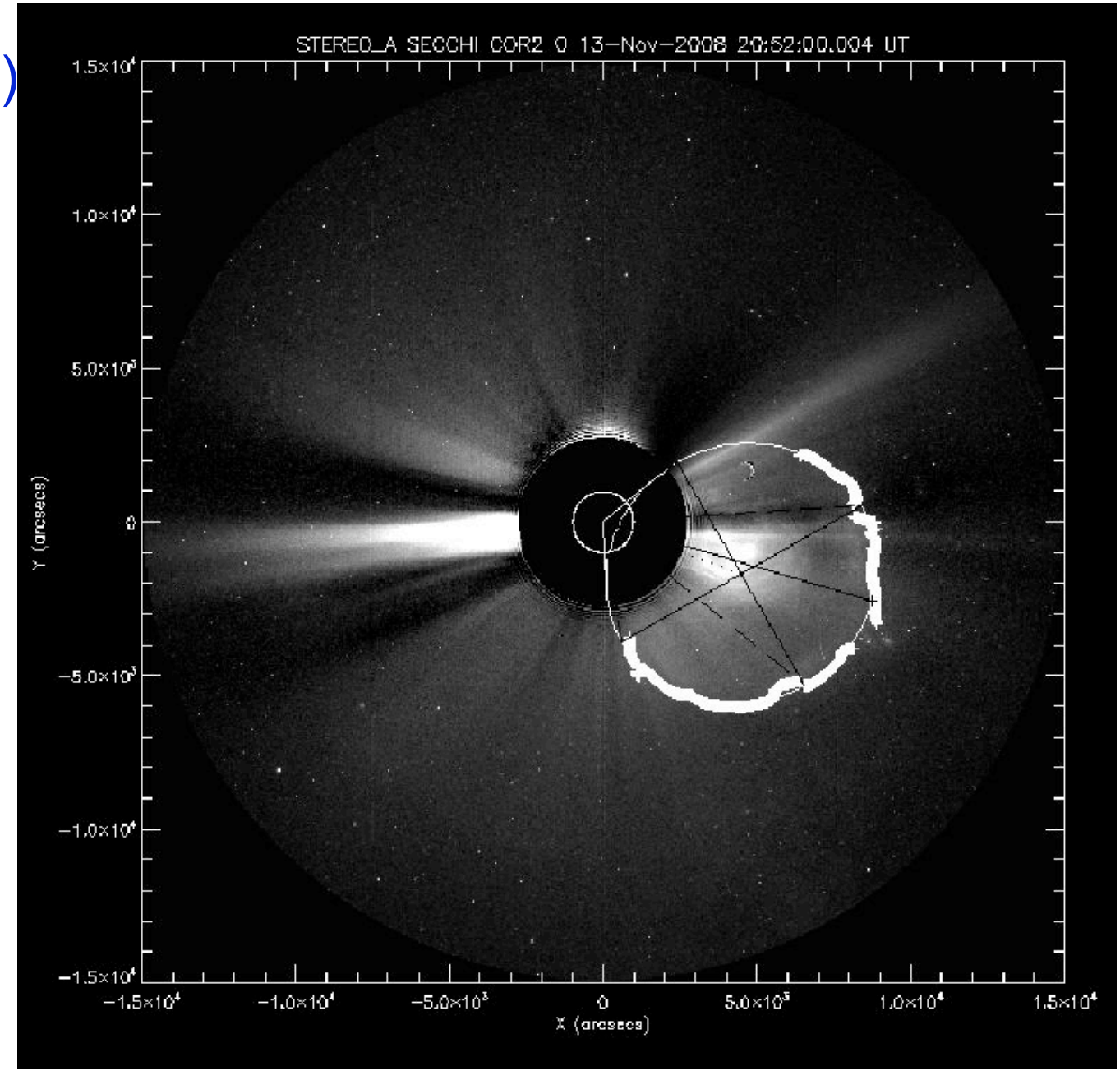
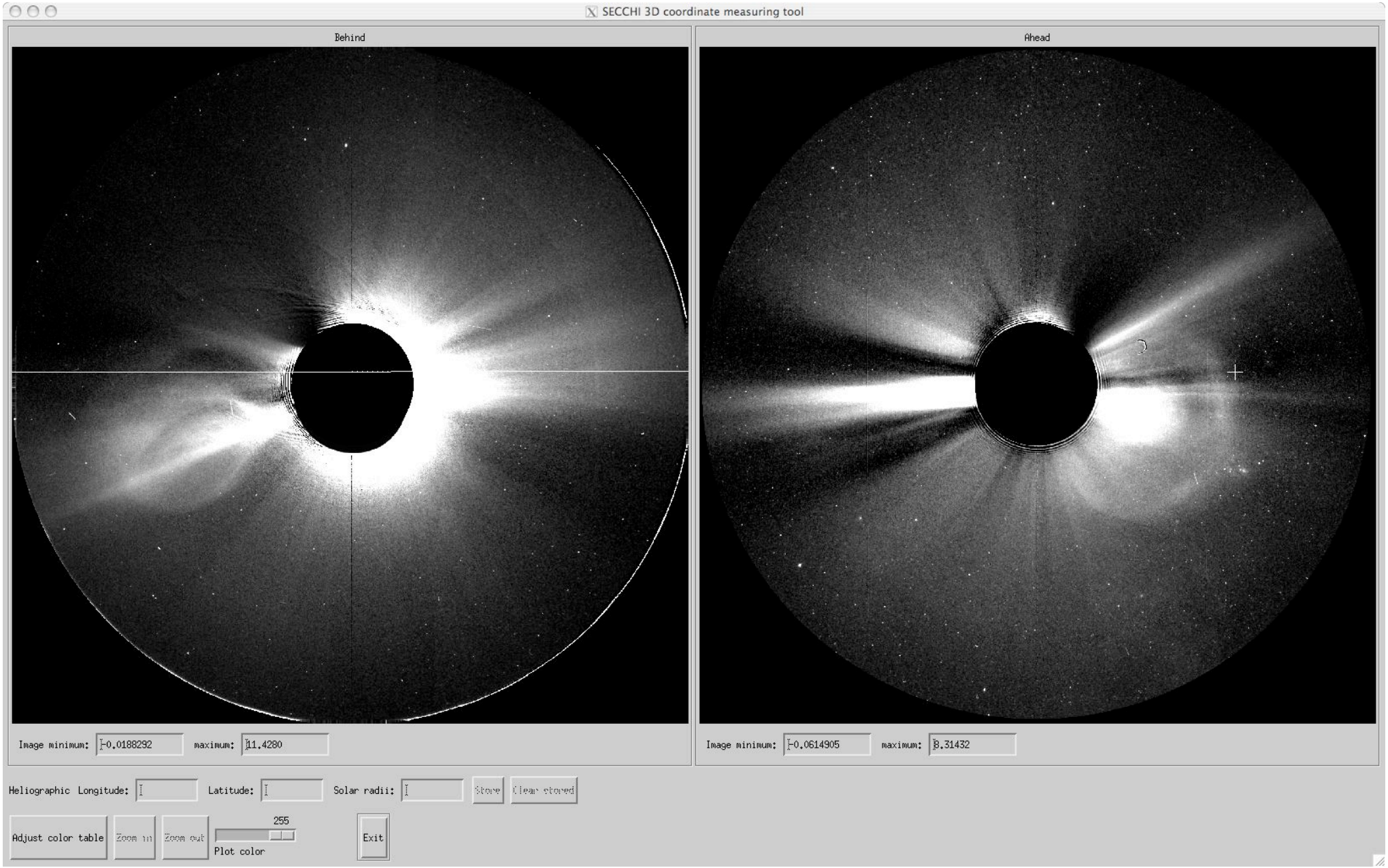
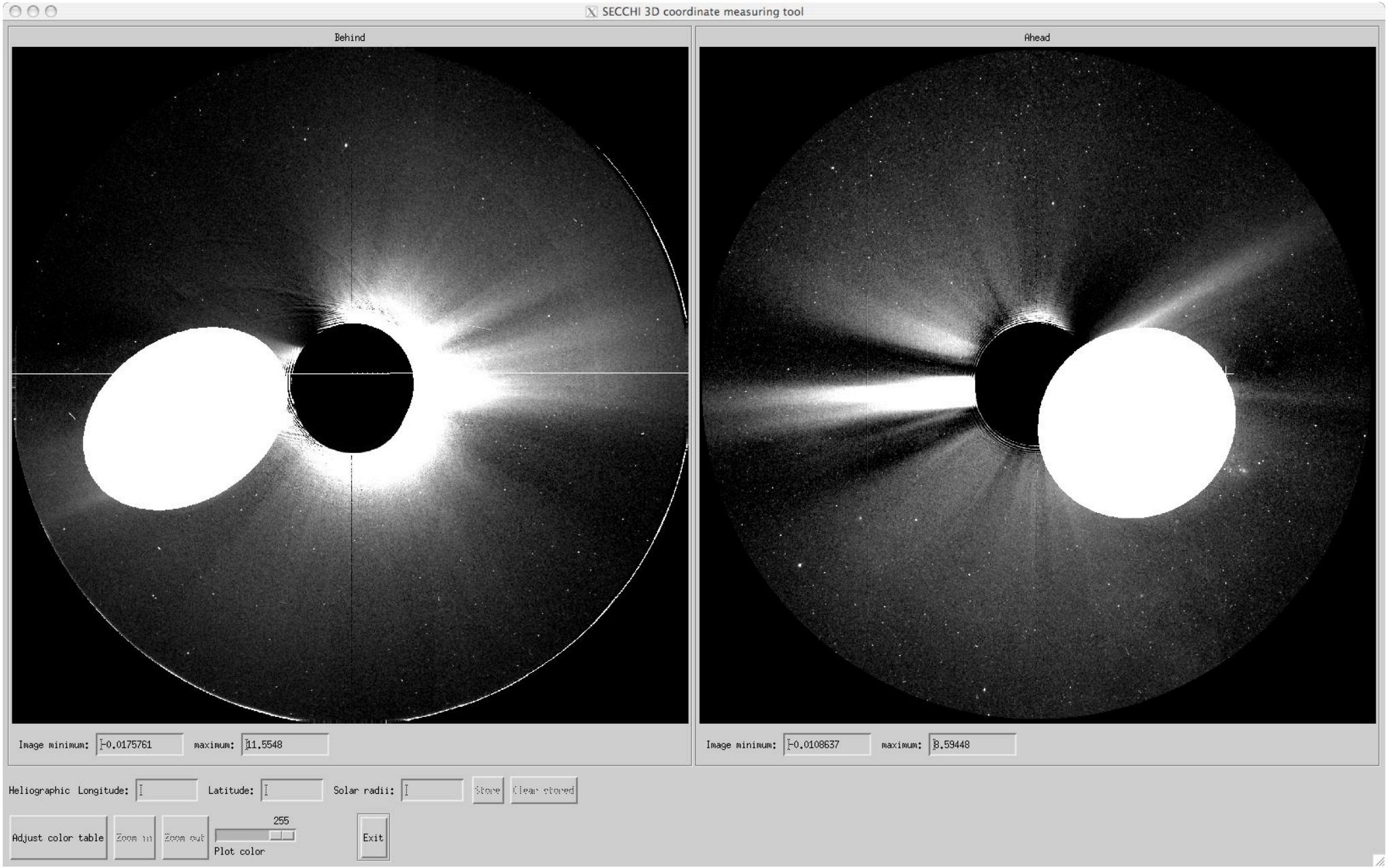


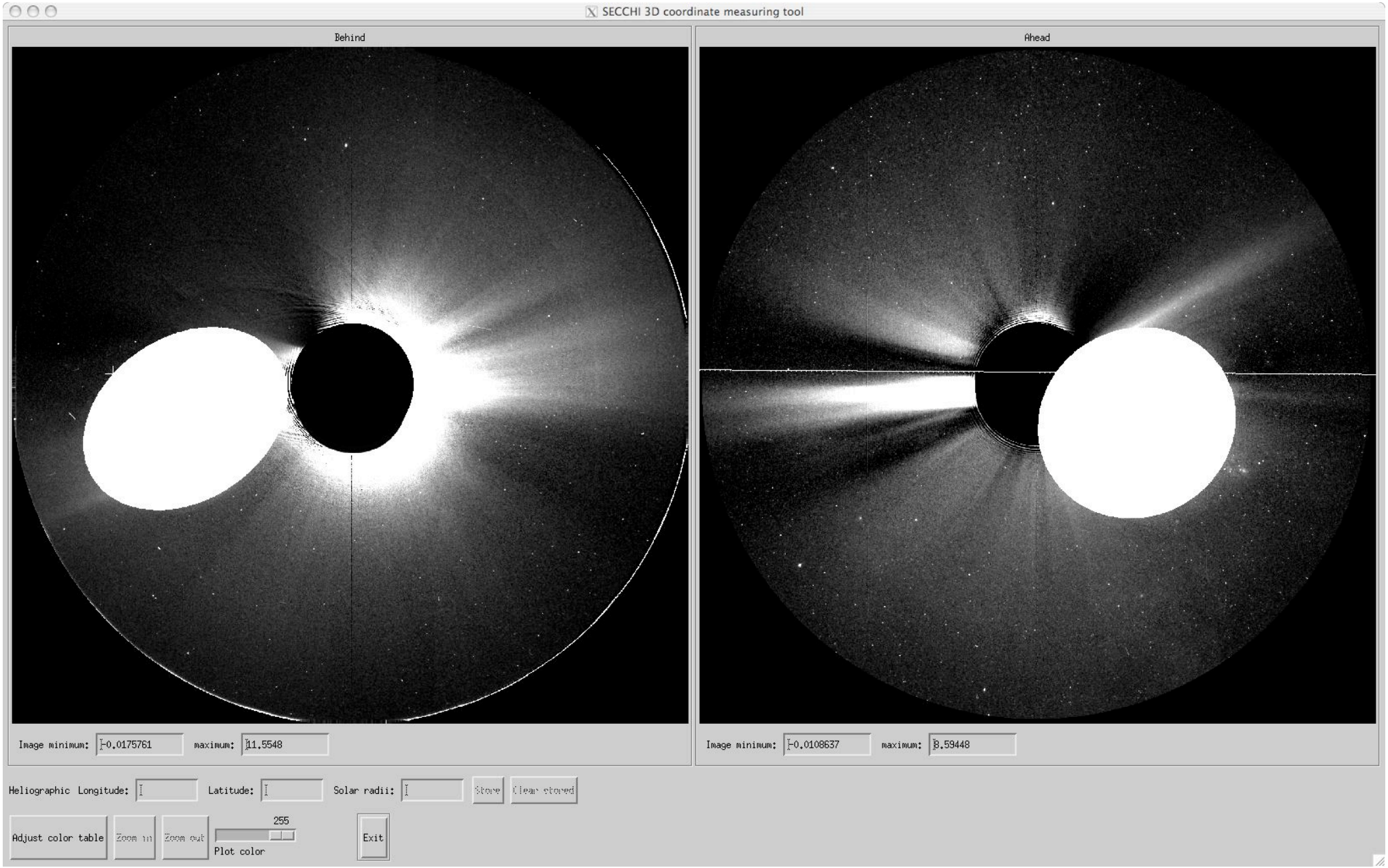
Stereoscopic Analysis



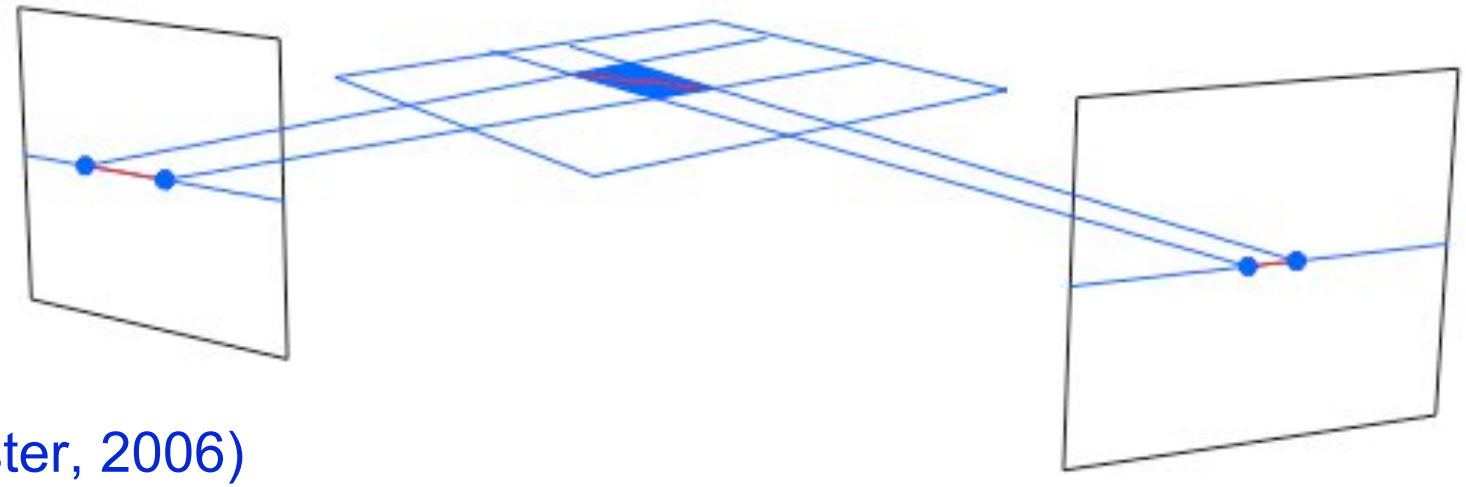
Stereoscopic Analysis



Stereoscopic Analysis



Stereoscopic Analysis

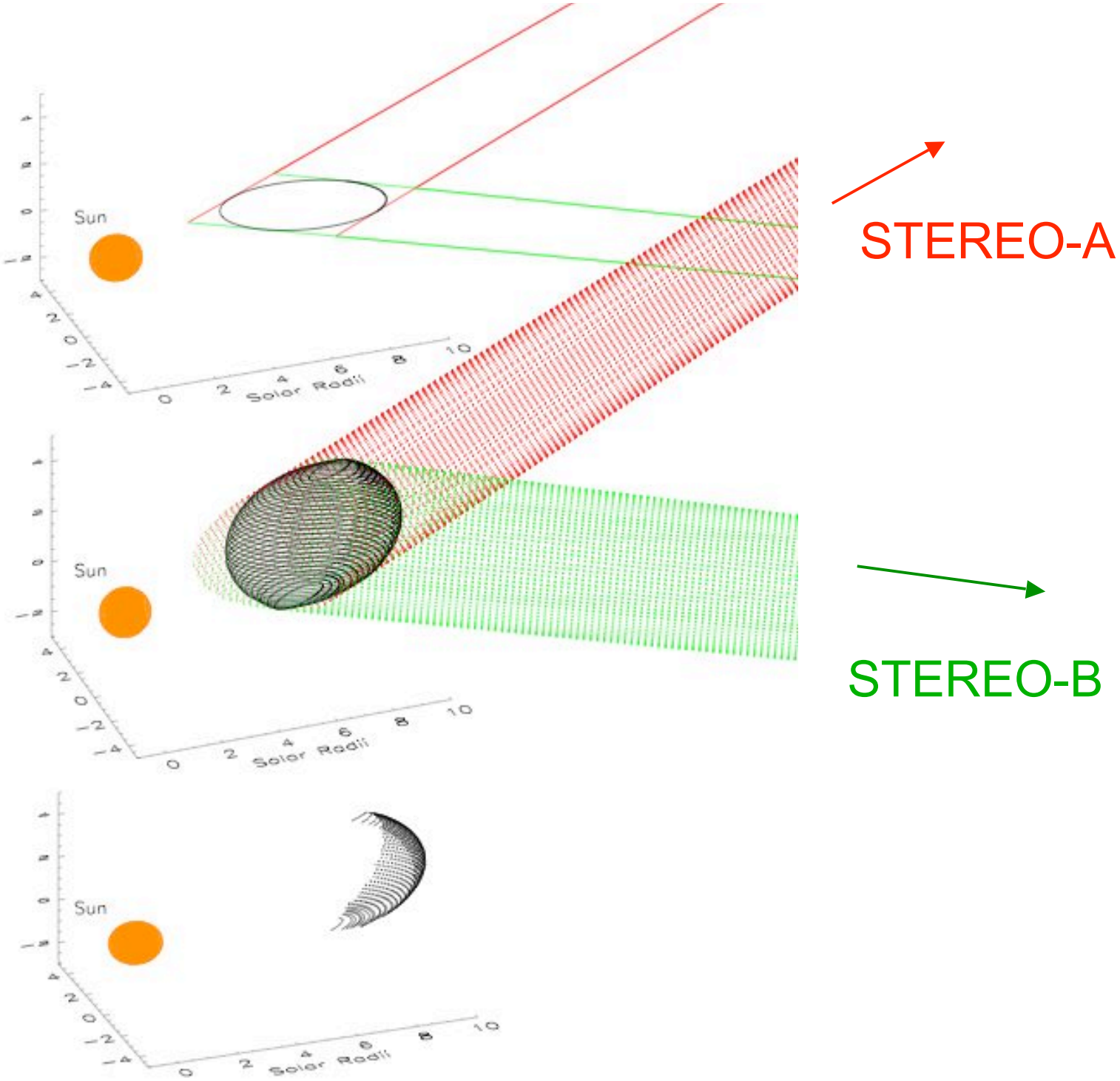


(Inhester, 2006)

Theorem:

Let T_1 , T_2 , T_3 , T_4 be four given lines in the plane, such that no three of the T_j are parallel or have a common intersection point. Then there is an ellipse E which is tangent to each of the T_j .

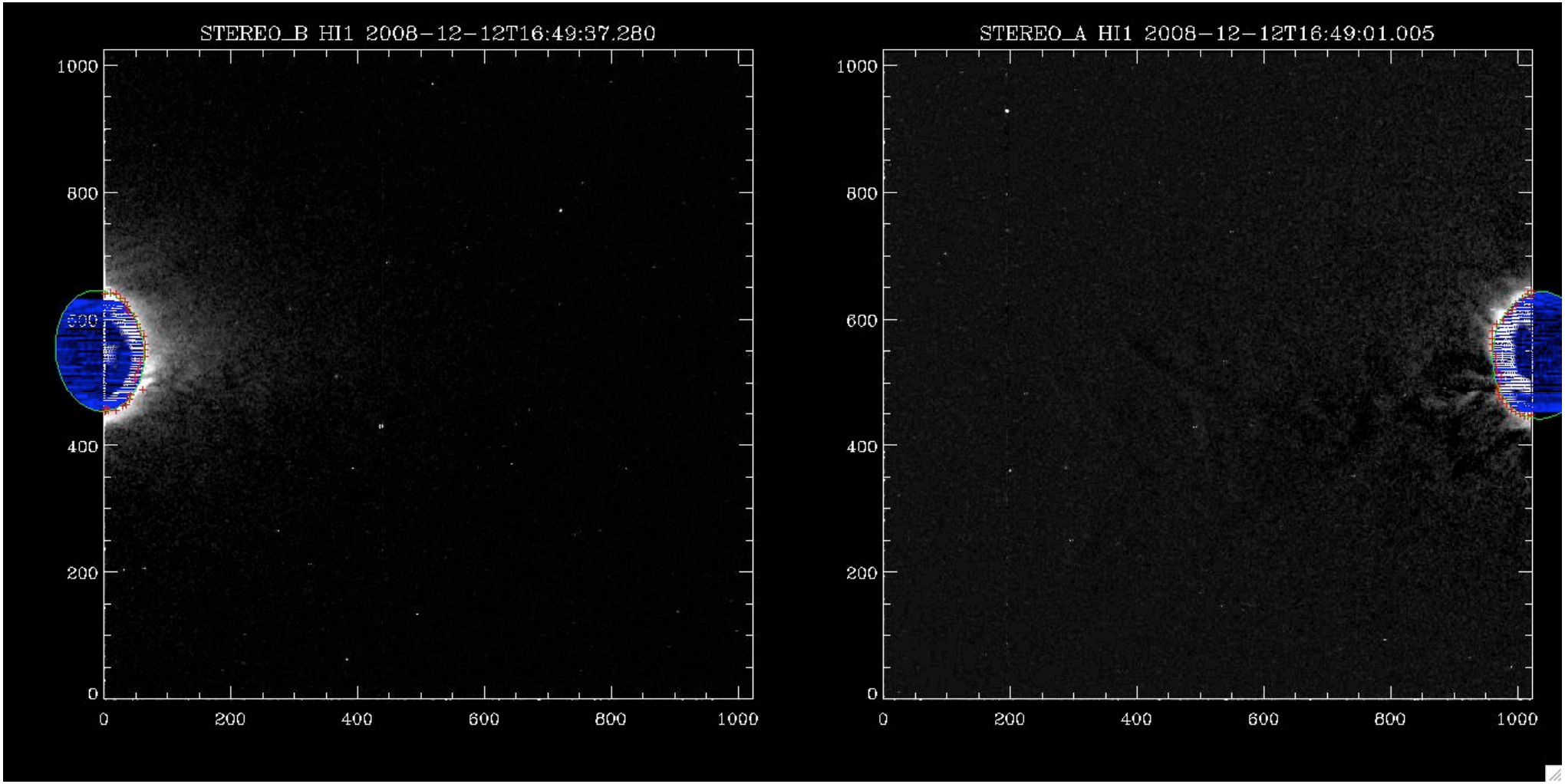
(Horwitz, 1999)



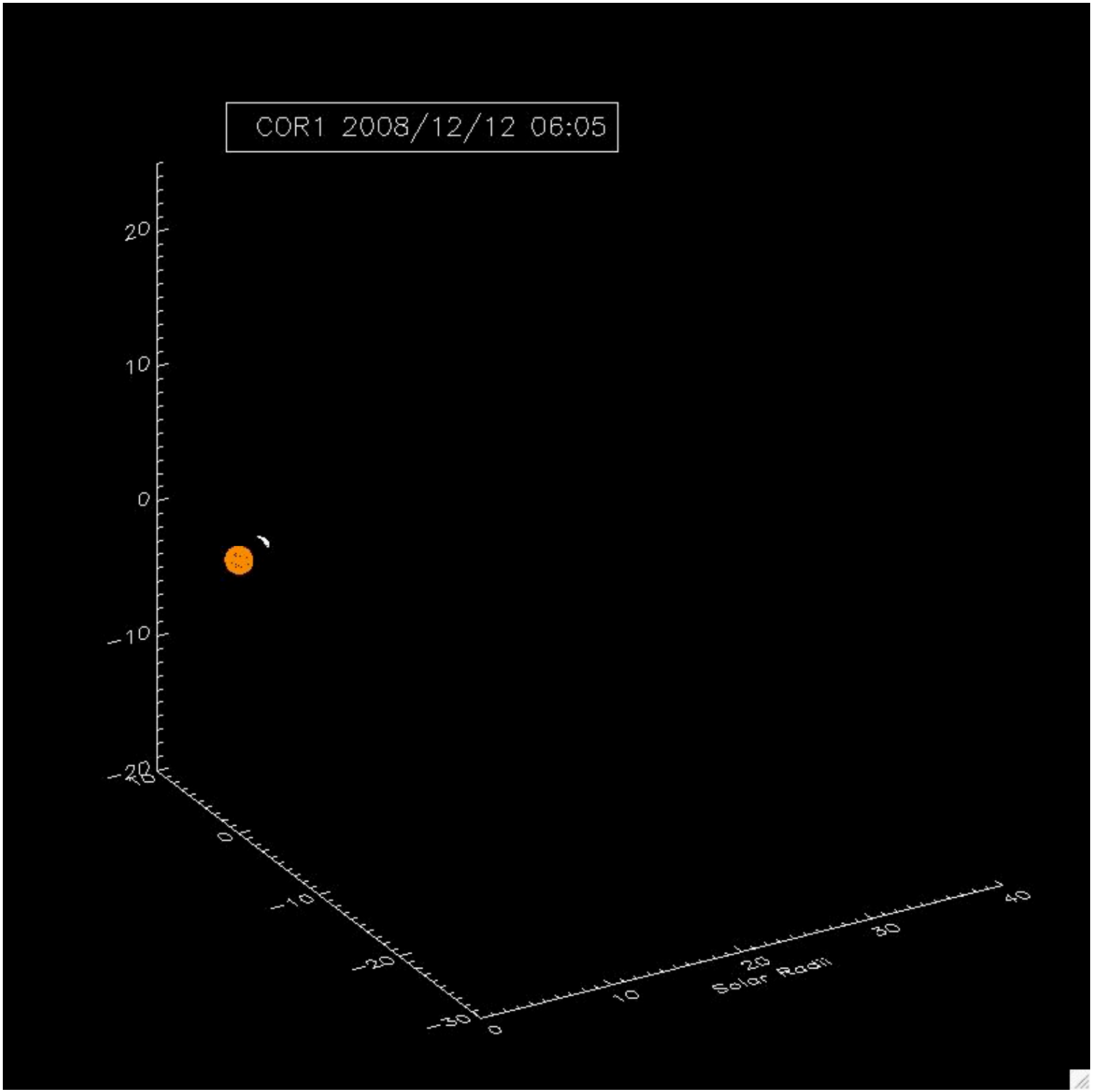
STEREO-A

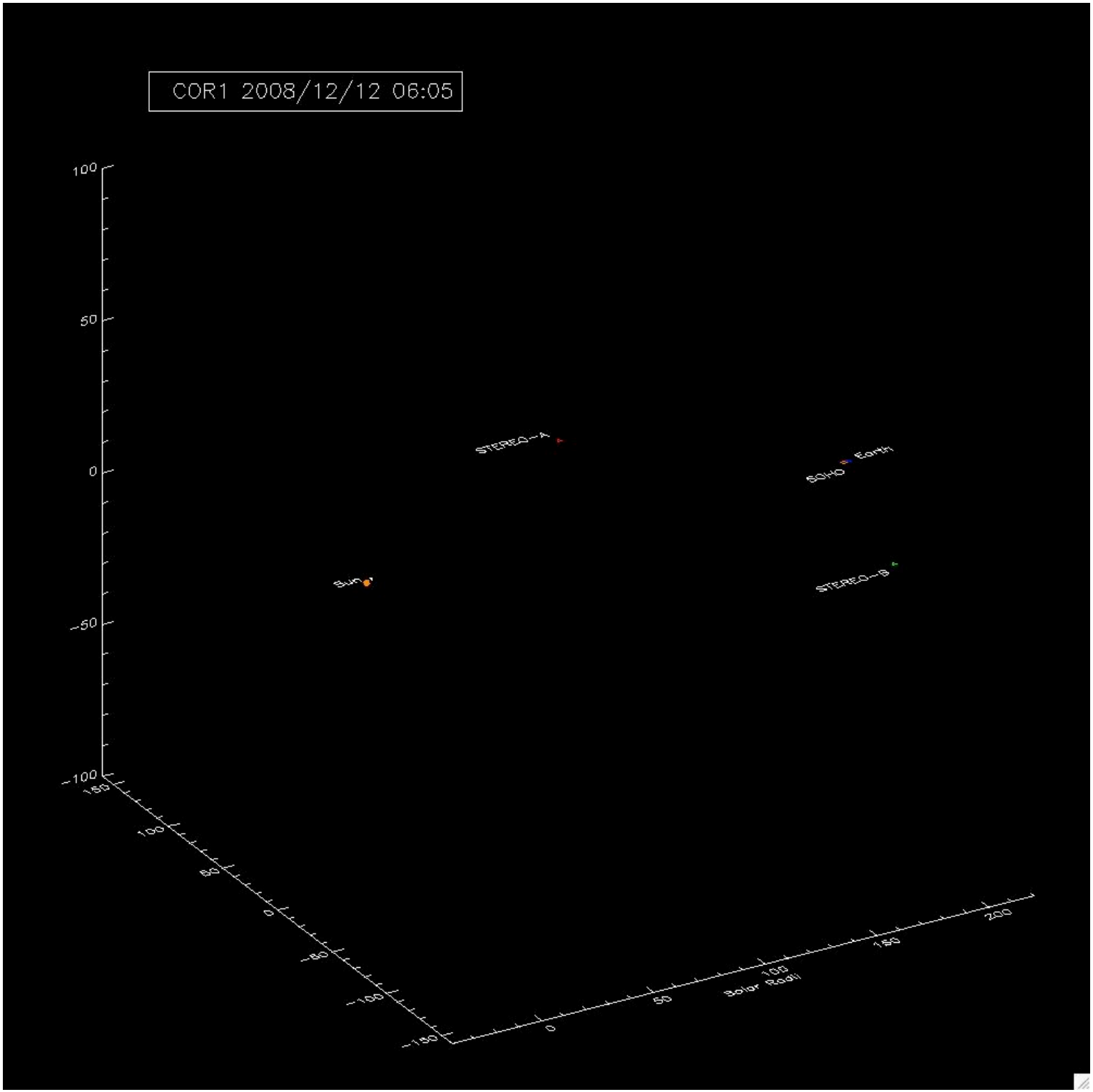
STEREO-B

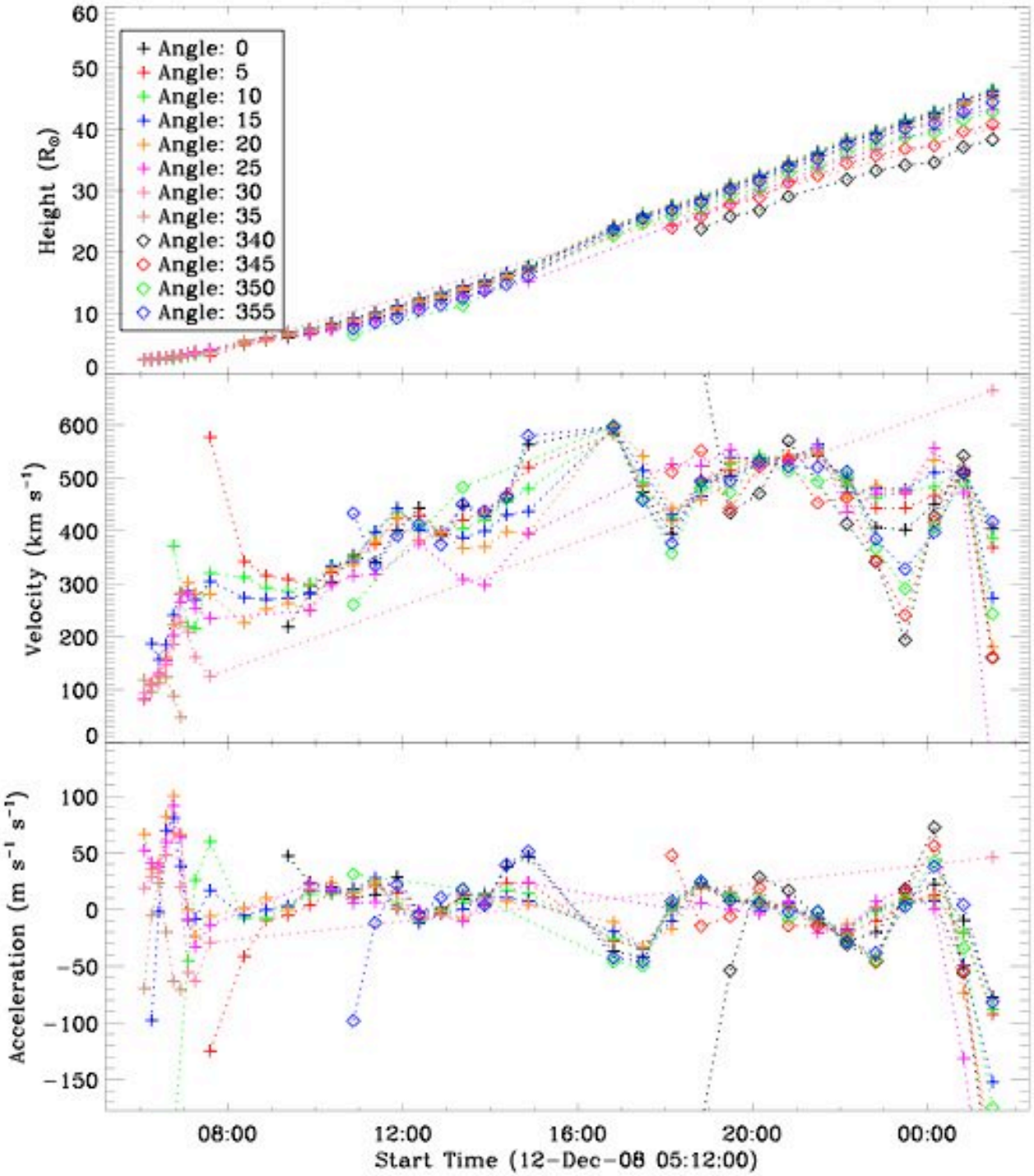
Stereoscopic Analysis

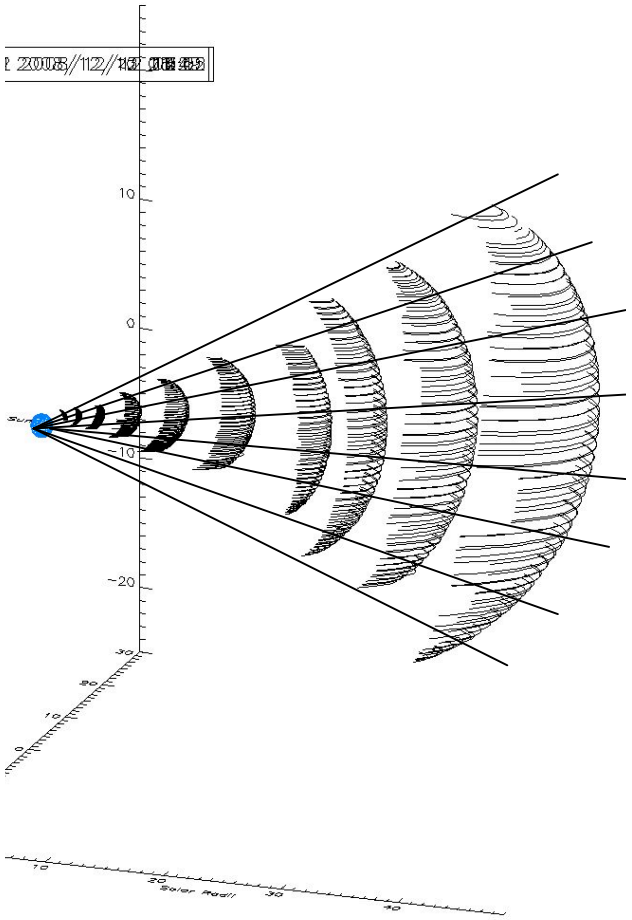


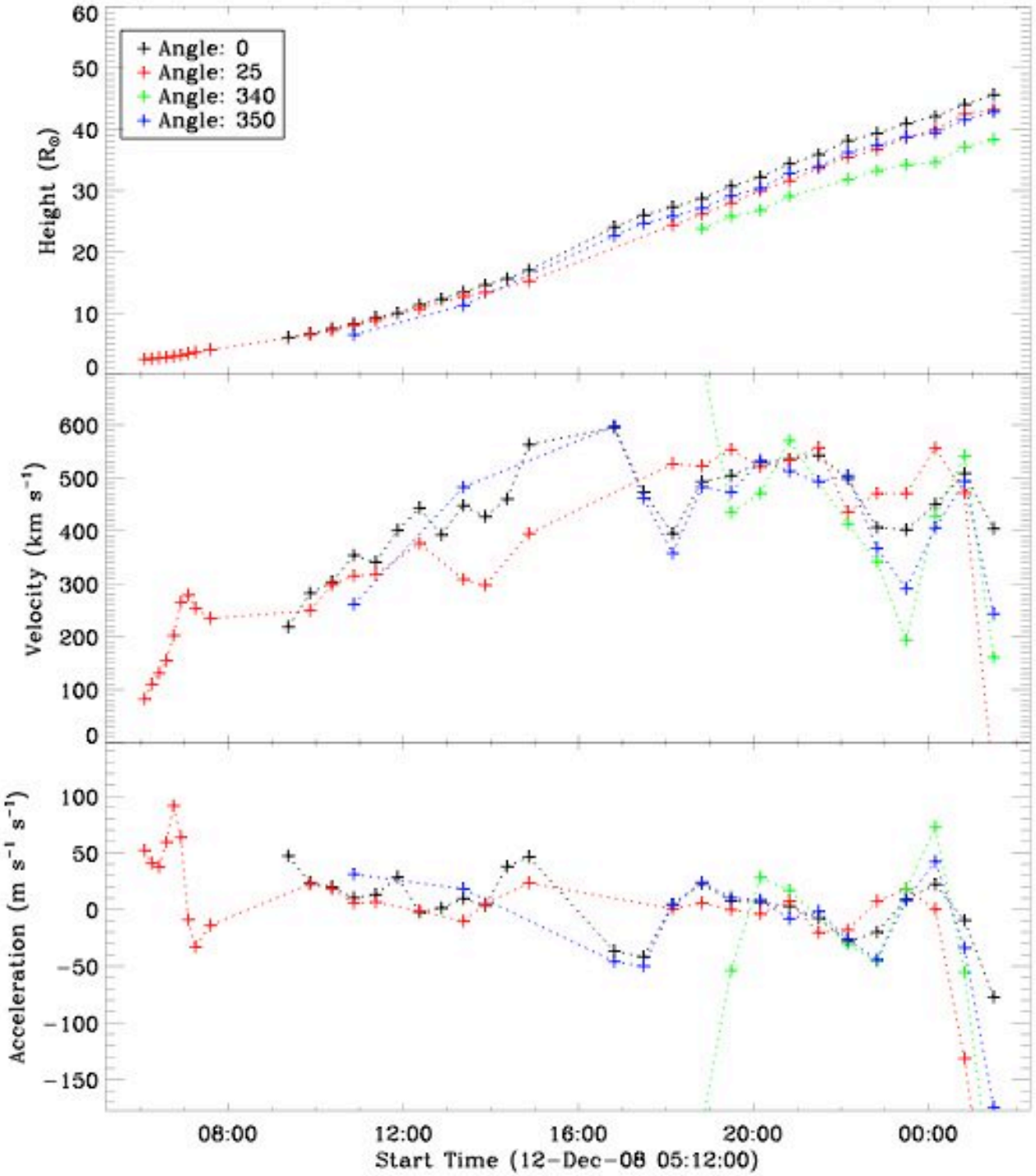
Heliospheric Imager (HI-1)

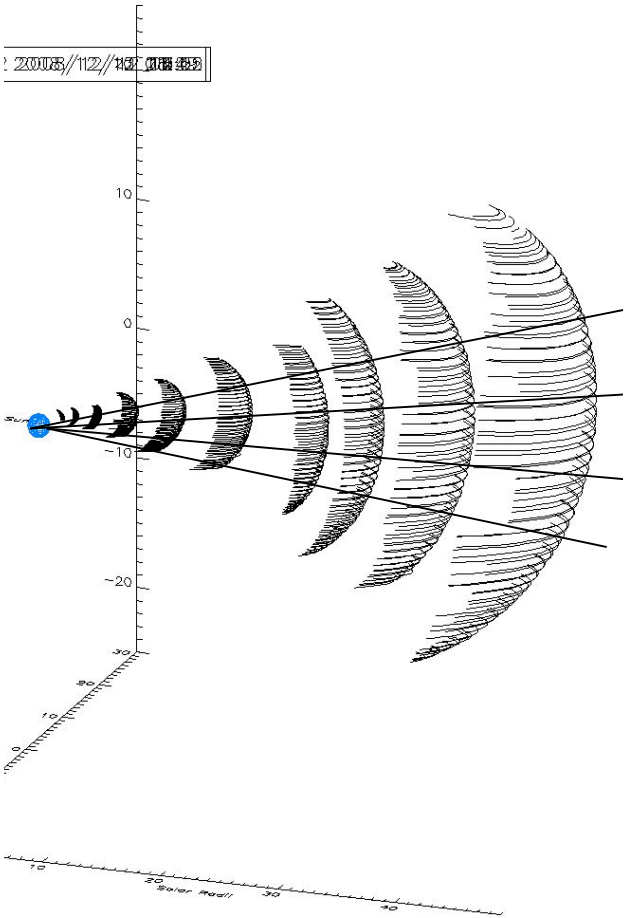

COR1 2008/12/12 06:05
20
10
0
-10
-20
-30
0
10
20
30
40
Solar Radii

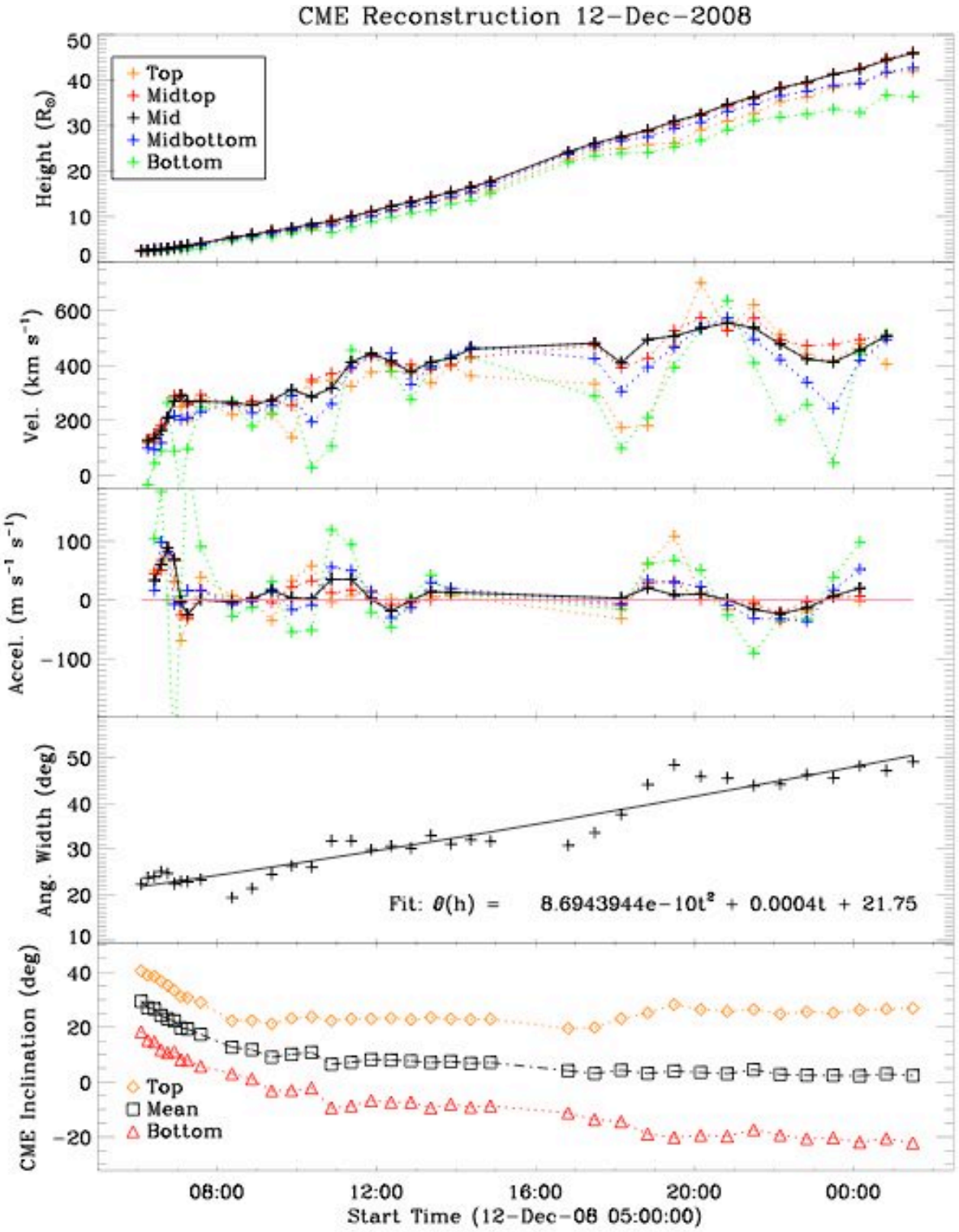

COR1 2008/12/12 06:05
100
50
0
−50
−100
STEREO−A
SOHO
Earth
Sun
STEREO−B
150
100
50
0
−50
−100
−150
0
50
100
150
200
Solar Radii

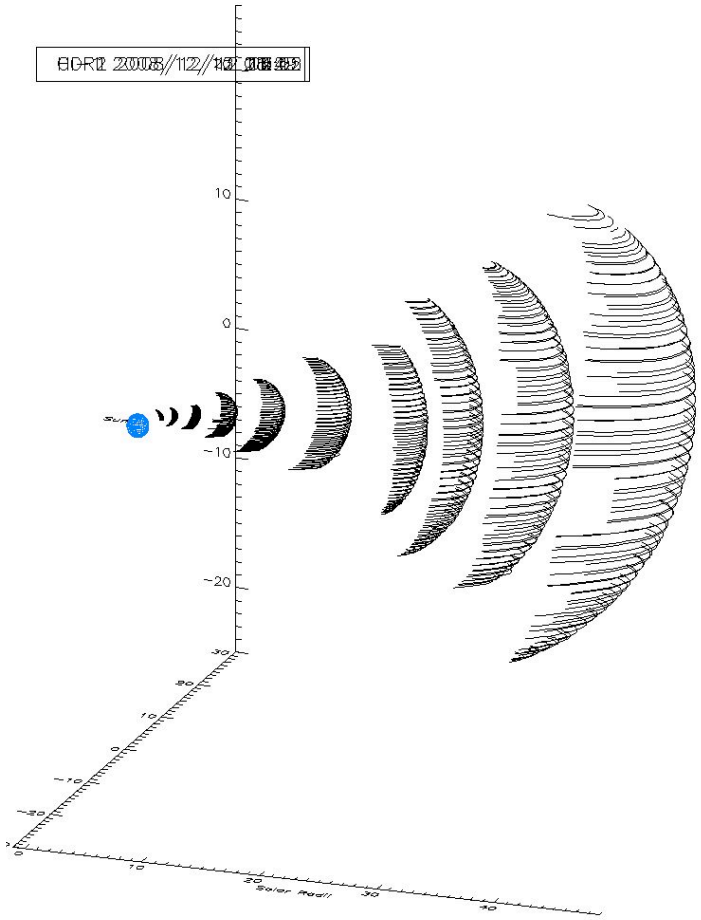

Angle: 0
Angle: 5
Angle: 10
Angle: 15
Angle: 20
Angle: 25
Angle: 30
Angle: 35
Angle: 340
Angle: 345
Angle: 350
Angle: 355
Height ($R_\odot$)
Velocity (km s^{-1})
Acceleration (m s^{-1} s^{-1})
08:00
12:00
16:00
20:00
00:00
Start Time (12-Dec-08 05:12:00)

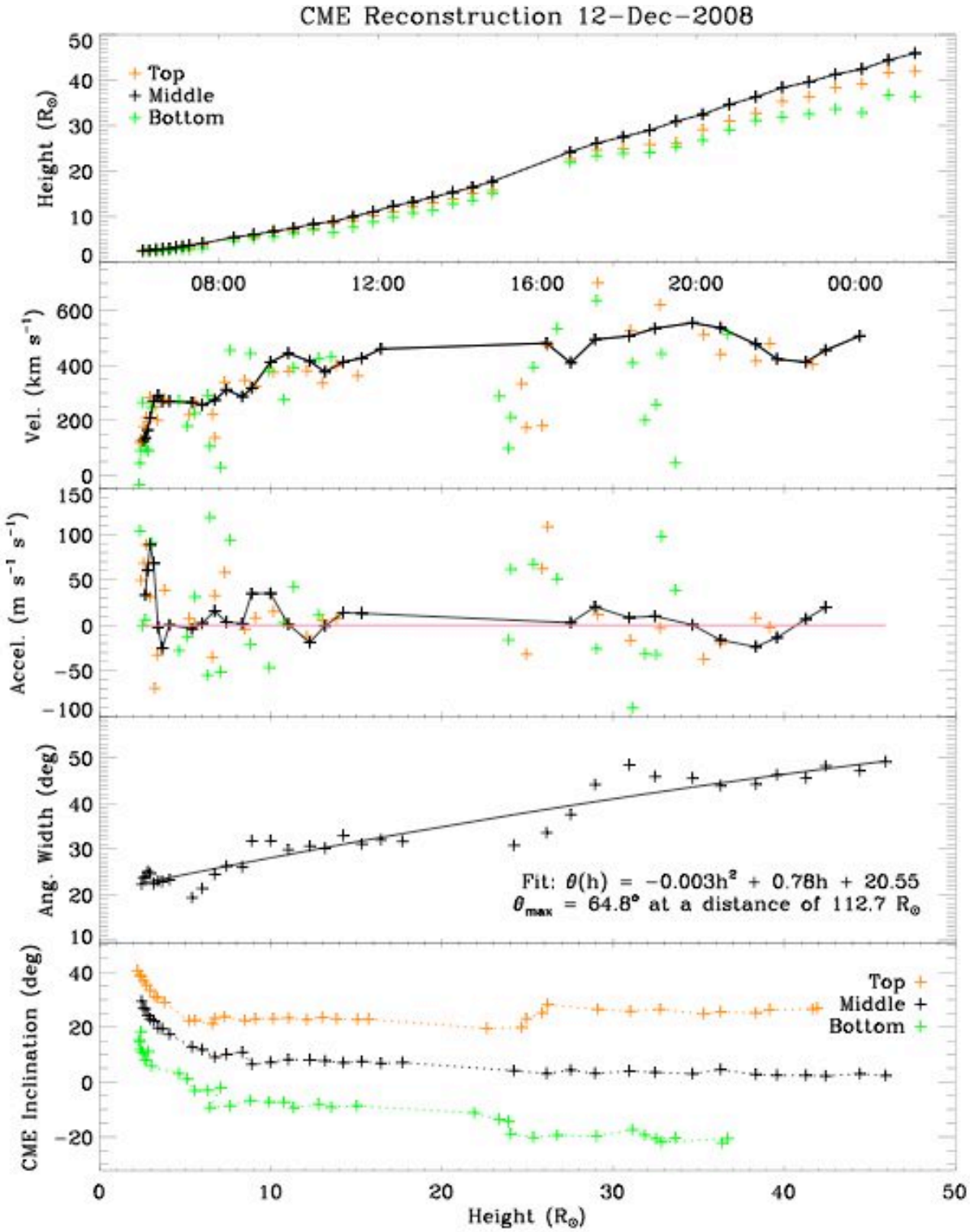

Solar Radii

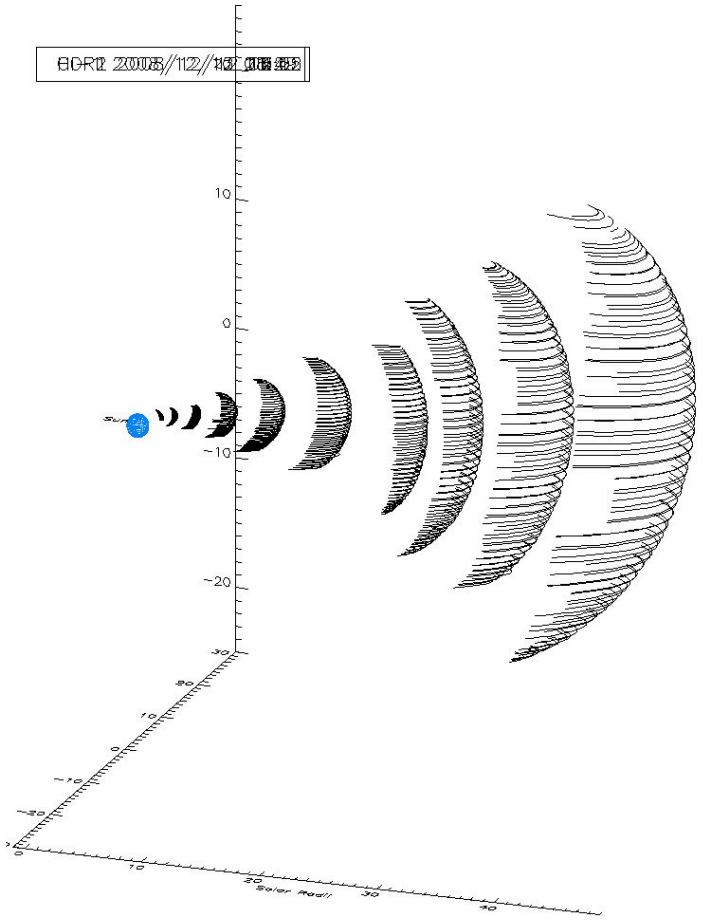

Angle: 0
Angle: 25
Angle: 340
Angle: 350
Height ($R_\odot$)
Velocity (km s^{-1})
Acceleration (m s^{-1} s^{-1})
08:00
12:00
16:00
20:00
00:00
Start Time (12-Dec-08 05:12:00)

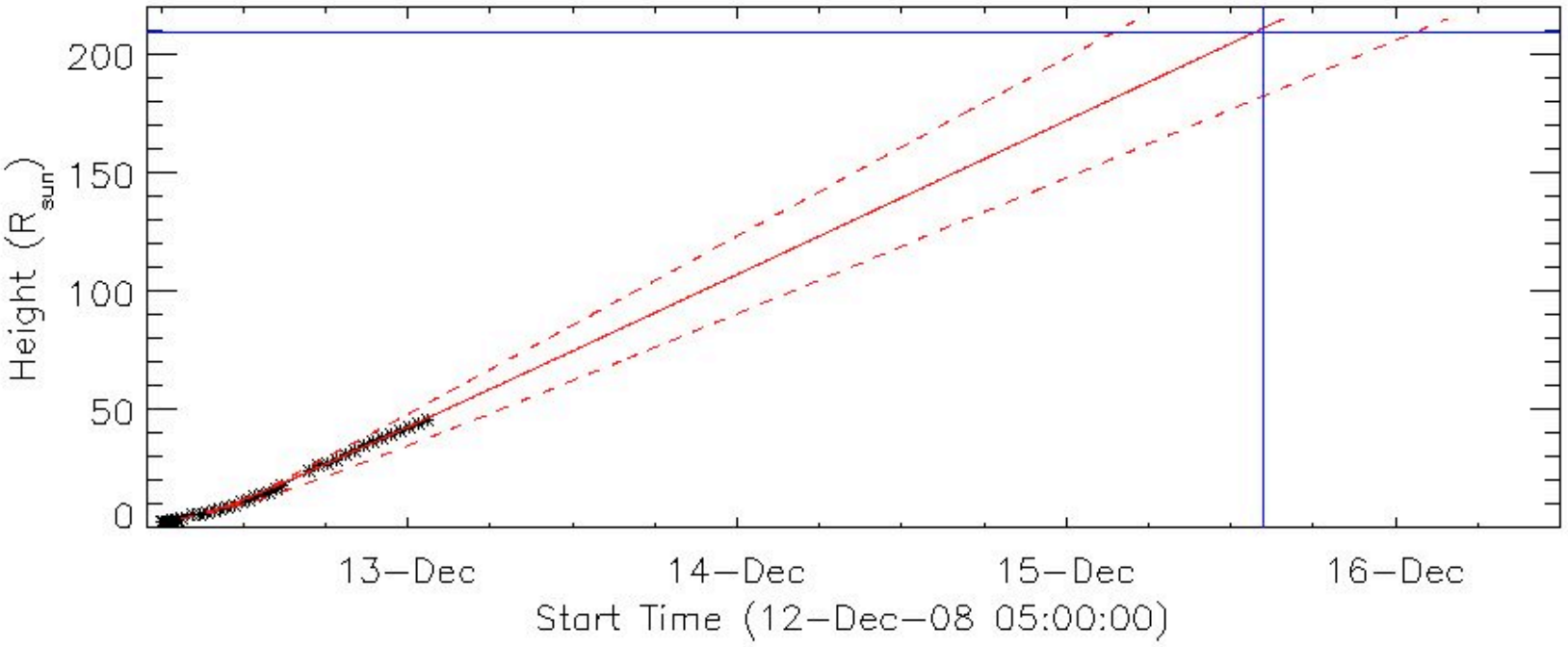


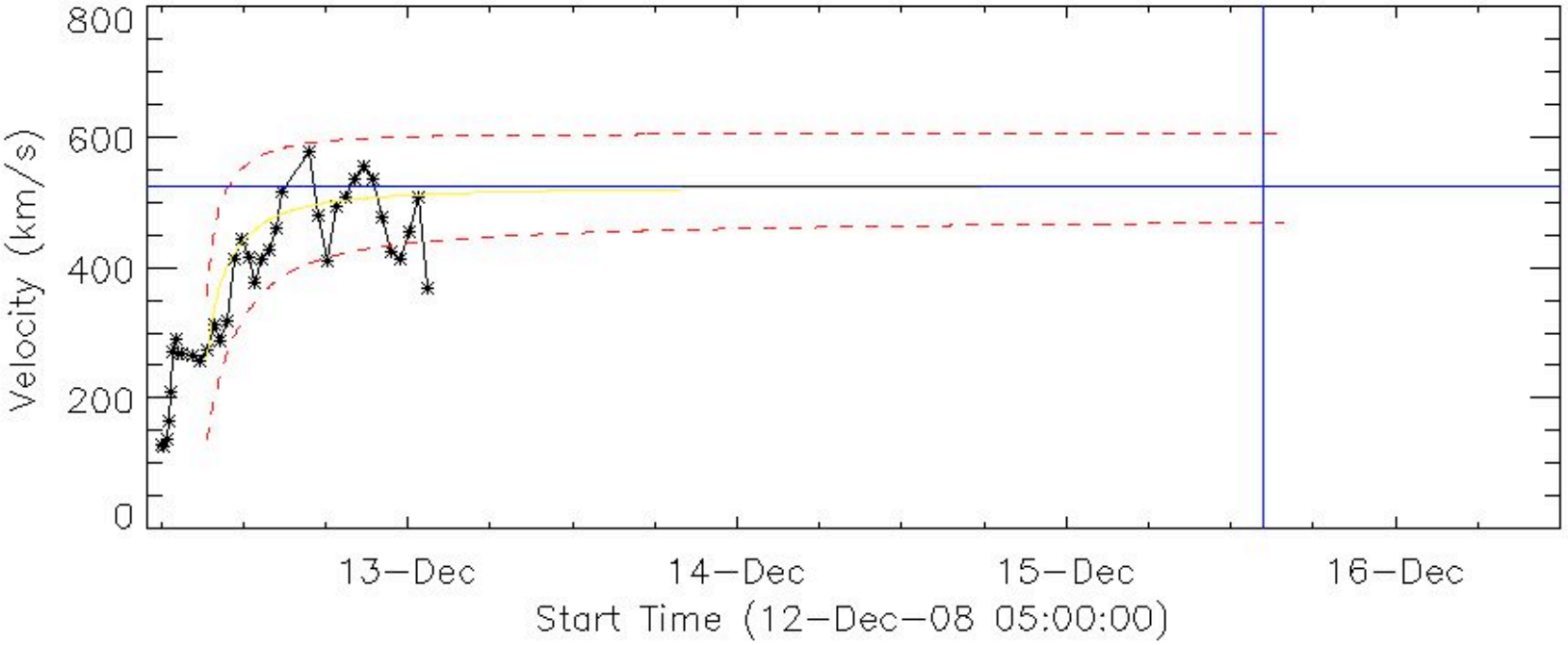

CME Reconstruction 12-Dec-2008
Top
Midtop
Mid
Midbottom
Bottom
Height ($R_\odot$)
Vel. (km s^{-1})
Accel. (m s^{-1} s^{-1})
Ang. Width (deg)
Fit: θ(h) = 8.6943944e-10t² + 0.0004t + 21.75
CME Inclination (deg)
Top
Mean
Bottom
08:00
12:00
16:00
20:00
00:00
Start Time (12-Dec-08 05:00:00)


Solar Radii


CME Reconstruction 12-Dec-2008
Top
Middle
Bottom
Height (R⊙)
08:00
12:00
16:00
20:00
00:00
Vel. (km s⁻¹)
Accel. (m s⁻¹ s⁻¹)
Ang. Width (deg)
Fit: θ(h) = −0.003h² + 0.78h + 20.55
θmax = 64.8° at a distance of 112.7 R⊙
CME Inclination (deg)
Top
Middle
Bottom
Height (R⊙)


Solar Radii


200
150
100
50
0
Height (R_{sun})
13−Dec
14−Dec
15−Dec
16−Dec
Start Time (12−Dec−08 05:00:00)


800
600
400
200
0
Velocity (km/s)
13−Dec
14−Dec
15−Dec
16−Dec
Start Time (12−Dec−08 05:00:00)

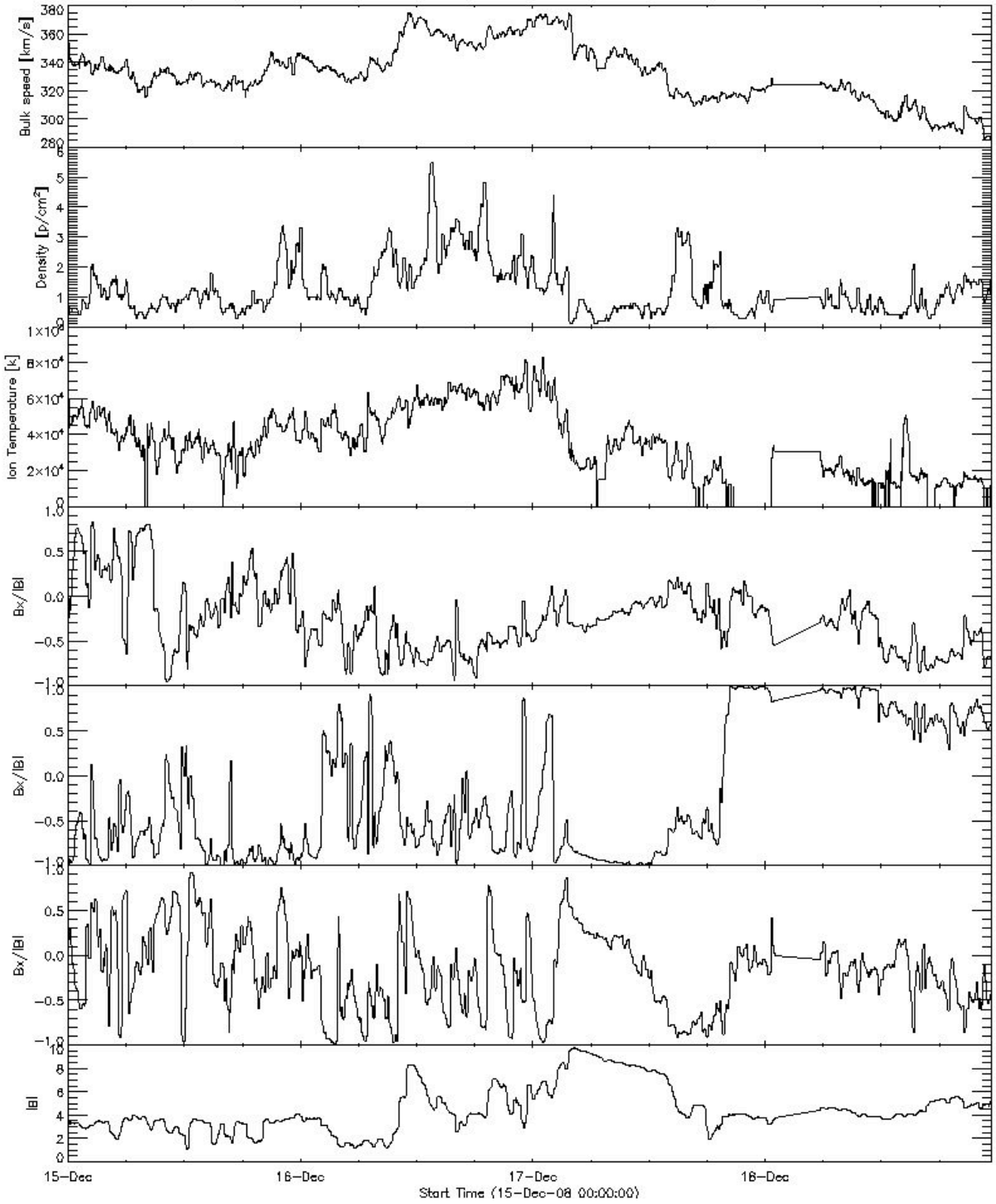
Bulk speed [km s^{-1}]

Density [cm^{-3}]

Ion temperature [K]

B-field components (normalised)

B-field magnitude [nT]



Bulk speed [km s^{-1}]

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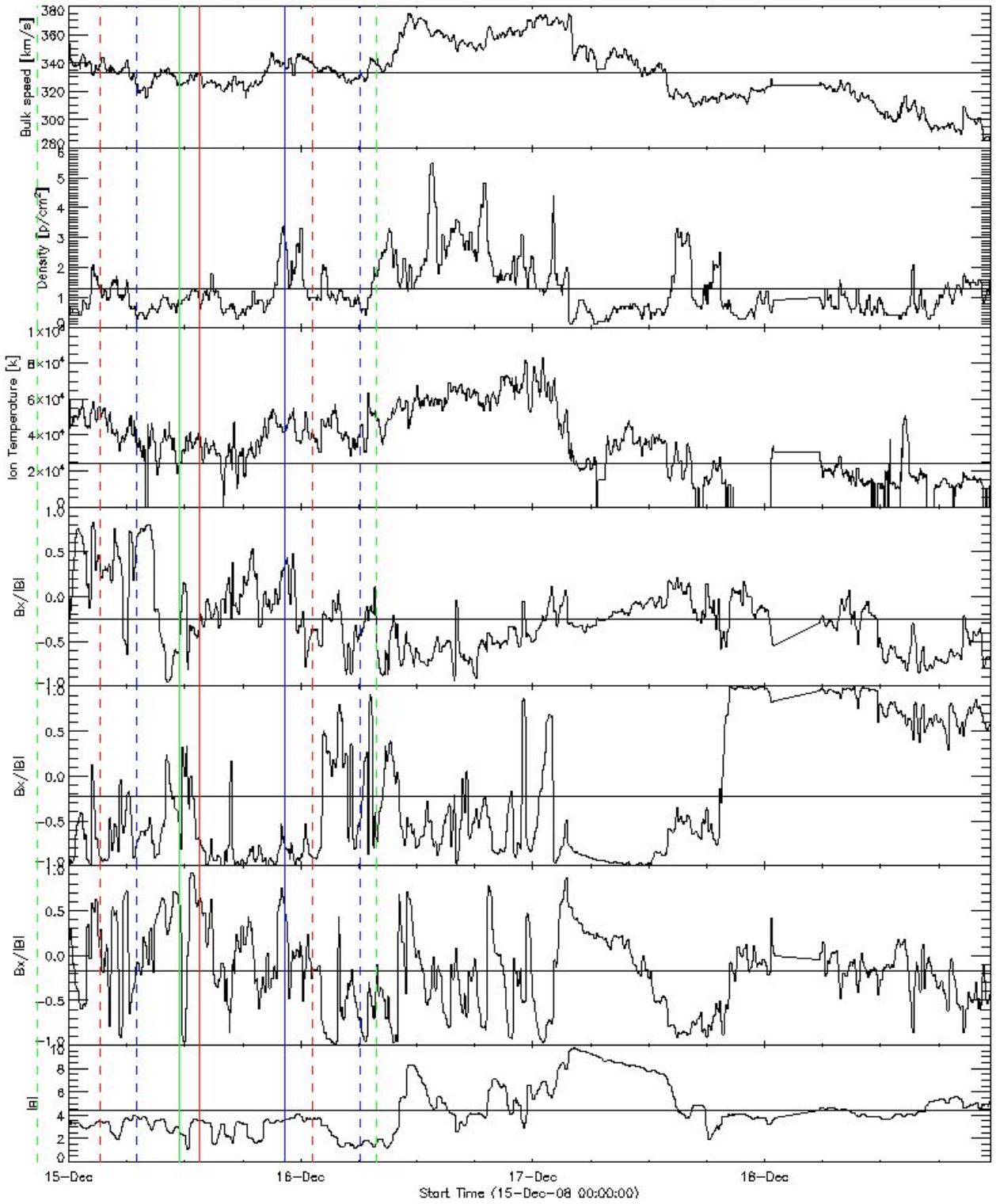
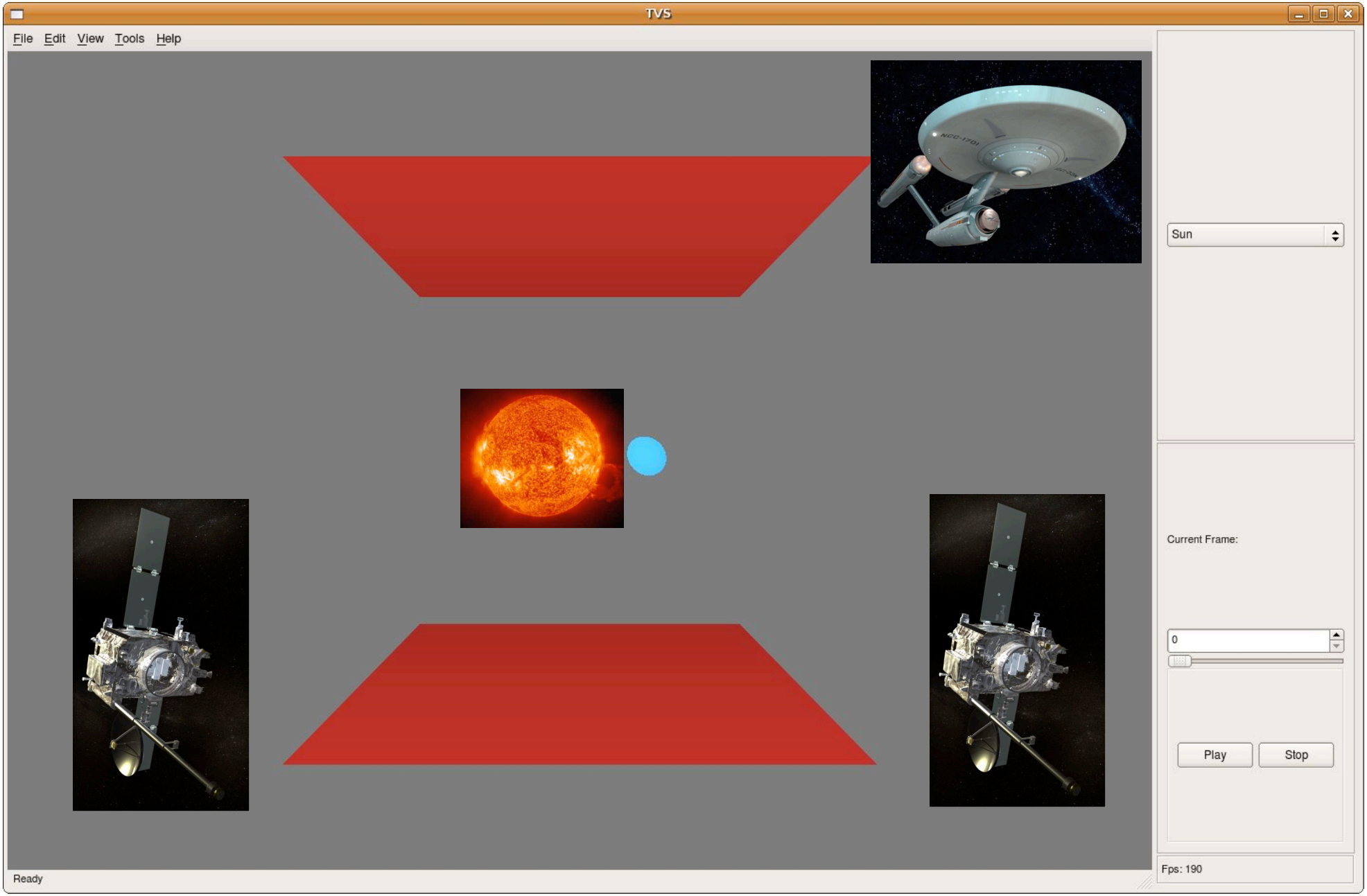


3D Visualization



Conclusions

“True” properties of CMEs:

1. Kinematics - correcting for projection effects.
2. Morphology - 3D structure, expansion, deflection.
3. Space weather - forecast arrival times.
4. 3D visualization suite.

⇒ Satisfying some of the main objectives of STEREO.