Three-Dimensional Reconstruction of an Earth-Directed CME Front

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Solar Group Meeting, November 2009.

Funded by SFI's Research Frontiers Programme.

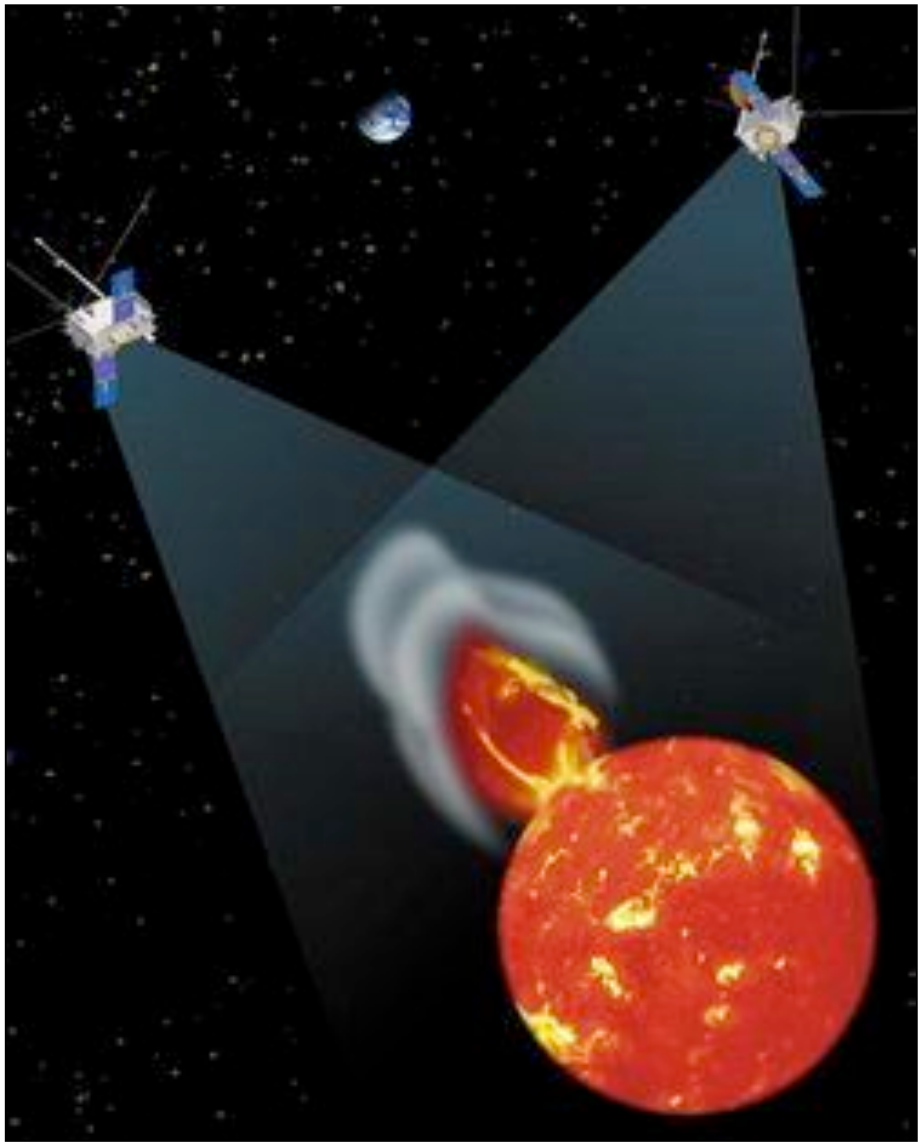
Overview

1) CME Dynamics & Morphology

2) The STEREO Mission
   - 12 Dec. 2008 CME
   - Stereoscopic analysis
   - 3D visualisation

3) Important Results
   - Drag / expansion / deflection
   - Interplanetary propagation
   - Arrival time (ACE)

4) Summary



STEREO illustration

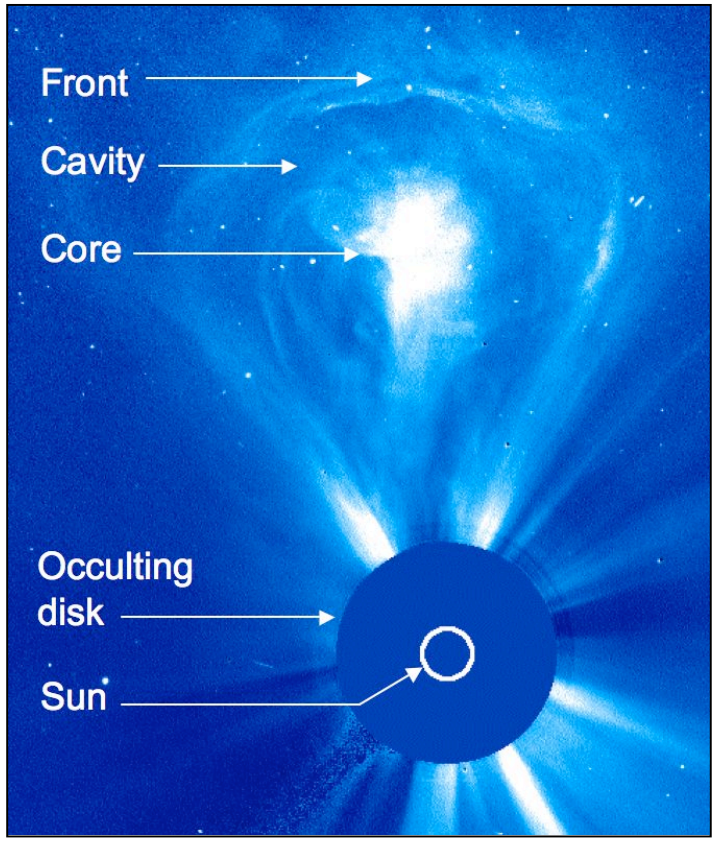
CME Dynamics

Equation of motion:

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

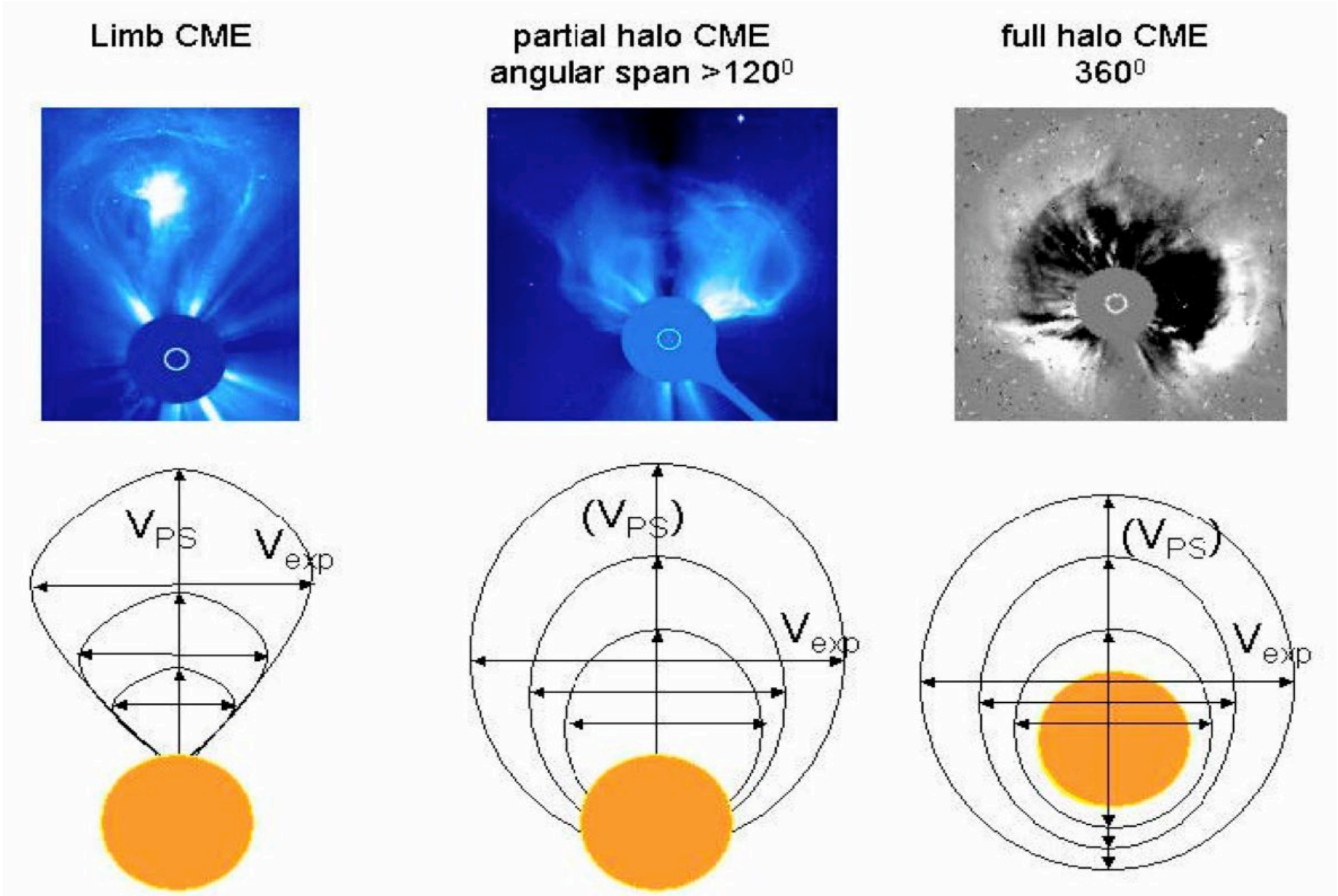
$$\rho \frac{D\vec{v}}{Dt} = \vec{j} \times \vec{B} - \nabla P - \rho \vec{g} - \frac{1}{2} \rho \vec{v}^2$$

Density
Lorentz force
Pressure gradient
Gravitational force
Drag force

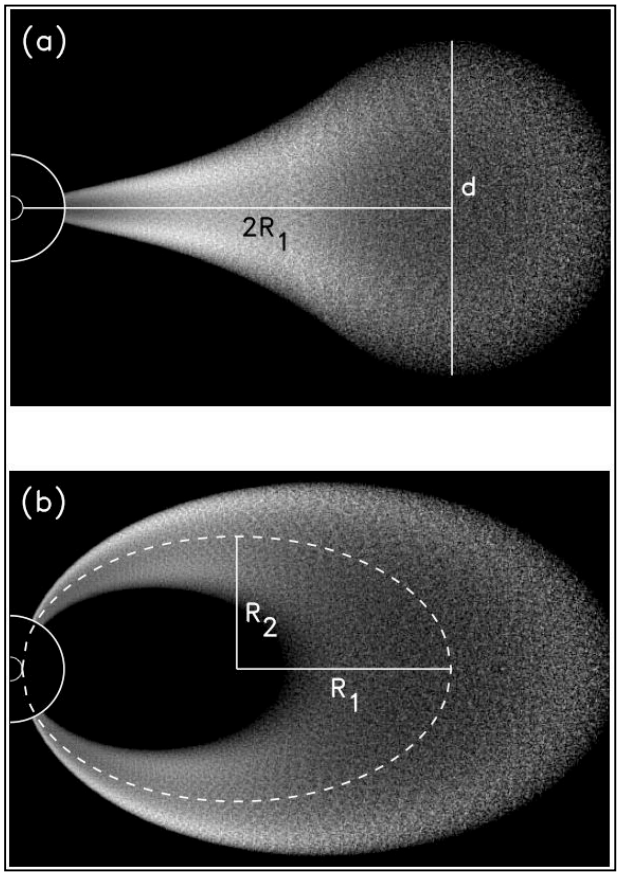


SOHO/LASCO-C3

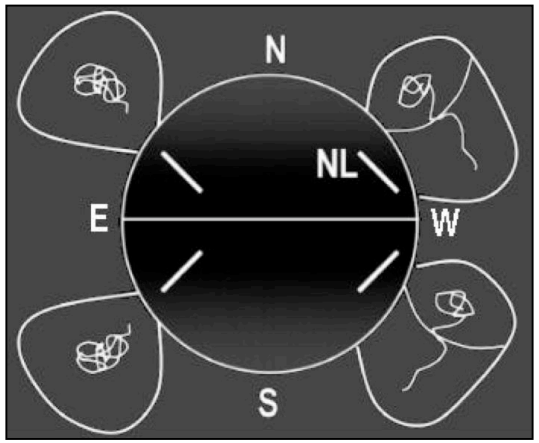
CME Morphology



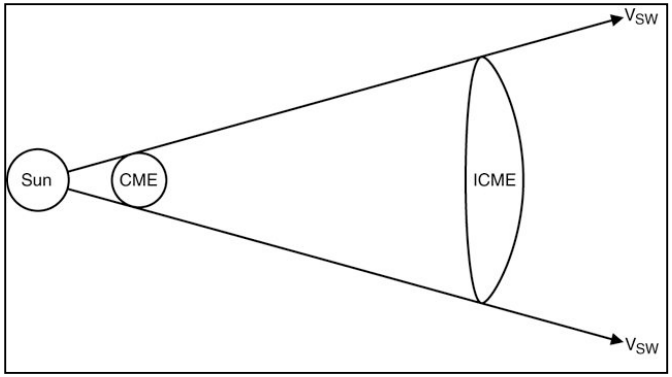
3D Flux Rope (Krall & Chen)



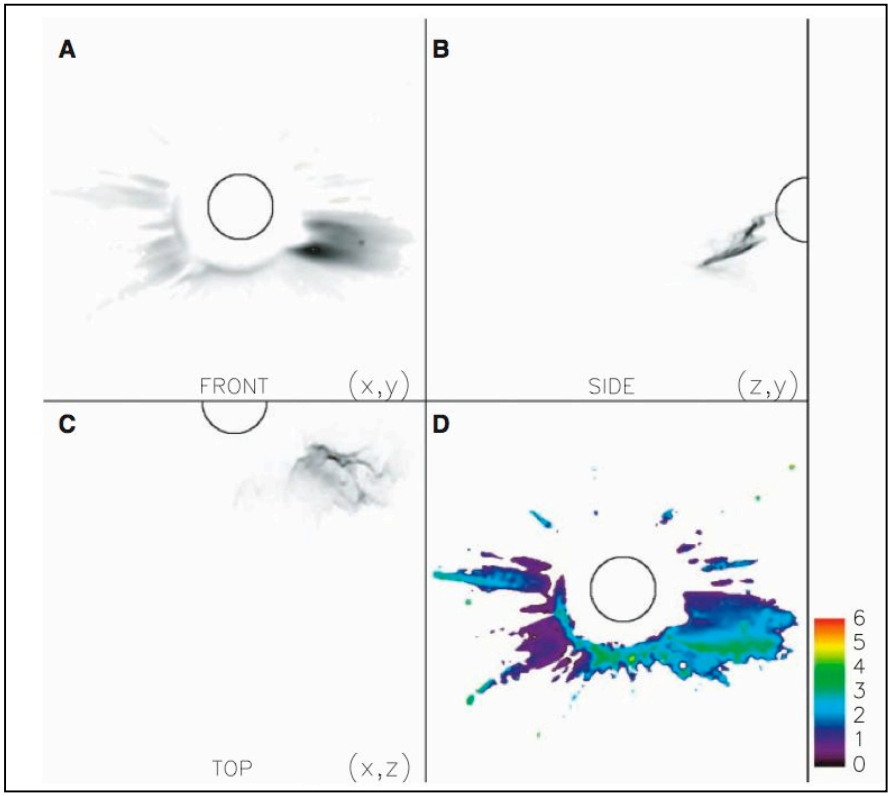
Cylindrical Model (Cremades & Bothmer)



CME Flattening (Russell & Milligan)

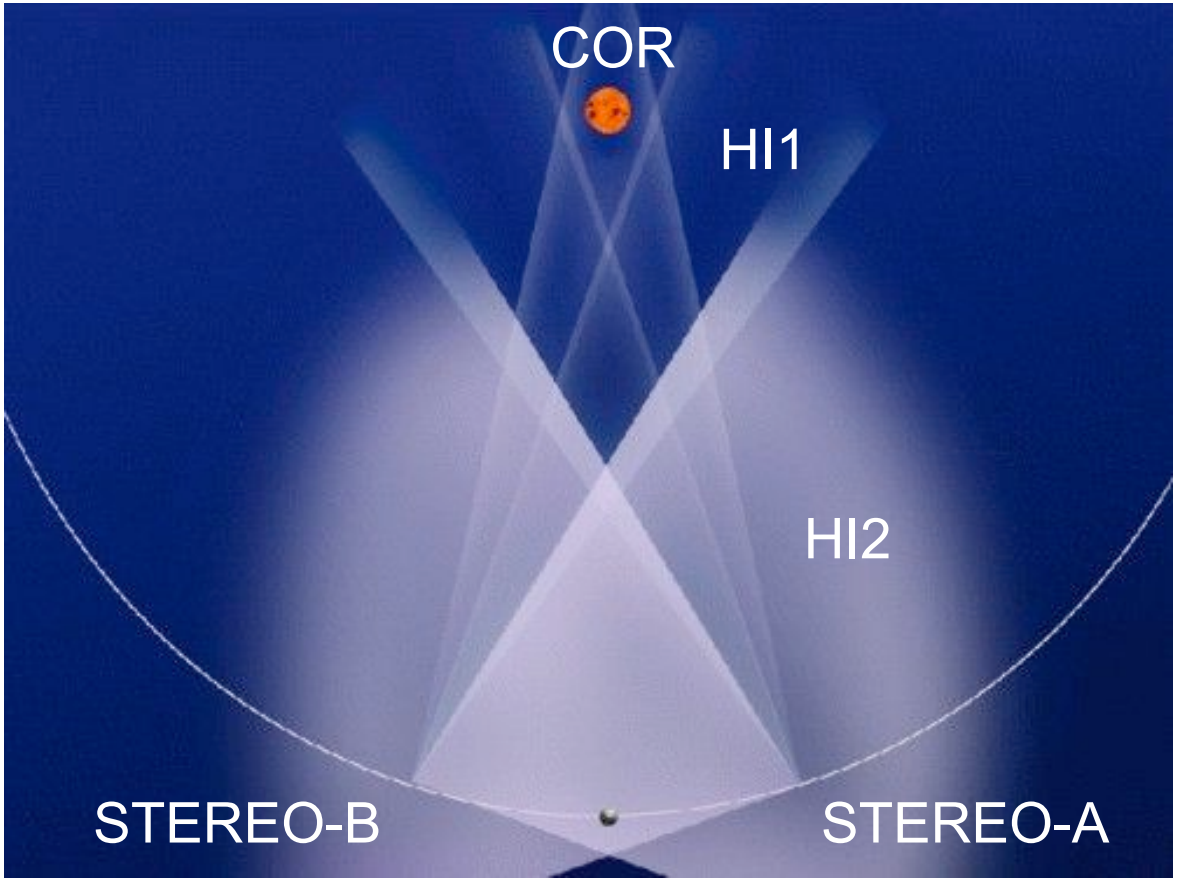


Polarization Analysis (Moran & Davilla)



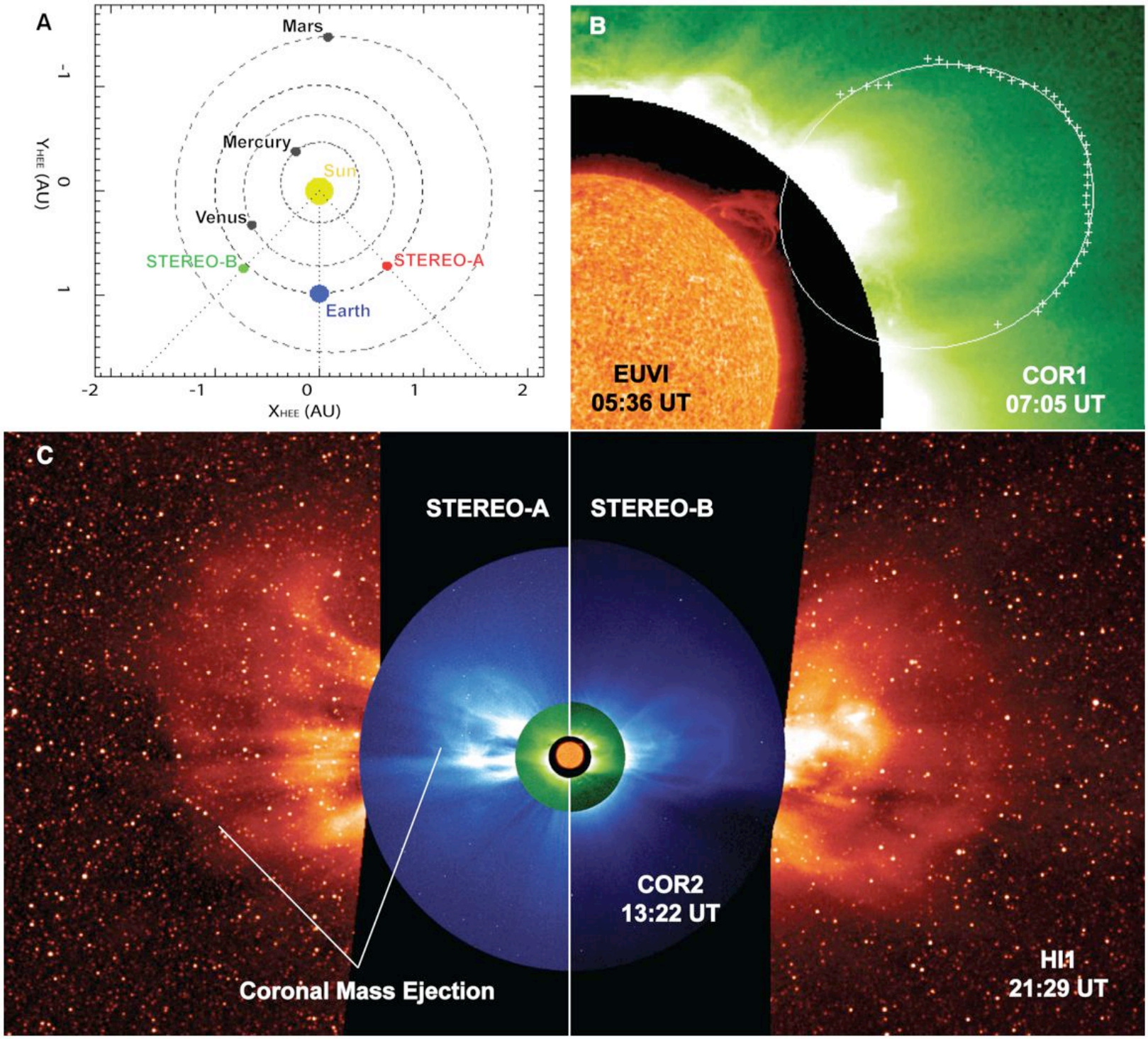
The STEREO Mission

- Launched Oct. 2006
- Separation ± 22°/yr.
  - Currently 125° apart.
- SECCHI
  - EUVI
  - COR1 / 2
  - HI1 / 2



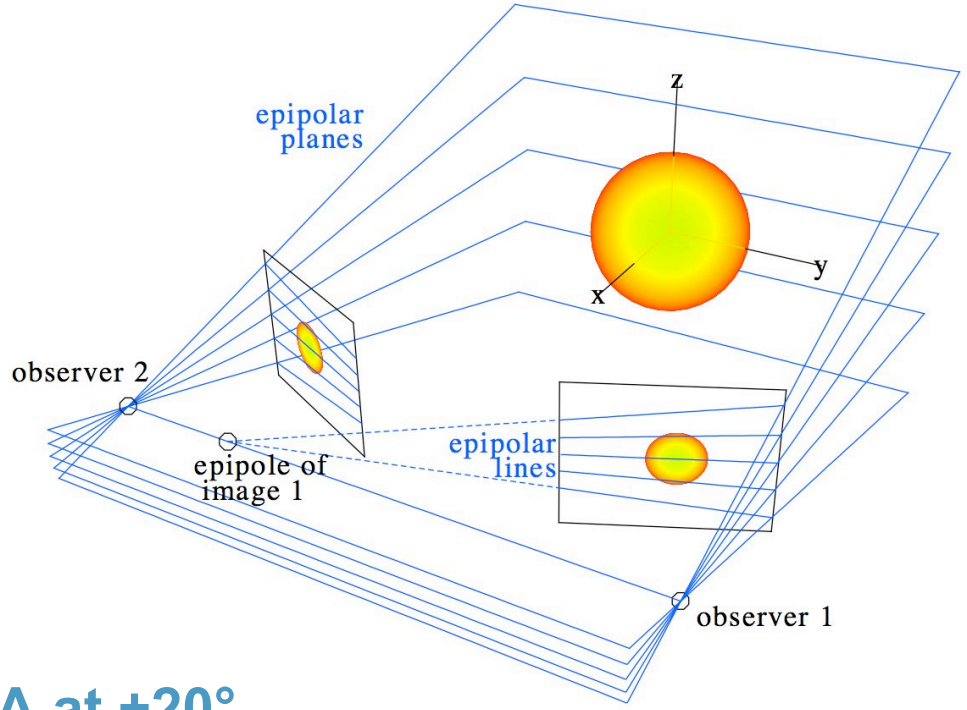
One of STEREO's main scientific objectives:

"Characterize the propagation of CMEs through the Heliosphere."

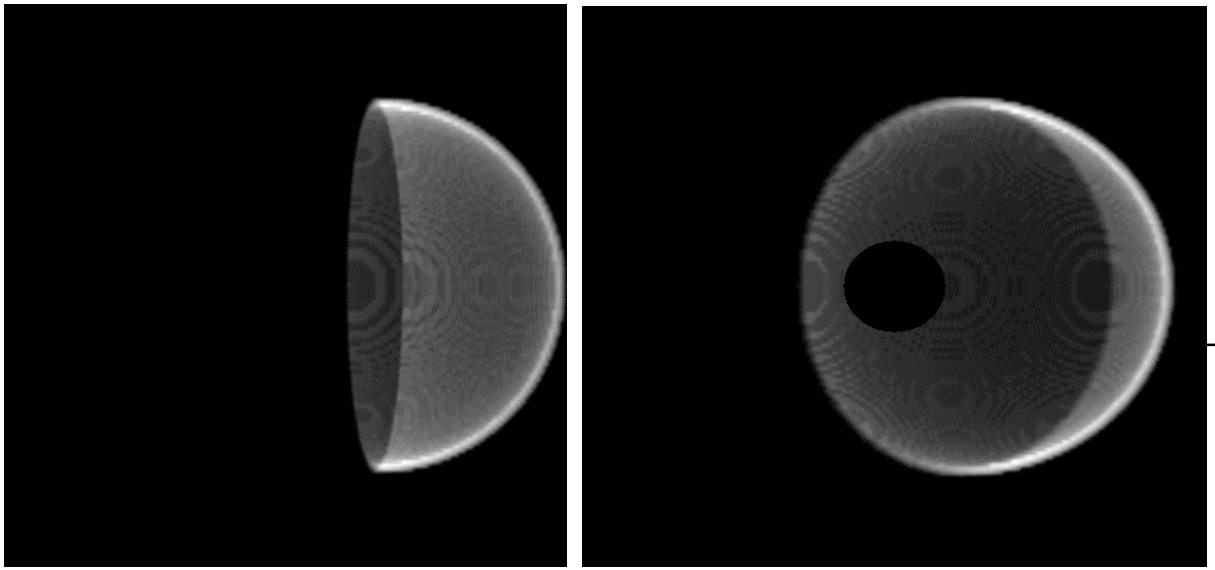

A
Mars
Mercury
Sun
Venus
STEREO-B
STEREO-A
Earth
-2
-1
0
1
2
-1
0
1
YHEE (AU)
XHEE (AU)
B
EUVI
05:36 UT
COR1
07:05 UT
C
STEREO-A
STEREO-B
COR2
13:22 UT
HI1
21:29 UT
Coronal Mass Ejection

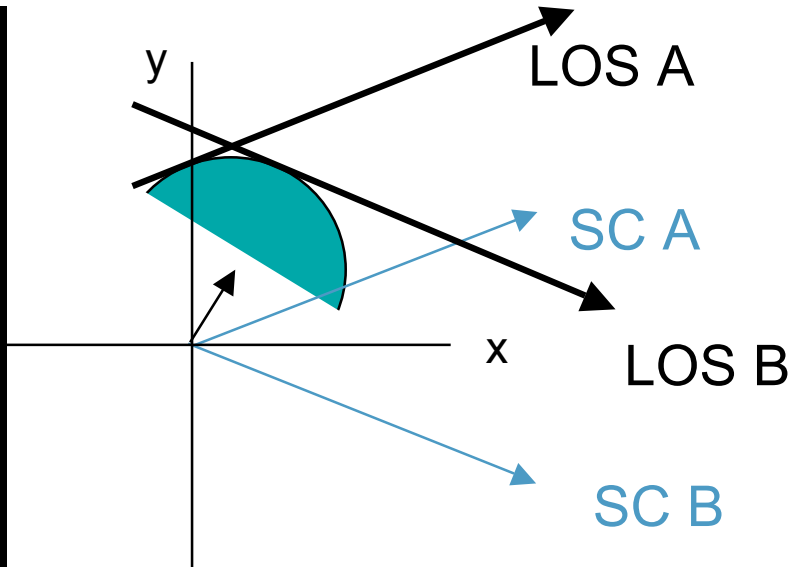
Stereoscopic Analysis

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°**

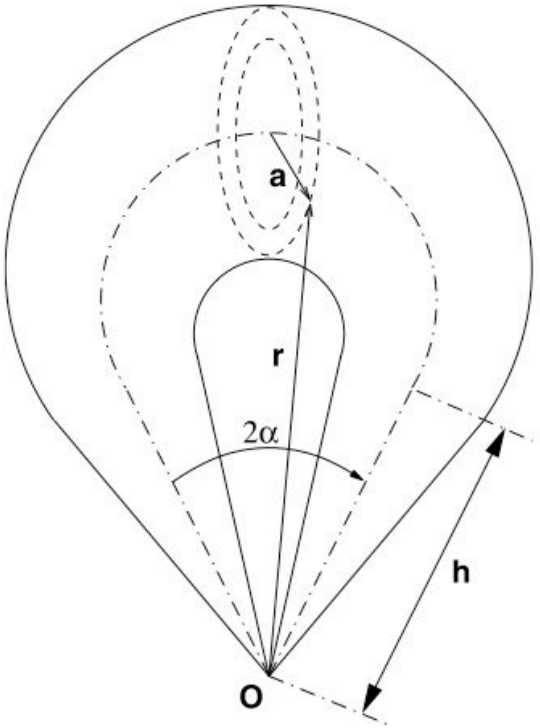


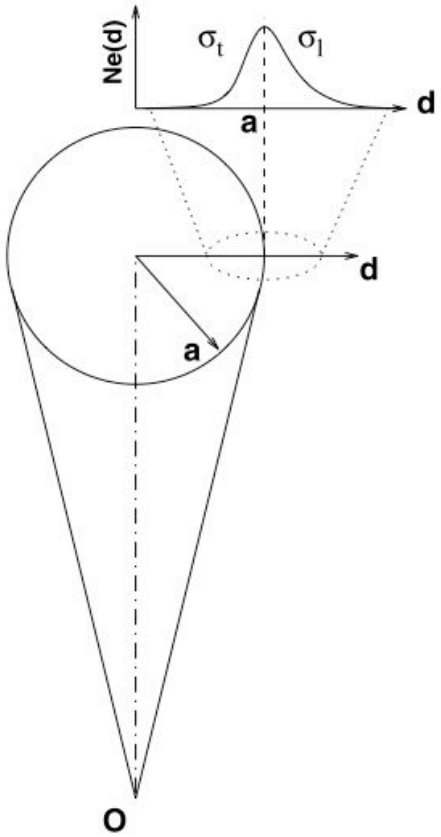


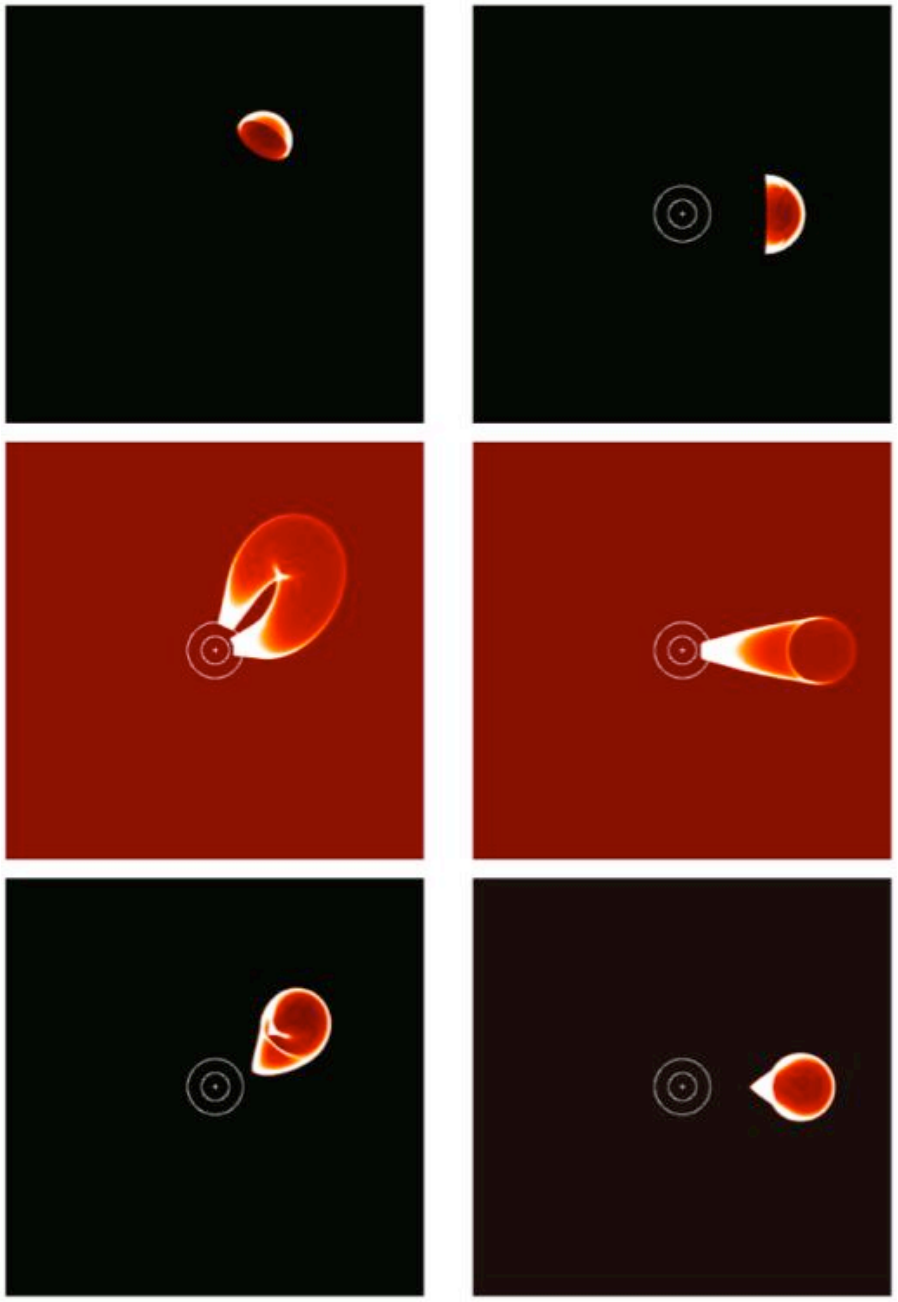
Stereoscopic Analysis

2) Forward-modeling techniques

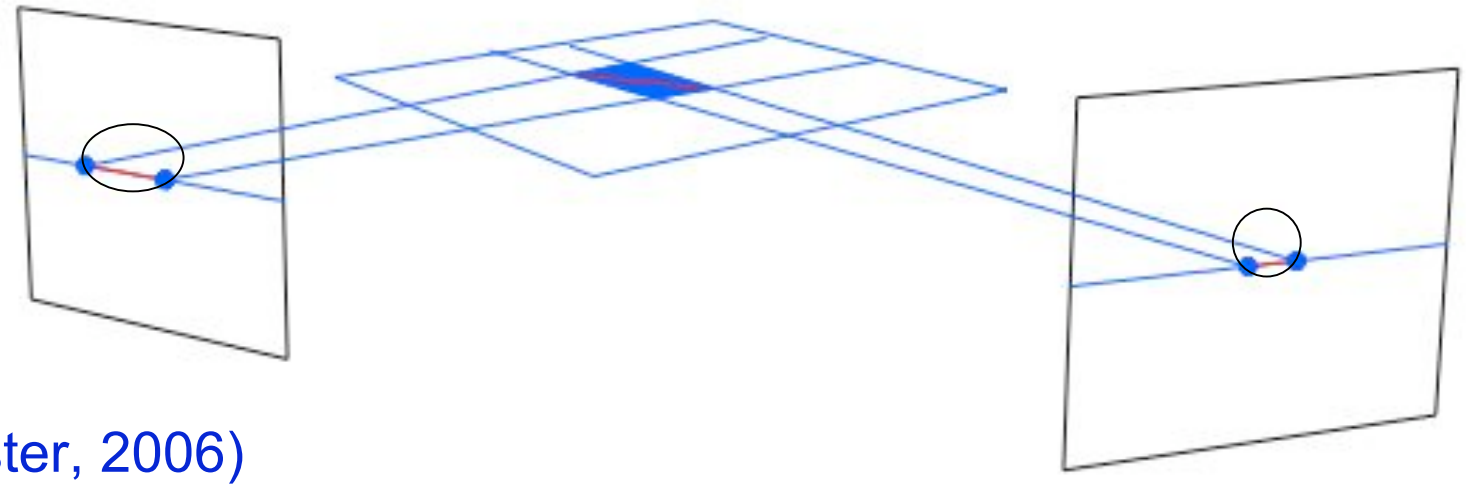
- Thernisien et al., 2009
- Boursier et al., 2009
- Antunes et al., 2009







Stereoscopic Analysis



(Inhester, 2006)

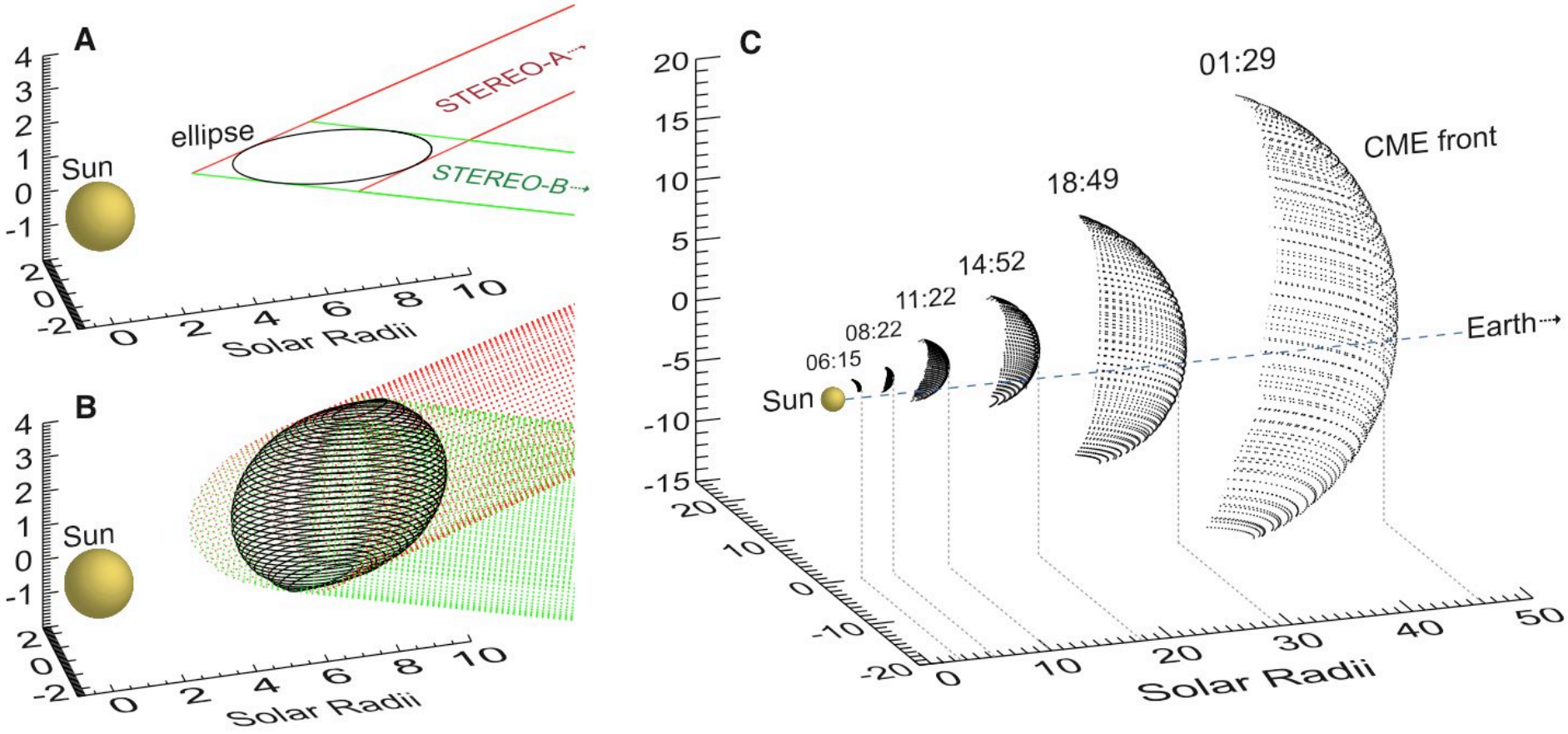
Theorem:

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)

Stereoscopic Analysis

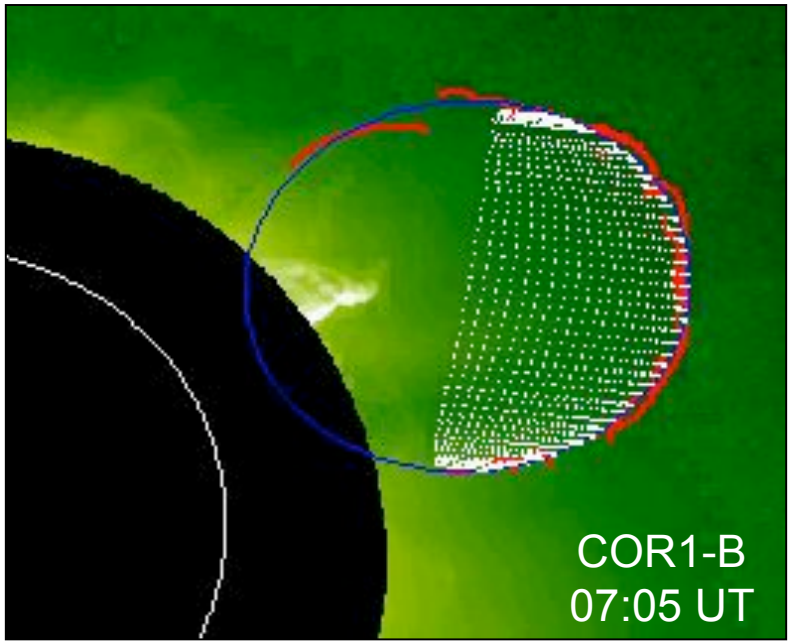
12 Dec. 2008 CME



Movie Data & Visualisation

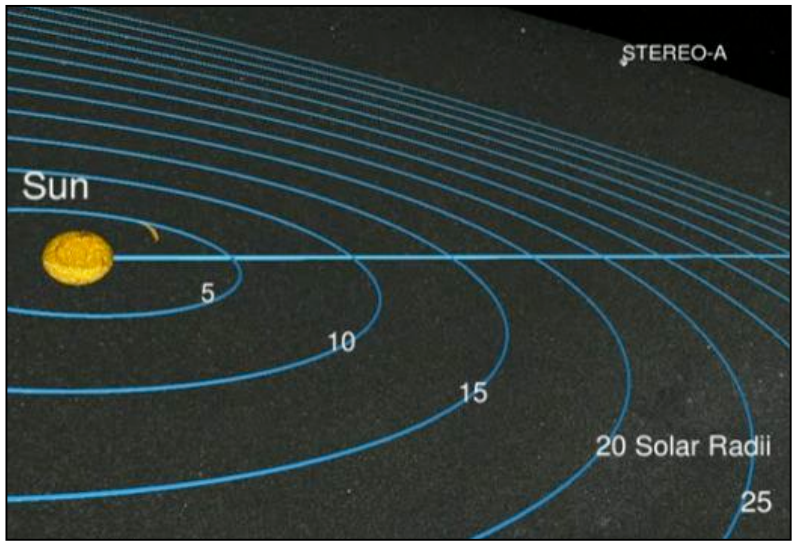
1) Movie data of the 12 Dec. 2008 CME.

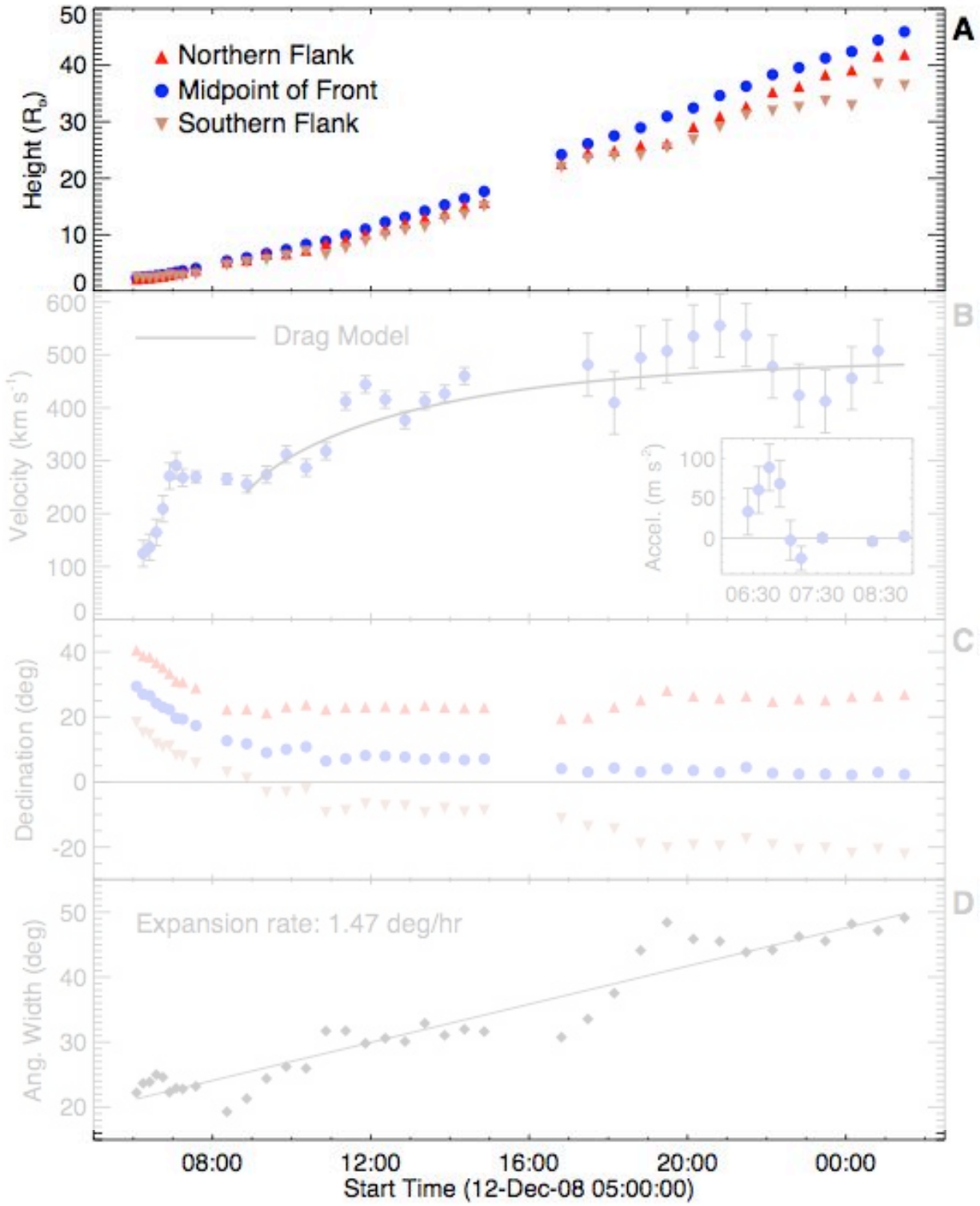
The frames show: the multiscale edge detections on COR1/2 (red lines), and running-difference front detections on HI1 (red points); the ellipse characterisations (blue); and the resulting 3D CME front reconstructions back-projected onto the plane-of-sky (white).



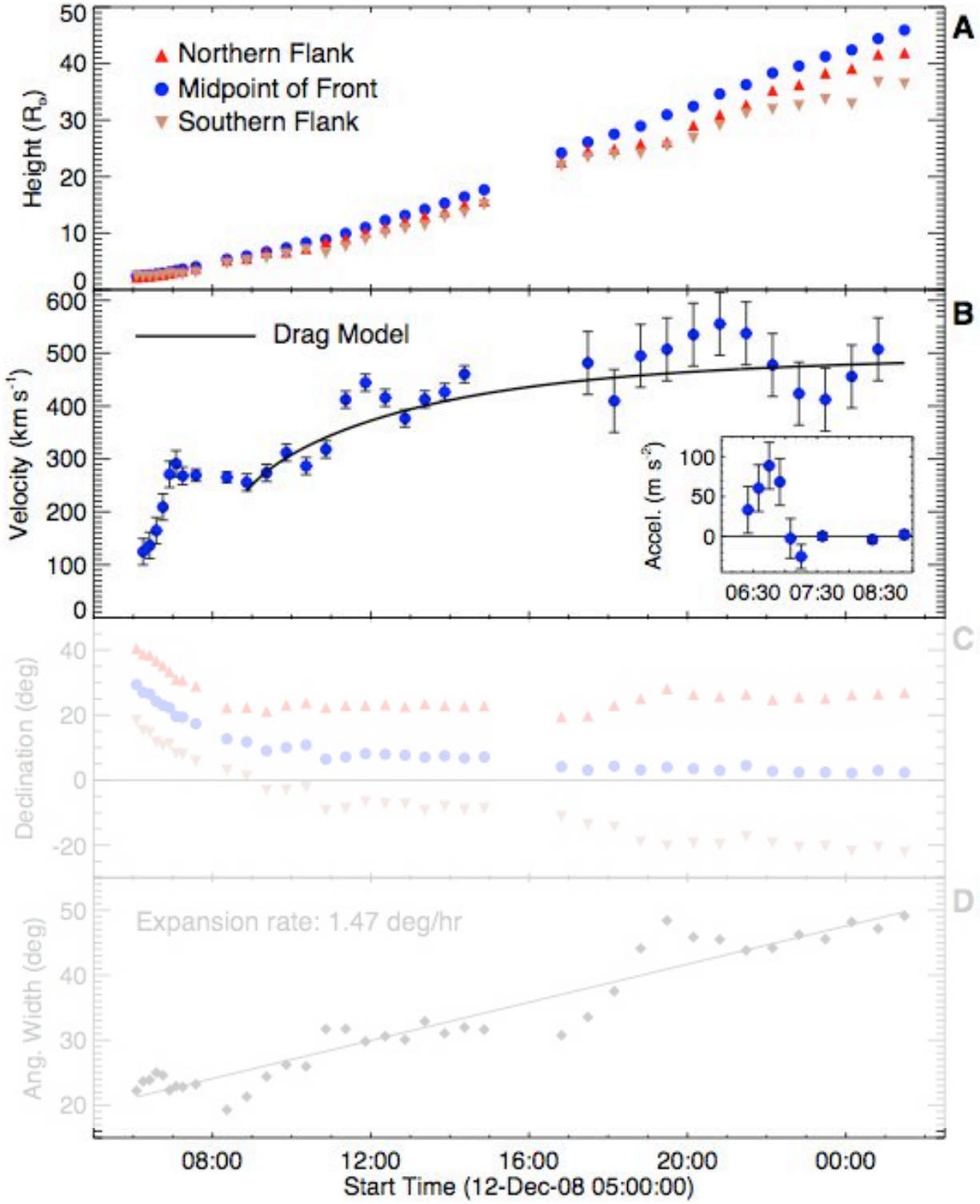
2) Visualisation of the 12 Dec. 2008 CME.

The 3D CME front reconstruction as it propagates along the Sun-Earth line into interplanetary space, at distances of 2-46 solar radii from the Sun. The deflection of the CME is very apparent as it crosses the ecliptic plane.





CME's northern flank attains a greater height than its southern flank.

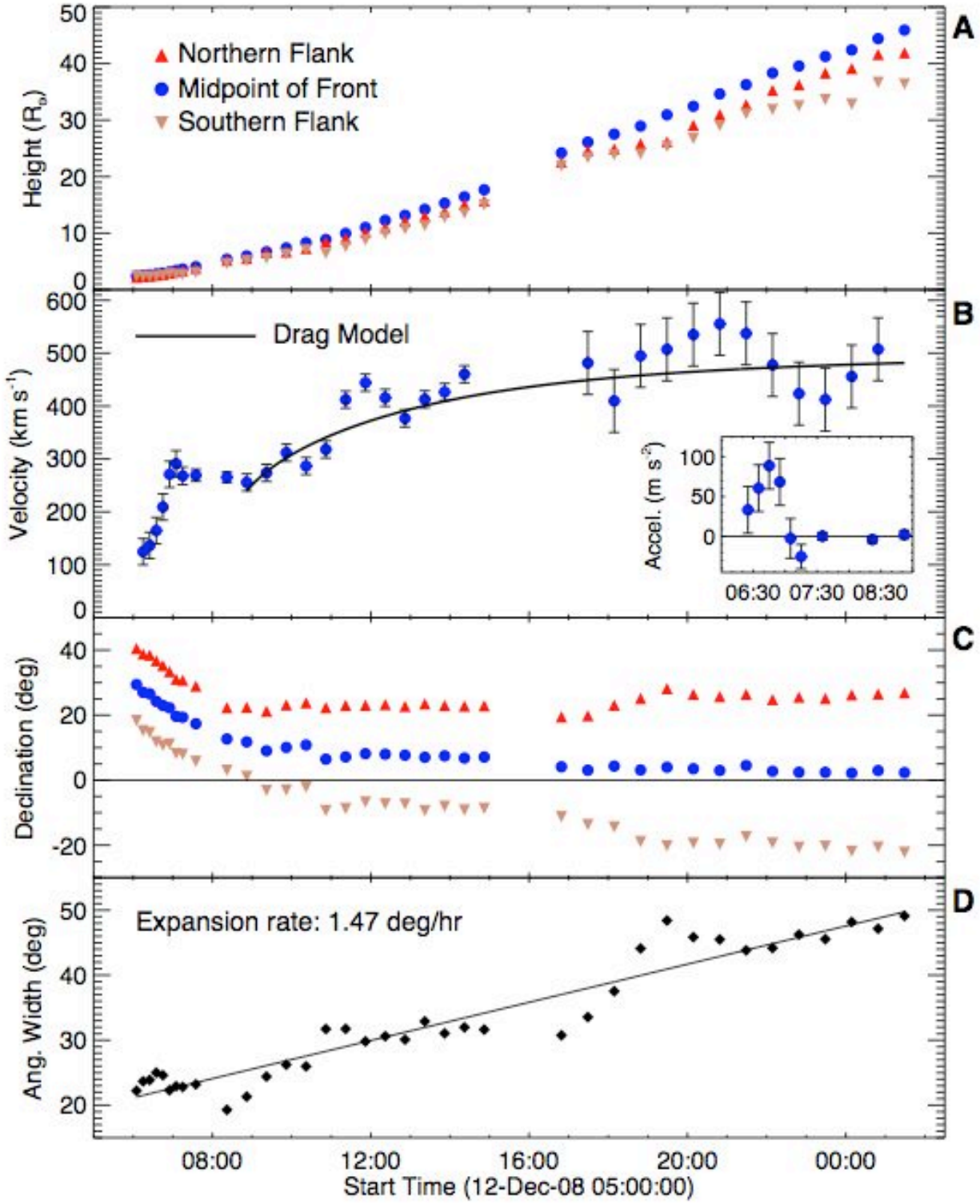


CME's northern flank attains a greater height than its southern flank.

Drag Model:

$$\frac{dv_{cme}}{dt} = -\frac{\rho_{sw}}{\tau\rho_{cme}}(v_{cme} - v_{sw})|v_{cme} - v_{sw}|A_{cme}C_D$$

$$\frac{dv_{cme}}{dR} = -\alpha R^{-\beta}\frac{1}{v_{cme}}(v_{cme} - v_{sw})^c$$



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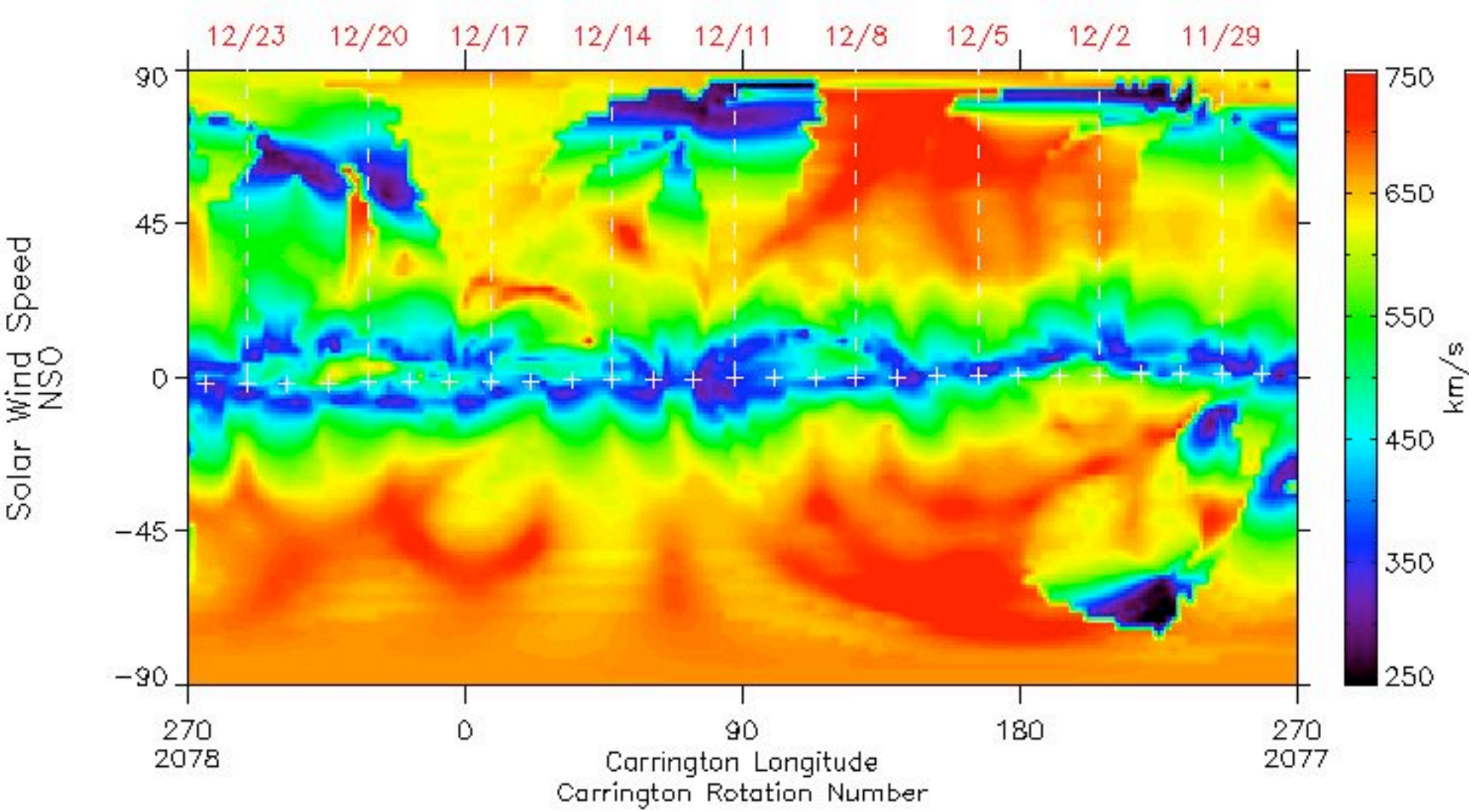
CME is deflected, from its initial trajectory, down towards the ecliptic.
The northern flank maintains constant declination, while the CME's expansion is manifested by the southern flank.

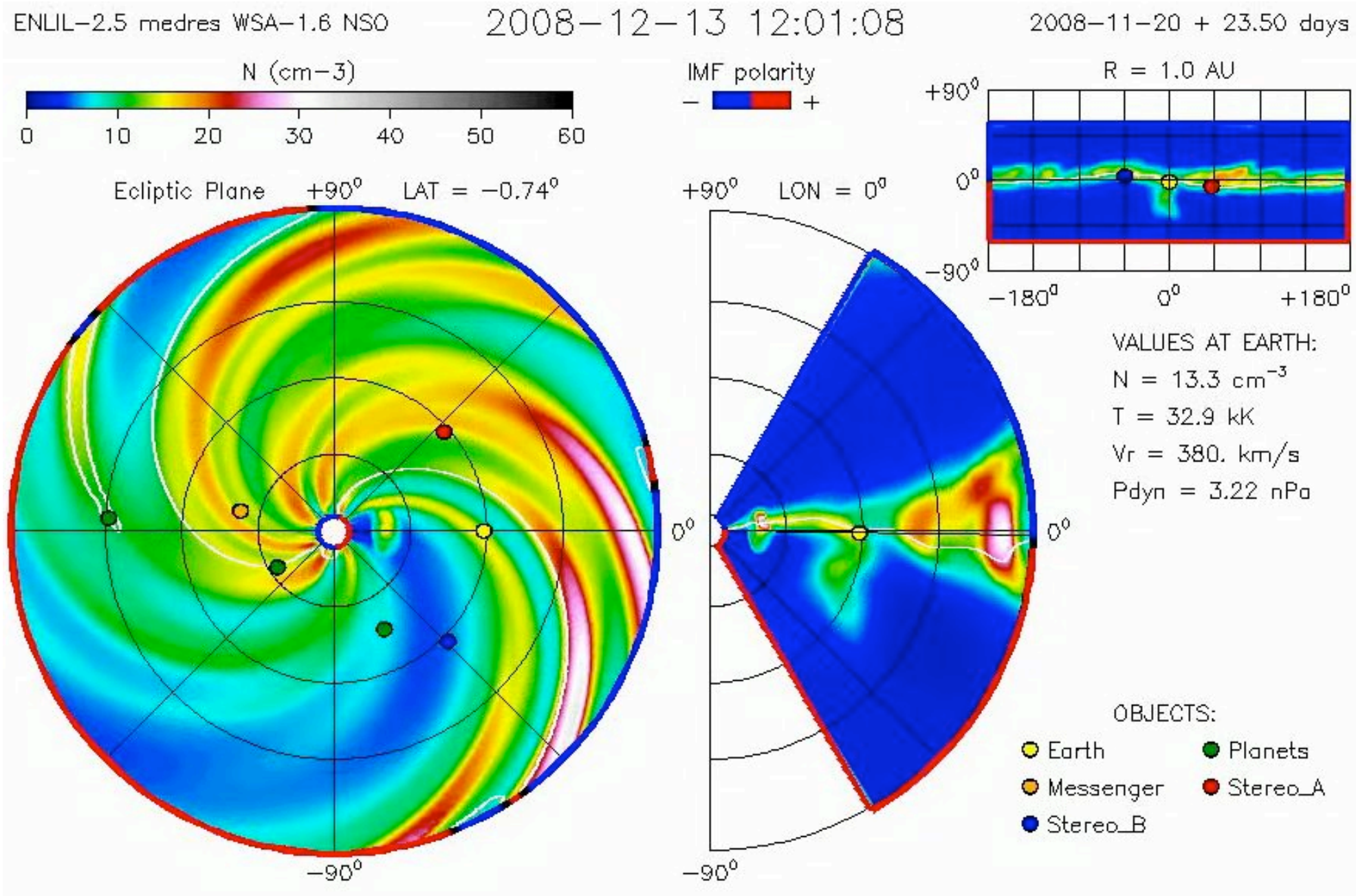
WSA PF+CS Model

Wang-Sheeley-Arge Model:

Potential Field + Current Sheet

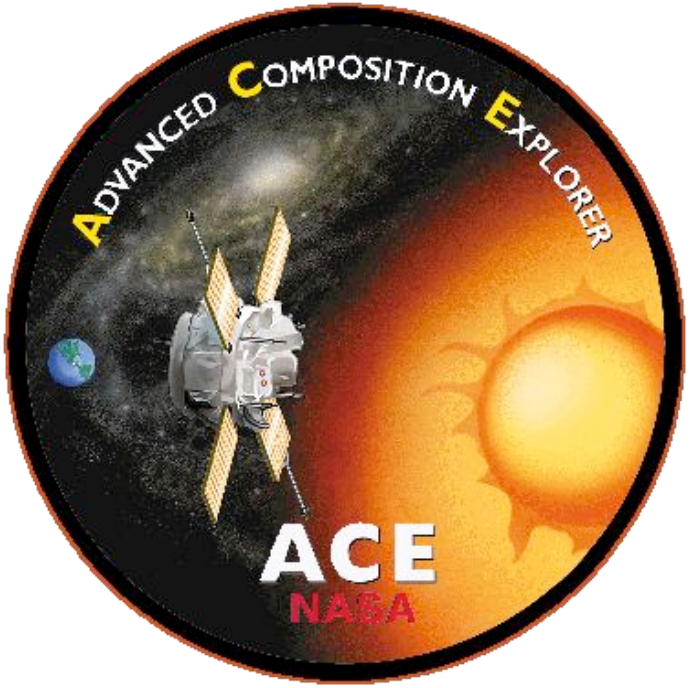


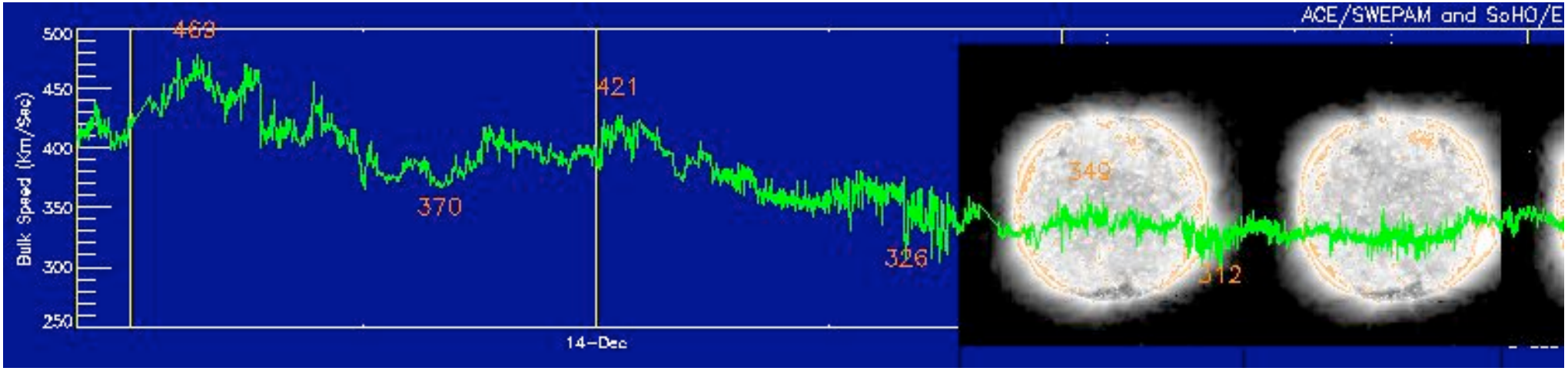
ENLIL with Cone Model



ACE Spacecraft

- Advanced Composition Explorer situated at L1
- Solar wind electron, proton and alpha monitor (SWEPAM)
- Magnetometer instruments (MAG)





ACE Data:

Ion Density [cm^{-3}]

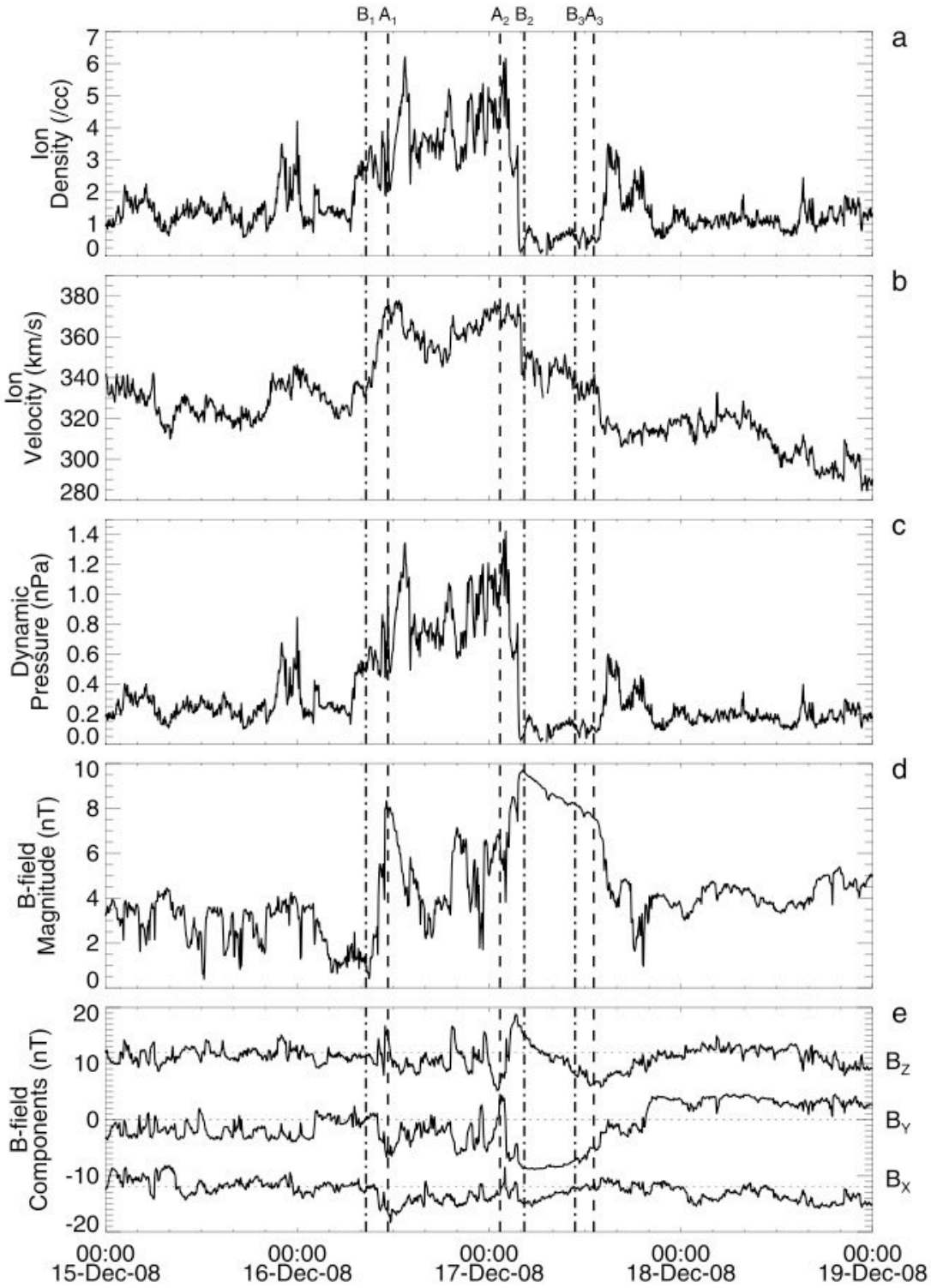
Ion Velocity [km s^{-1}]

Dynamic Pressure [nPa]

B-field Magnitude [nT]

B-field Components [nT]

(Davis et al., JGR 2009)



Summary

1. Prominence eruption in EUVI from ~03:00 UT on 12 Dec. 2008 becomes CME in COR1 from ~05:35 UT at a position angle of ~30°.
   ↪ *3D reconstruction* in COR1/2 and HI1 fields-of-view.

2. *Acceleration* from 100-300 km s^{-1} at heights < 4 $R_{\odot}$.

3. Solar wind *drags* CME velocity up to ~470 km s^{-1} at heights < 50 $R_{\odot}$.

4. High-speed solar wind stream emanating from ~35° declination causes a southward *deflection* of the CME.

5. CME undergoes *super-radial expansion*, manifested in its southern flank while the northern flank moves at constant declination alongside the high-speed stream (and attains greater speeds).

6. A slow-speed solar wind stream ahead of the CME causes deceleration in interplanetary space, which accounts for its *arrival time* at L1 of ~08:09 UT on 16 Dec. 2008 (c.f. ~08:36 UT measured by ACE).