Stereo Analysis of CMEs using Multiscale Methods and Ellipse Characterisations

Jason P. Byrne

Supervisor: Dr. Peter T. Gallagher

Group Meeting Dec. 2008

Astrophysics Research Group,
School of Physics, Trinity College Dublin

Funded by SFI's Research Frontiers Programme

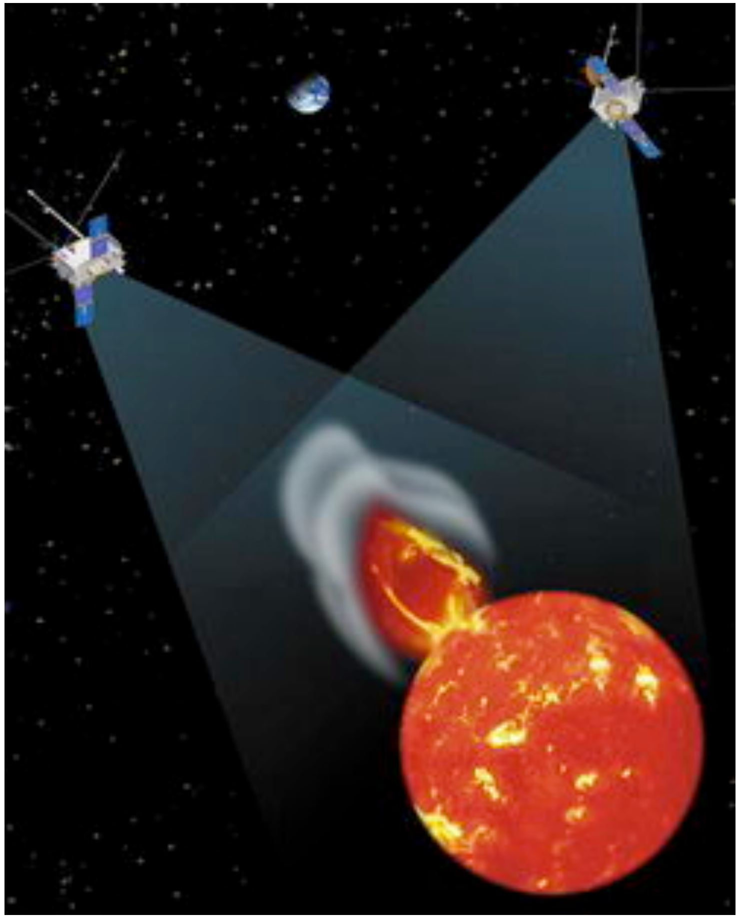
Overview

1. CME Theory
   a) Dynamics
   b) Structure

2. Multiscale Analysis

3. Stereoscopic Analysis
   a) Tie-pointing
   b) Ellipsoid?!

4. Next steps…



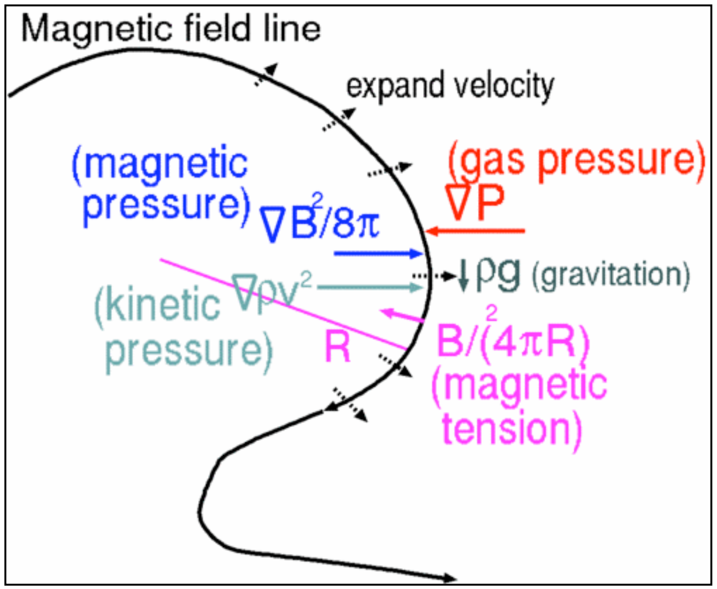
CME Dynamics

Equation of motion:

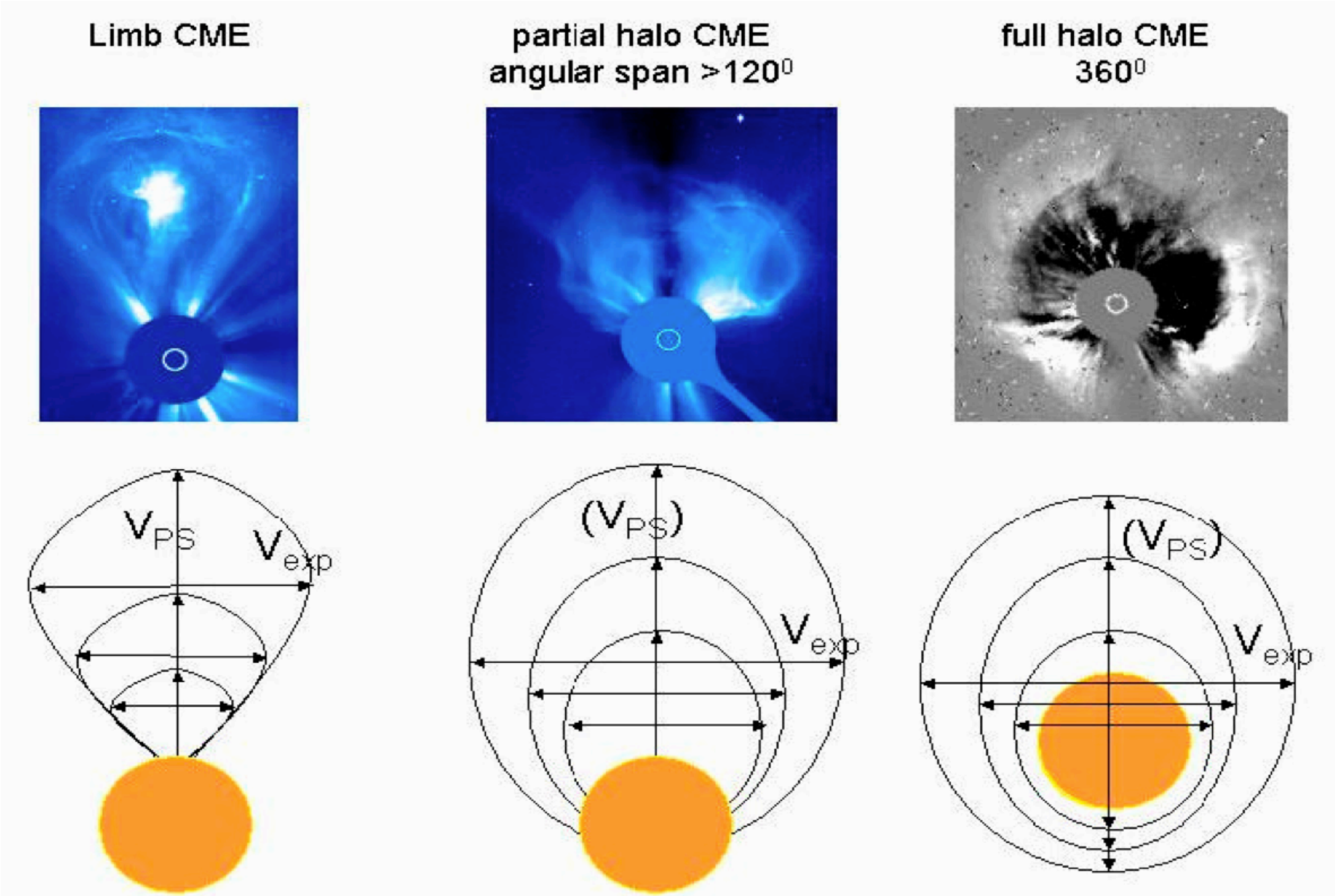
$$\sum F = F_B + F_P + F_G + F_D$$

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

Density
Lorentz force
Pressure gradient
Gravitational force
Drag force

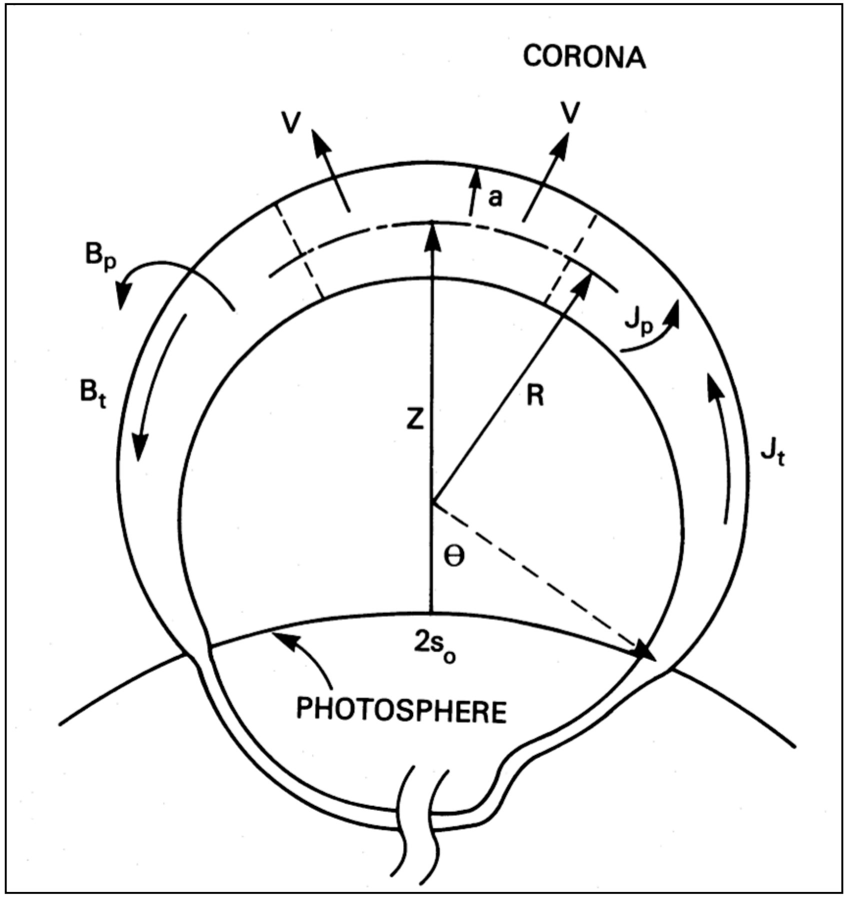


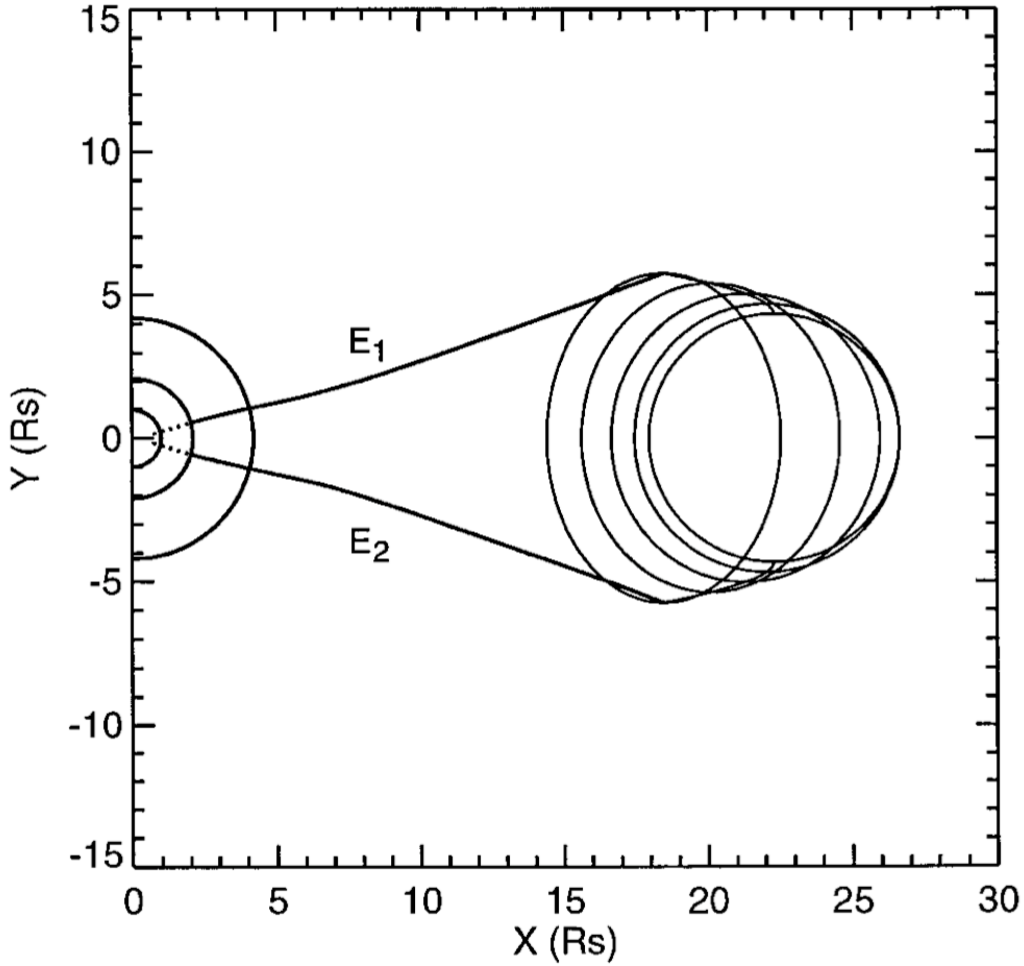
CME Dynamics



CME Structure

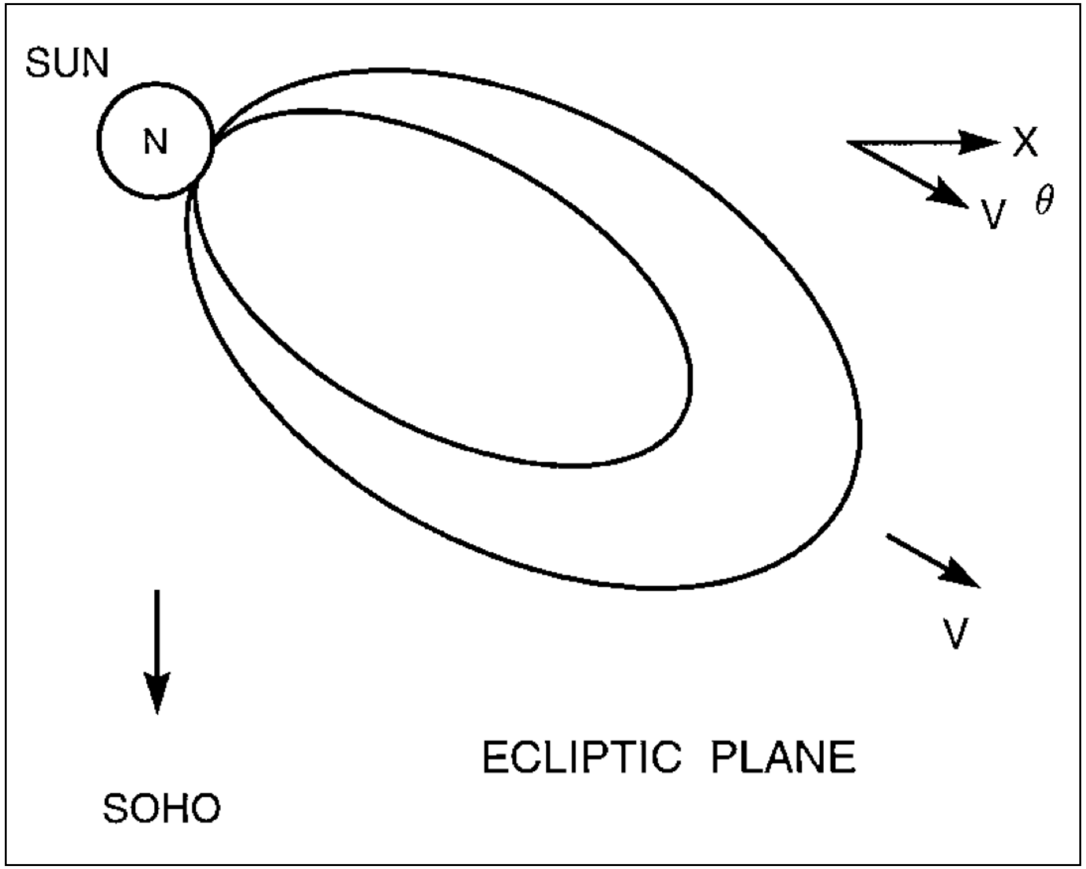
1) 3D Flux Rope; Chen & Krall

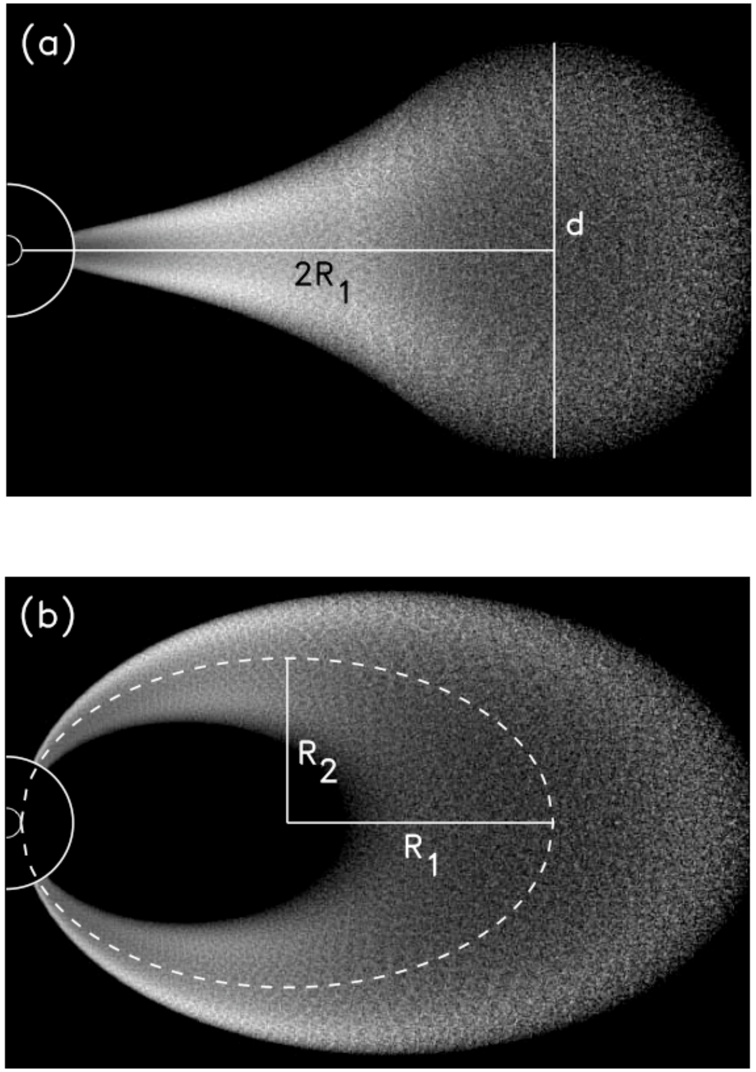




CME Structure

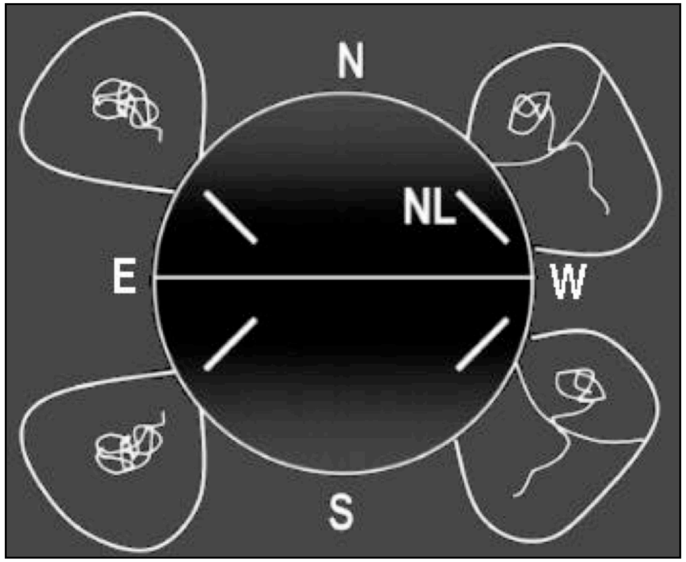
1) 3D Flux Rope; Chen & Krall

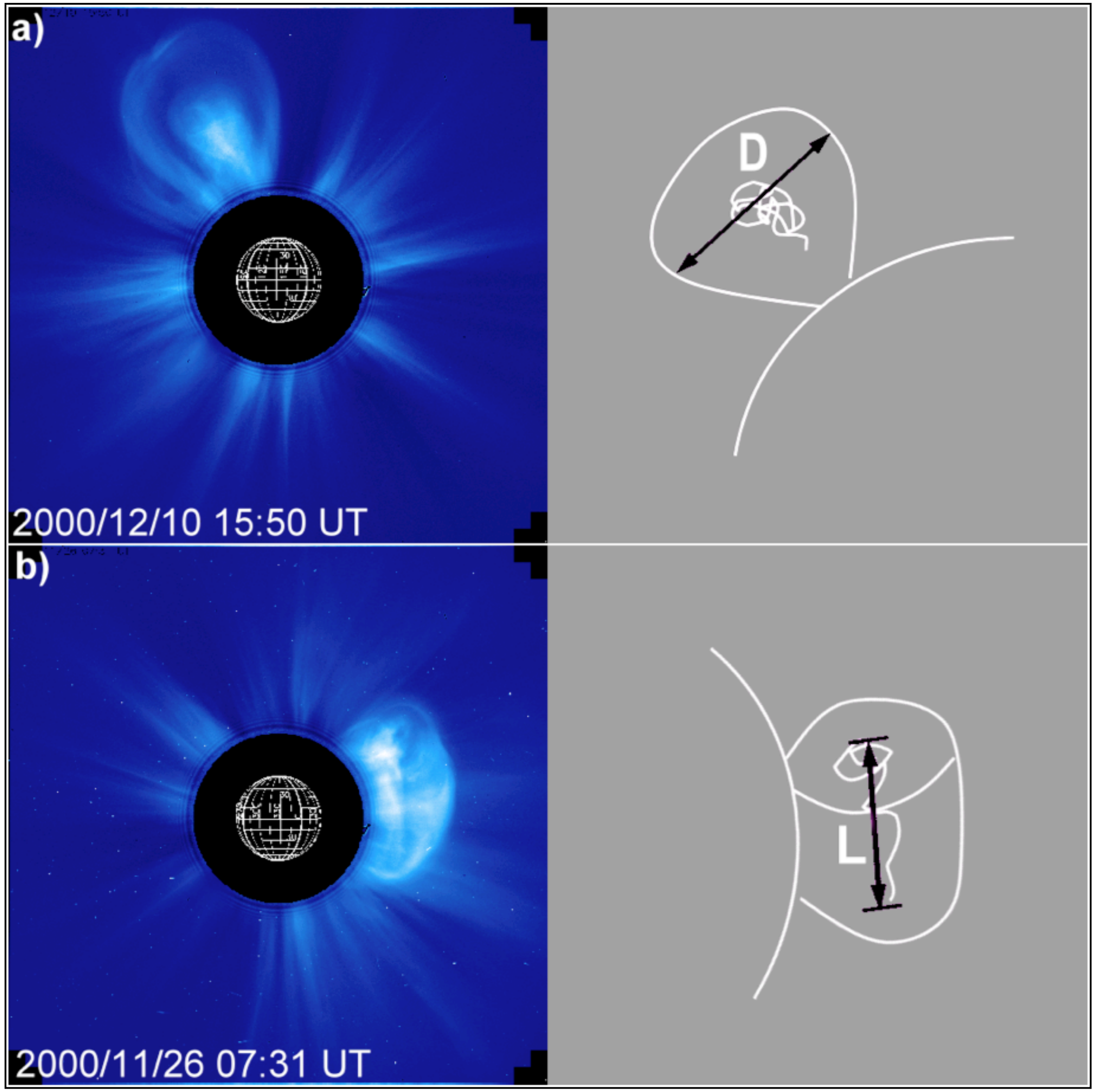




CME Structure

2) Cylindrical Model; Cremades

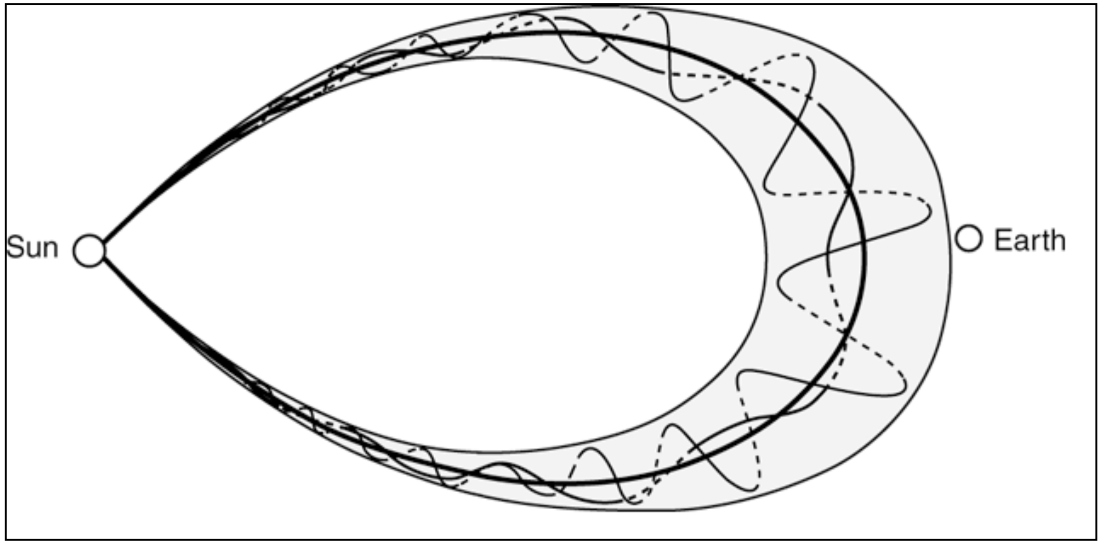


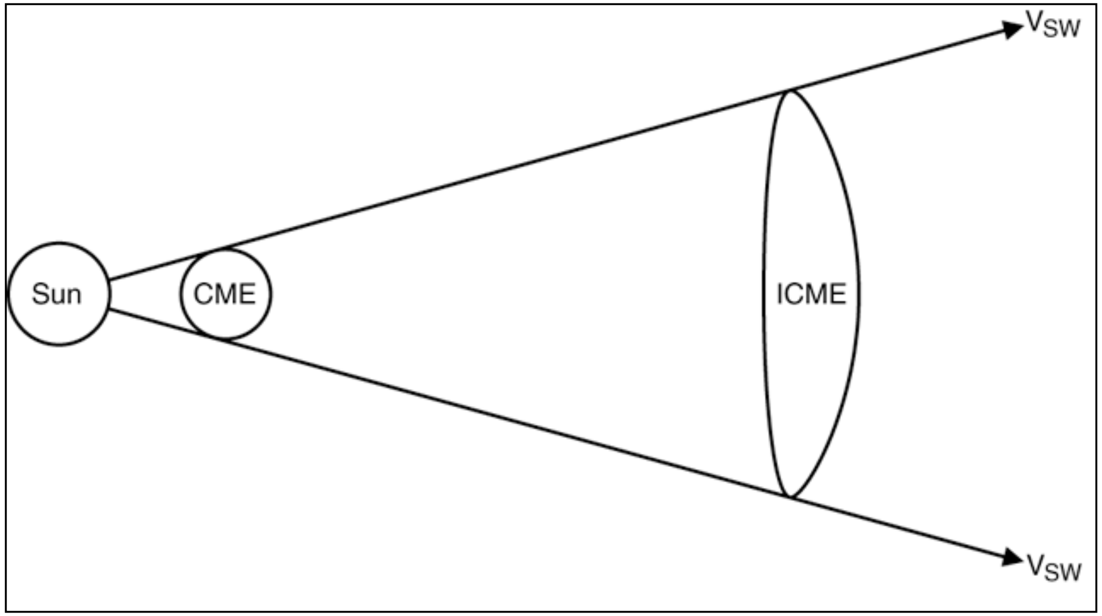


CME Structure

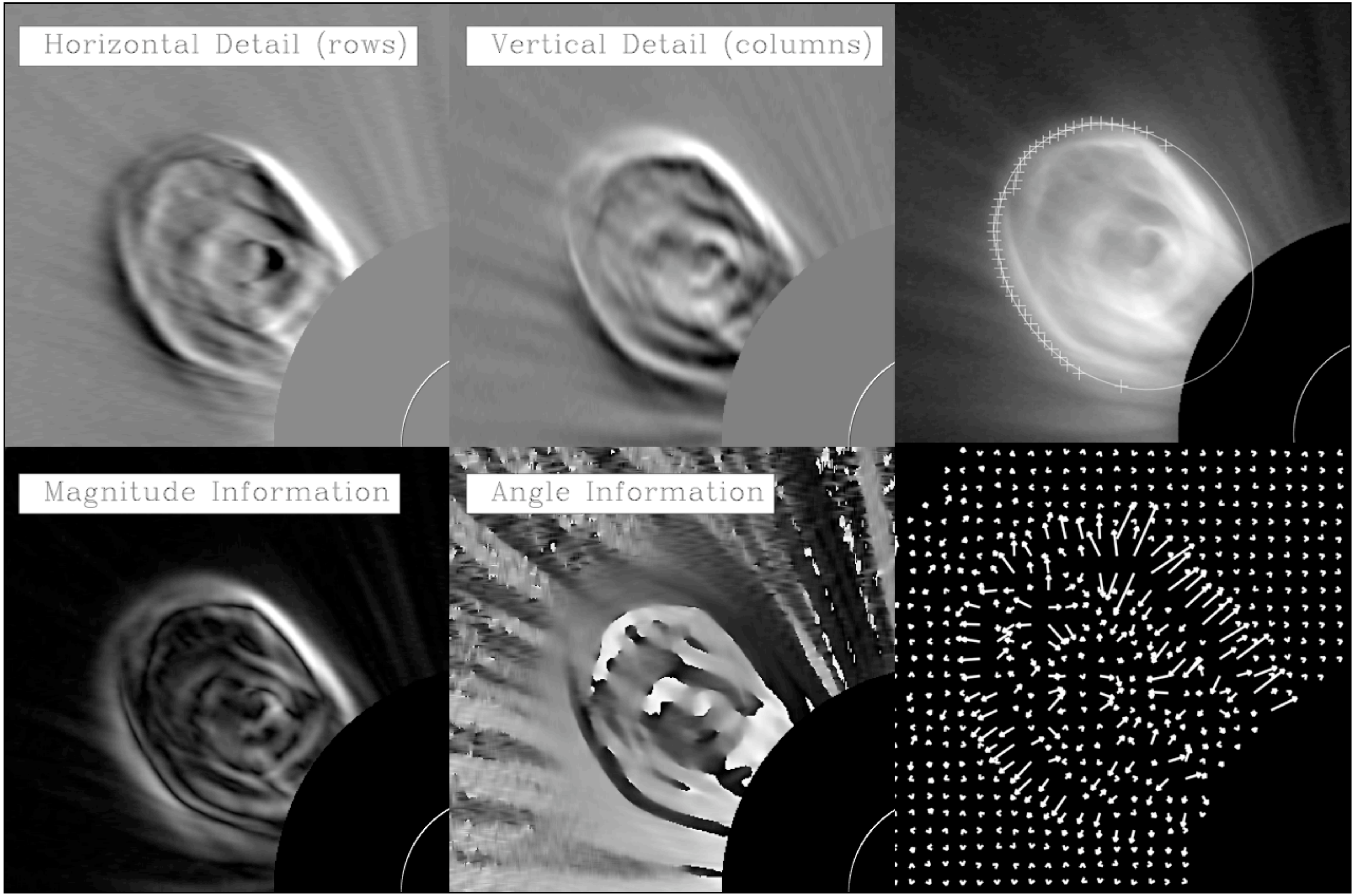
3) CME Flattening; Russell & Milligan

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

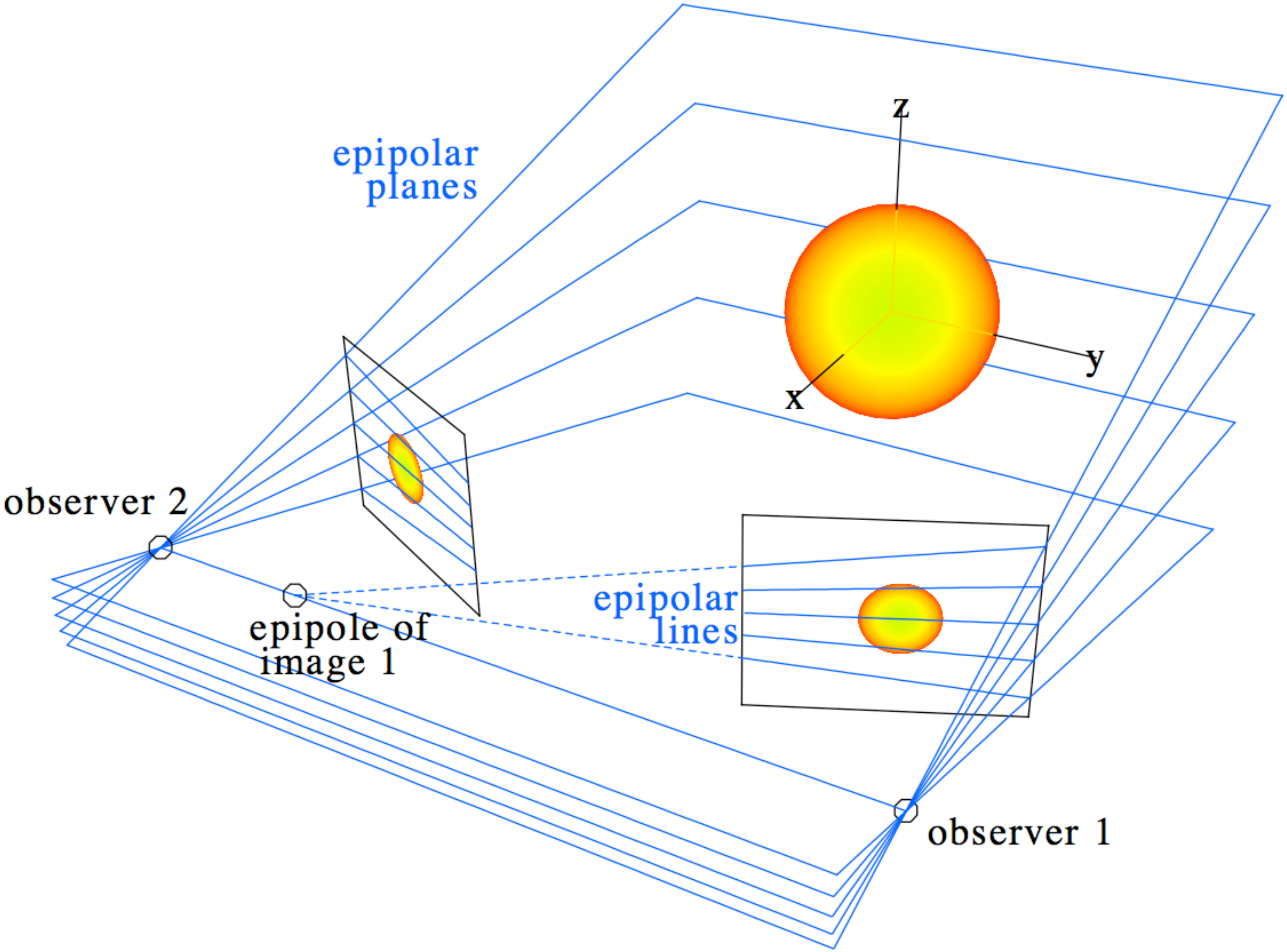




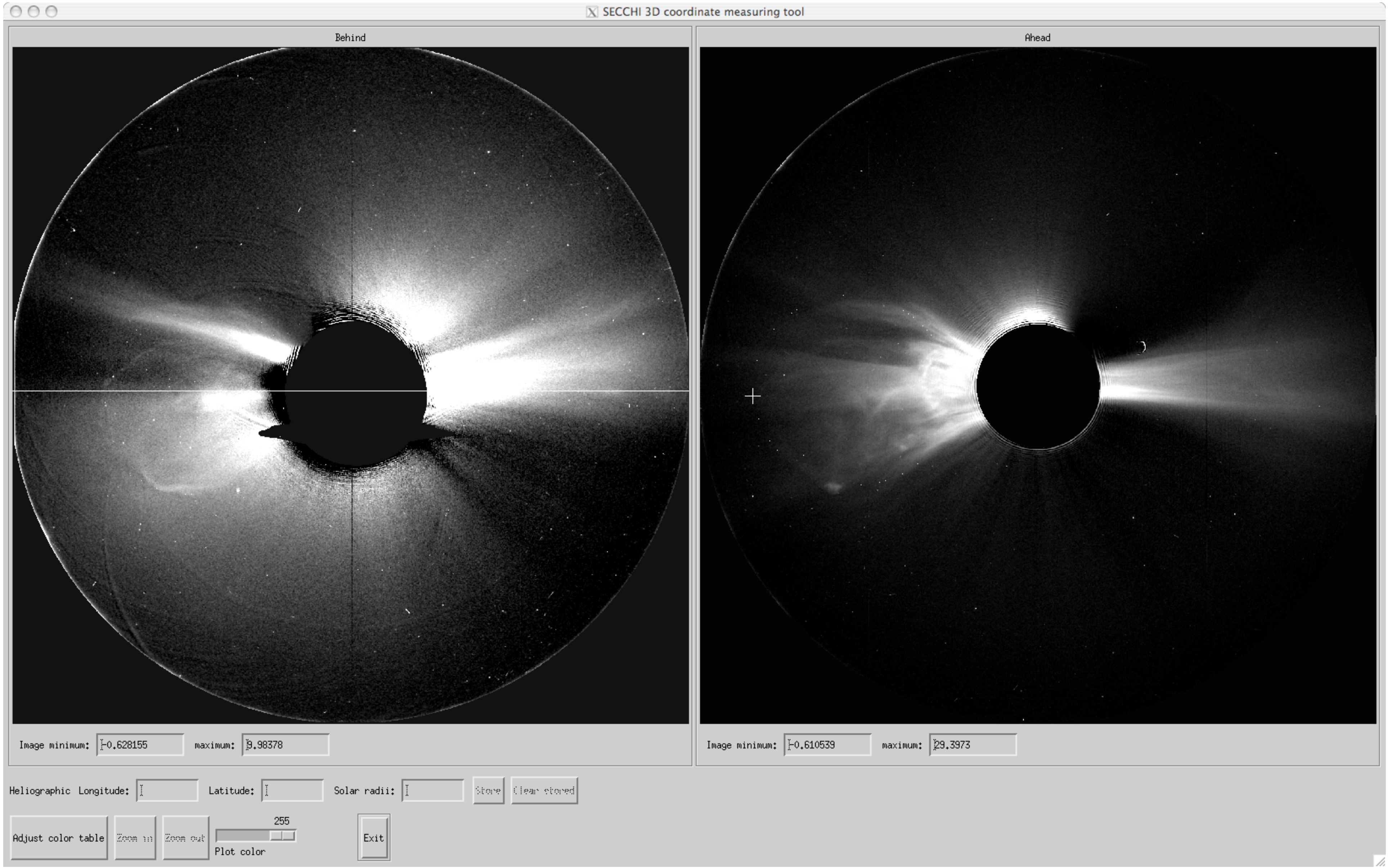
Multiscale Analysis



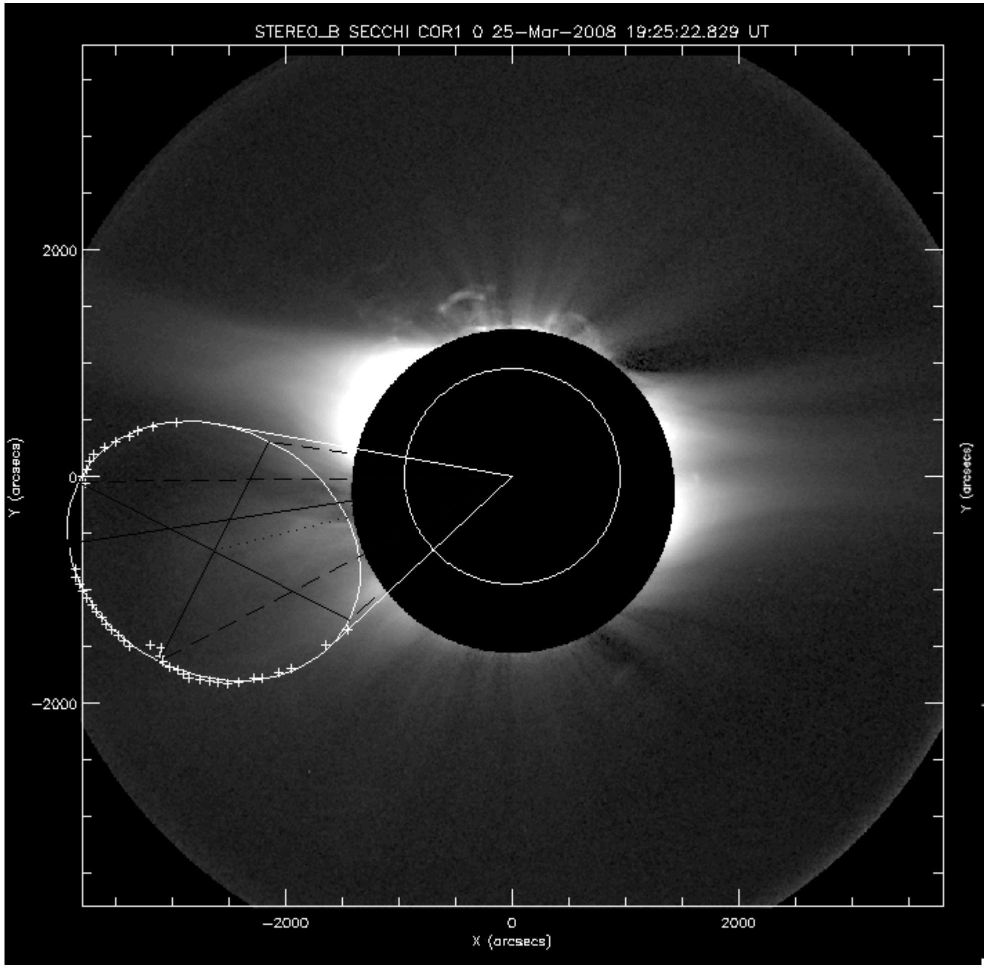
Stereoscopic Analysis

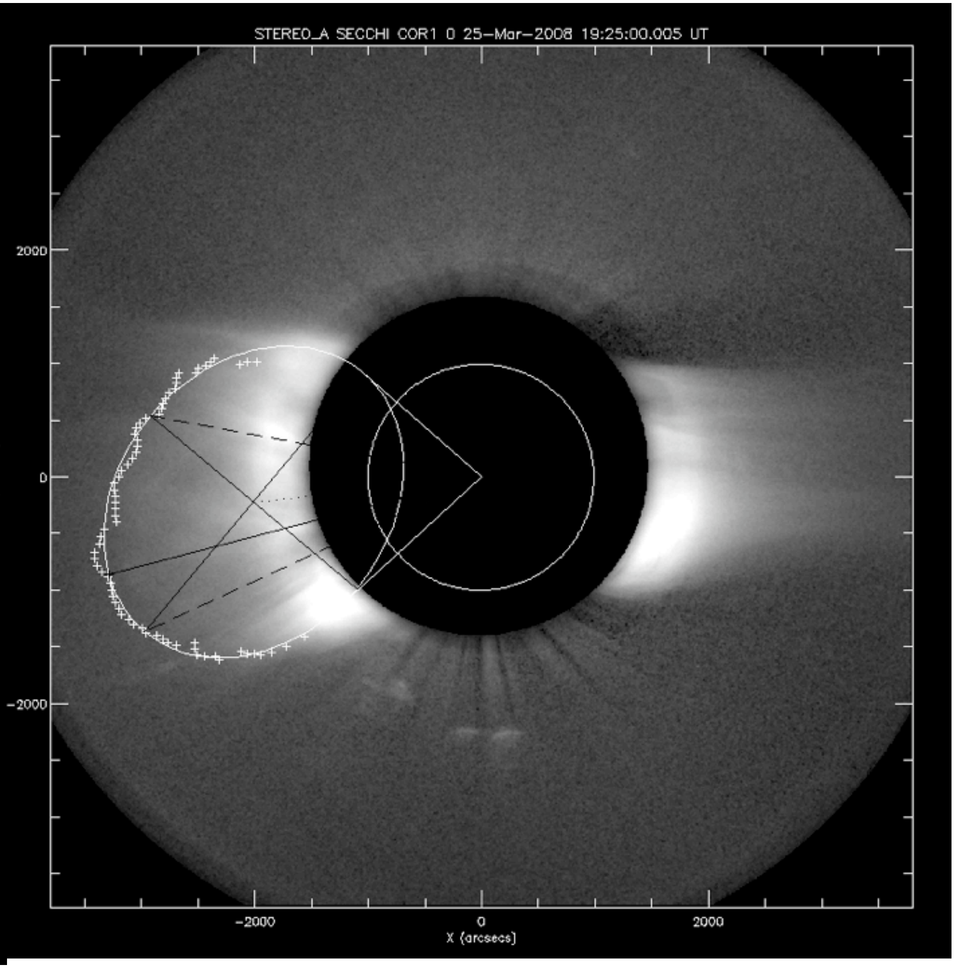


Stereoscopic Analysis



Stereoscopic Analysis



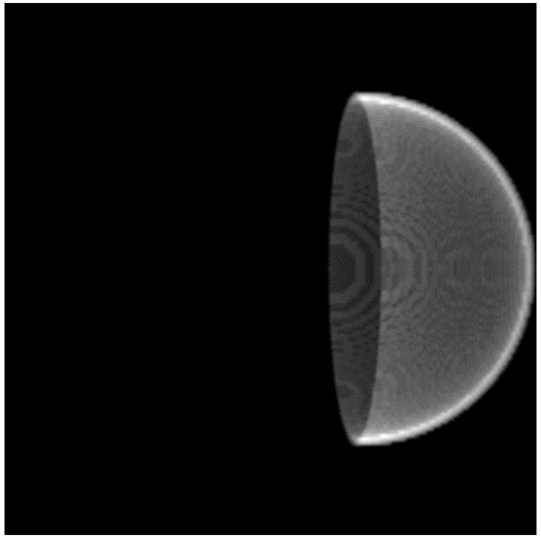


STEREO-B

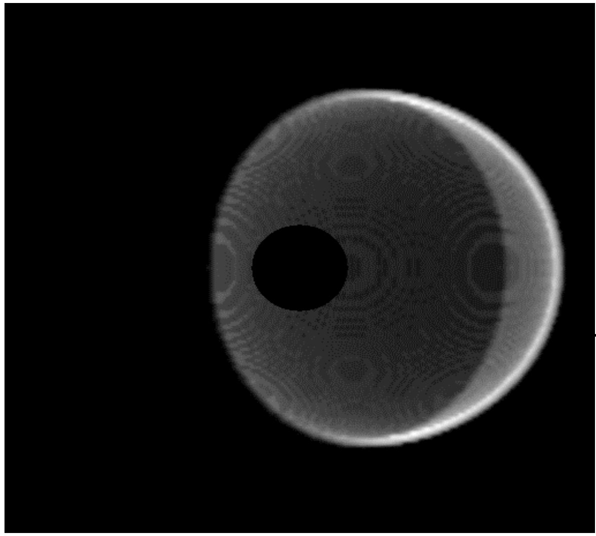
STEREO-A

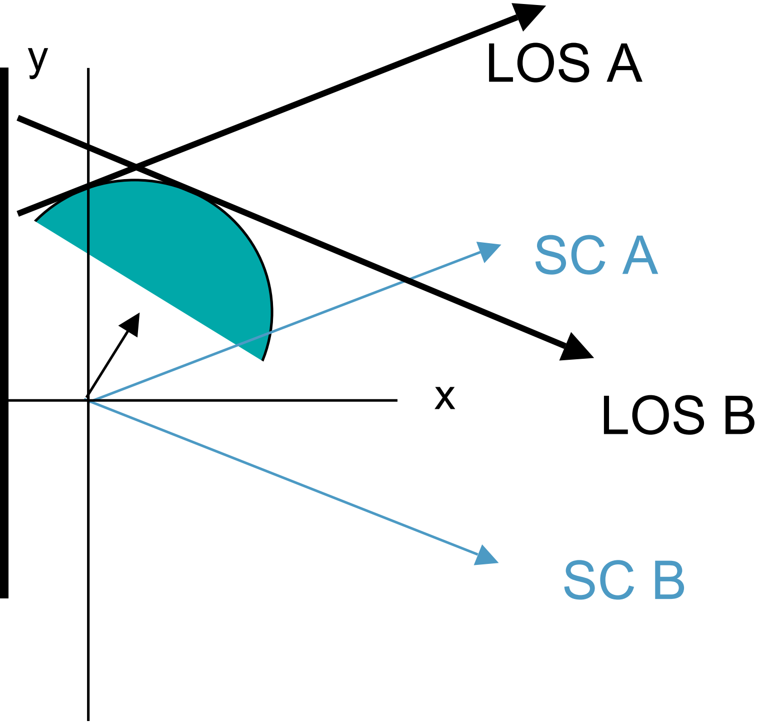
Stereoscopic Analysis

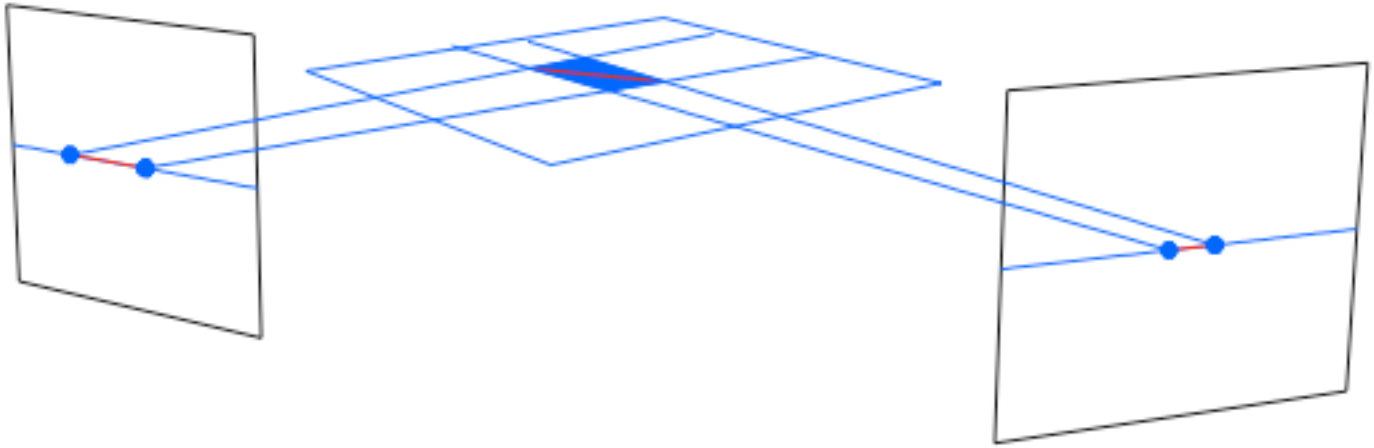
COR2 - SC B at -20°



COR2 - SC A at +20°







Stereoscopic Analysis

Inscribing an ellipse in a quadrilateral such that it is tangent to each of the four sides…

Theorem 1: 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.

Theorem 2: Let Đ be a convex quadrilateral in the xy plane. Let M_1 and M_2 be the midpoints of the diagonals of Đ. If E is an ellipse inscribed in Đ, then the center of E must lie on the open line segment, Z, connecting M_1 and M_2.

Theorem 3: Let Đ be a convex quadrilateral in the xy plane. Then there is a unique ellipse of maximal area inscribed in Đ.

Theorem 4: Let Đ be a convex quadrilateral in the xy plane. Then there is a unique ellipse of minimal eccentricity inscribed in Đ.

Stereoscopic Analysis

4.1. **Algorithm.** To find the ellipse of minimal eccentricity, E, inscribed in a convex quadrilateral Đ with no parallel sides, one does the following:

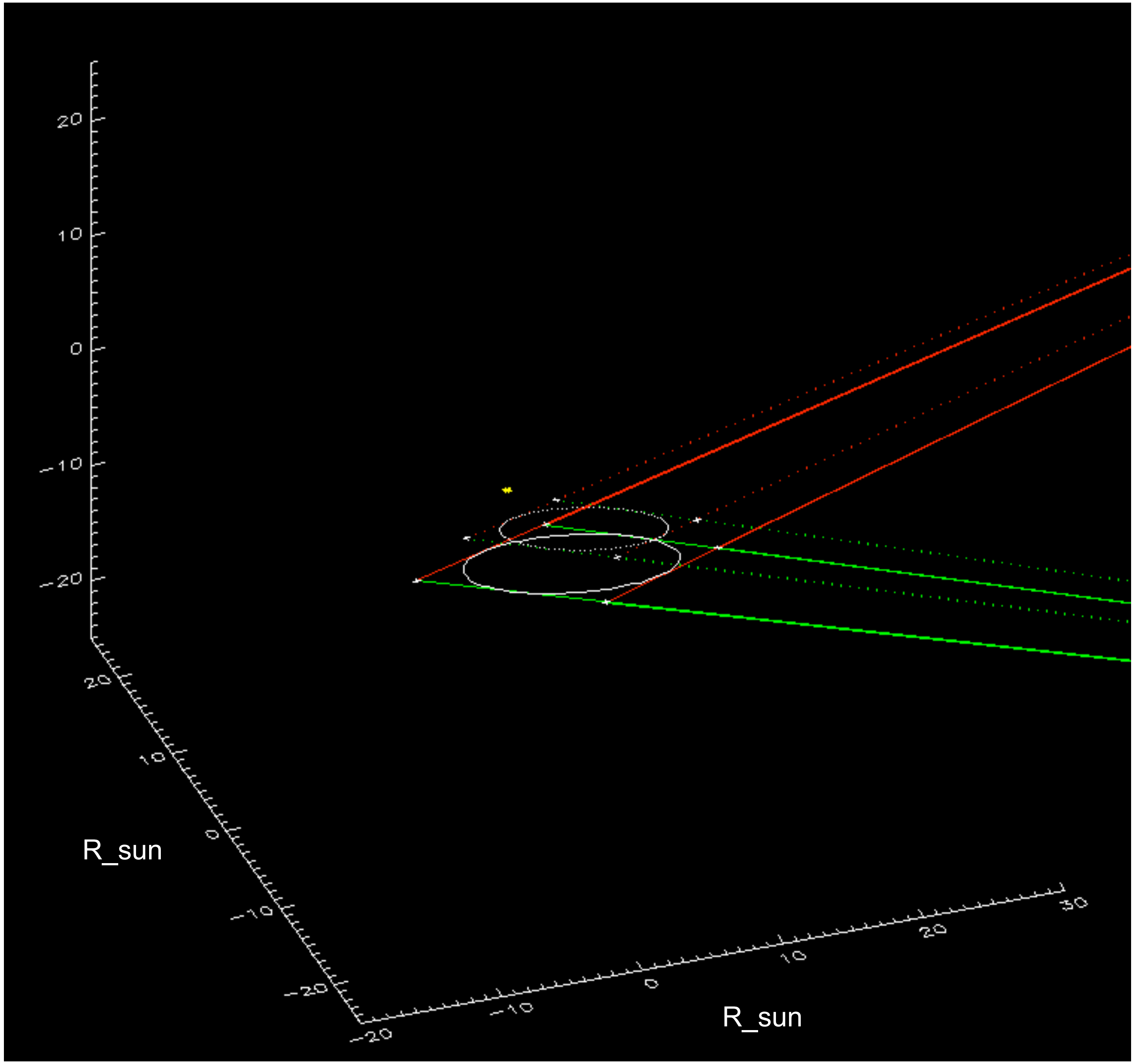
- Use an isometry of the plane so that Đ has vertices $(0,0), (0,C), (A,B)$, and (s,t), where $s > 0, A > 0, C > 0$ and $t > B$.
- Use (4.9) and (4.10) to find the quartic polynomial $u(h) = (r_1(h))^2 + (r_2(h))^2$
- Use (4.12) to find the sixth degree polynomial $N(h) = u(h)S'(h) - S(h)u'(h)$
- Factor $N(h) = M(h)q(h)$
- The x coordinate of the center of E is the unique root, h_0, in I of the quartic polynomial M. The y coordinate of the center of E is $\frac{1}{2}t + \frac{B+C-t}{A-s}\left(h_0 - \frac{1}{2}s\right)$. One could also skip the previous step and take h_0 to be the unique root in I of the sixth degree polynomial N.
- The foci of E are the roots of the polynomial $p_{h_0}(z)$ given in (4.8)
- The length of the major axis of E is $2a$, where $a^2 = \frac{1}{2}\left(R + \sqrt{R^2 + 4W}\right)$, $R^2 = \frac{1}{16(s-A)^4}u(h_0)$, and $W = \frac{1}{4}\frac{C}{(s-A)^2}S(h_0)$.

…so to simplify I take the midpoint of Z as my ellipse centre point, determine quantitatively the axes lengths from theorems above, then iteratively float the ellipse tilt to best fit inside the quadrilateral.

Stereoscopic Analysis

Steps:

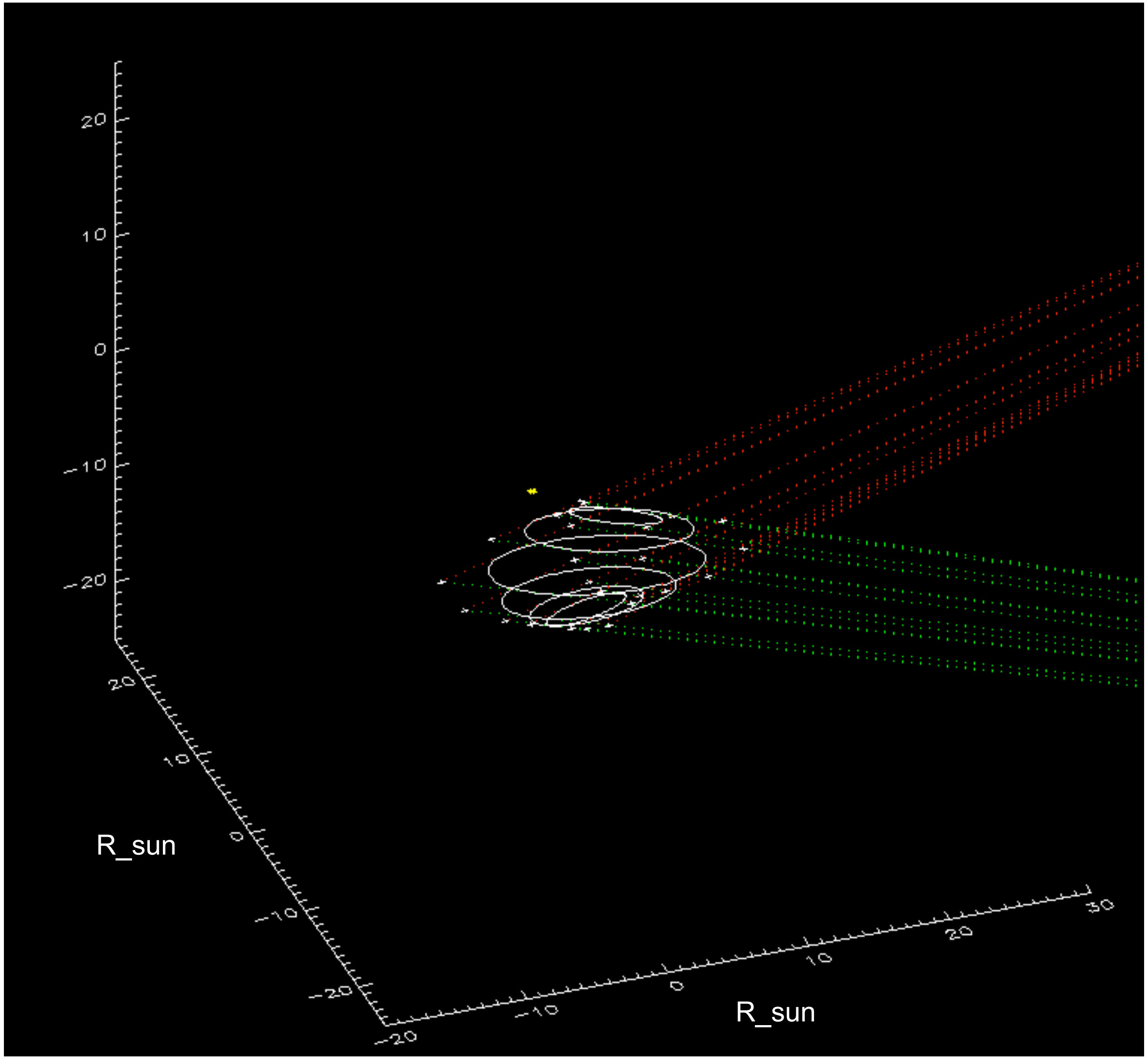
1. Epipolar slice
2. Quadrilateral
3. Isometry
4. Inscribe ellipse
5. Back transform
6. And repeat!



Stereoscopic Analysis

Steps:

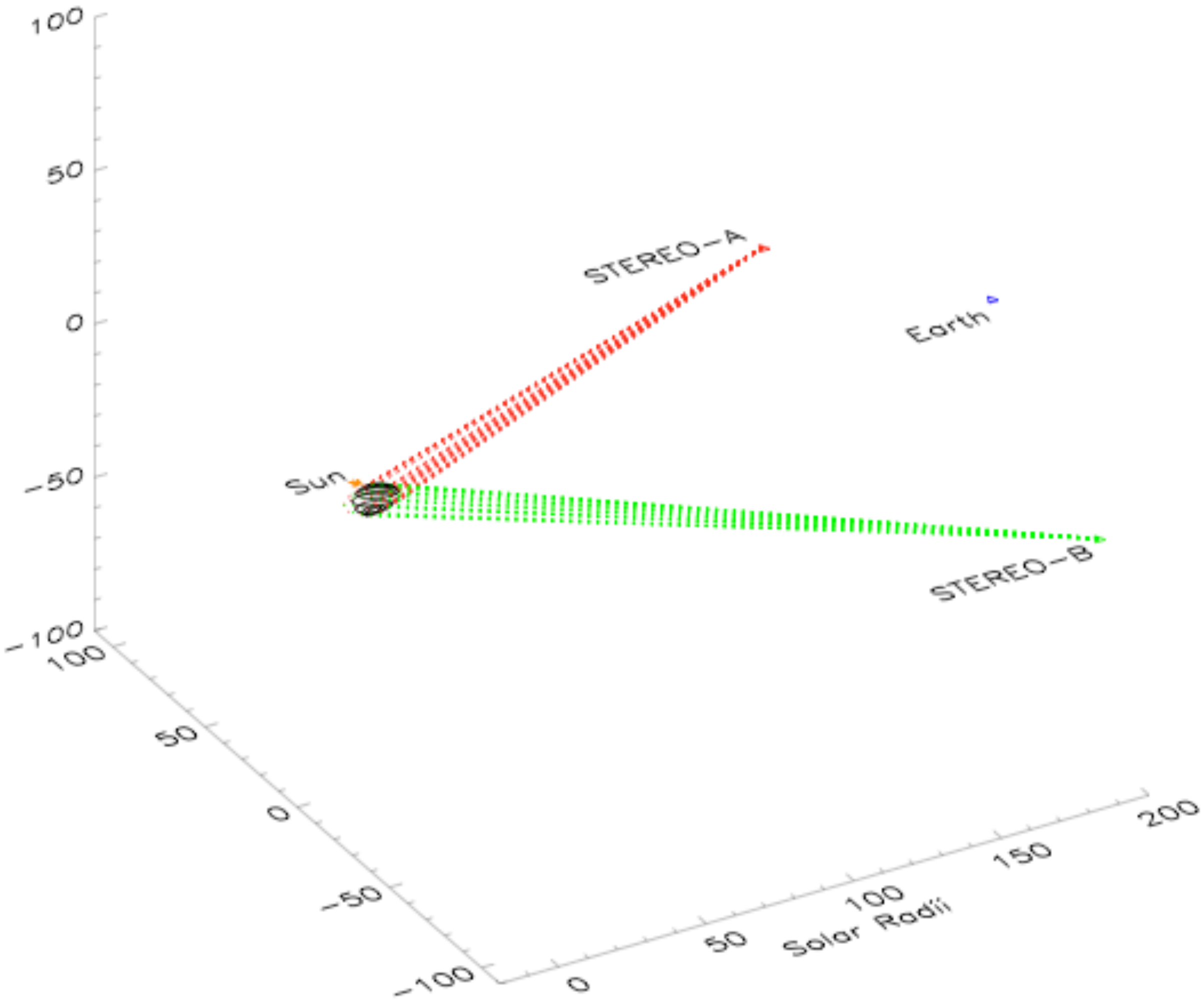
1. Epipolar slice
2. Quadrilateral
3. Isometry
4. Inscribe ellipse
5. Back transform
6. And repeat!



Stereoscopic Analysis

Steps:

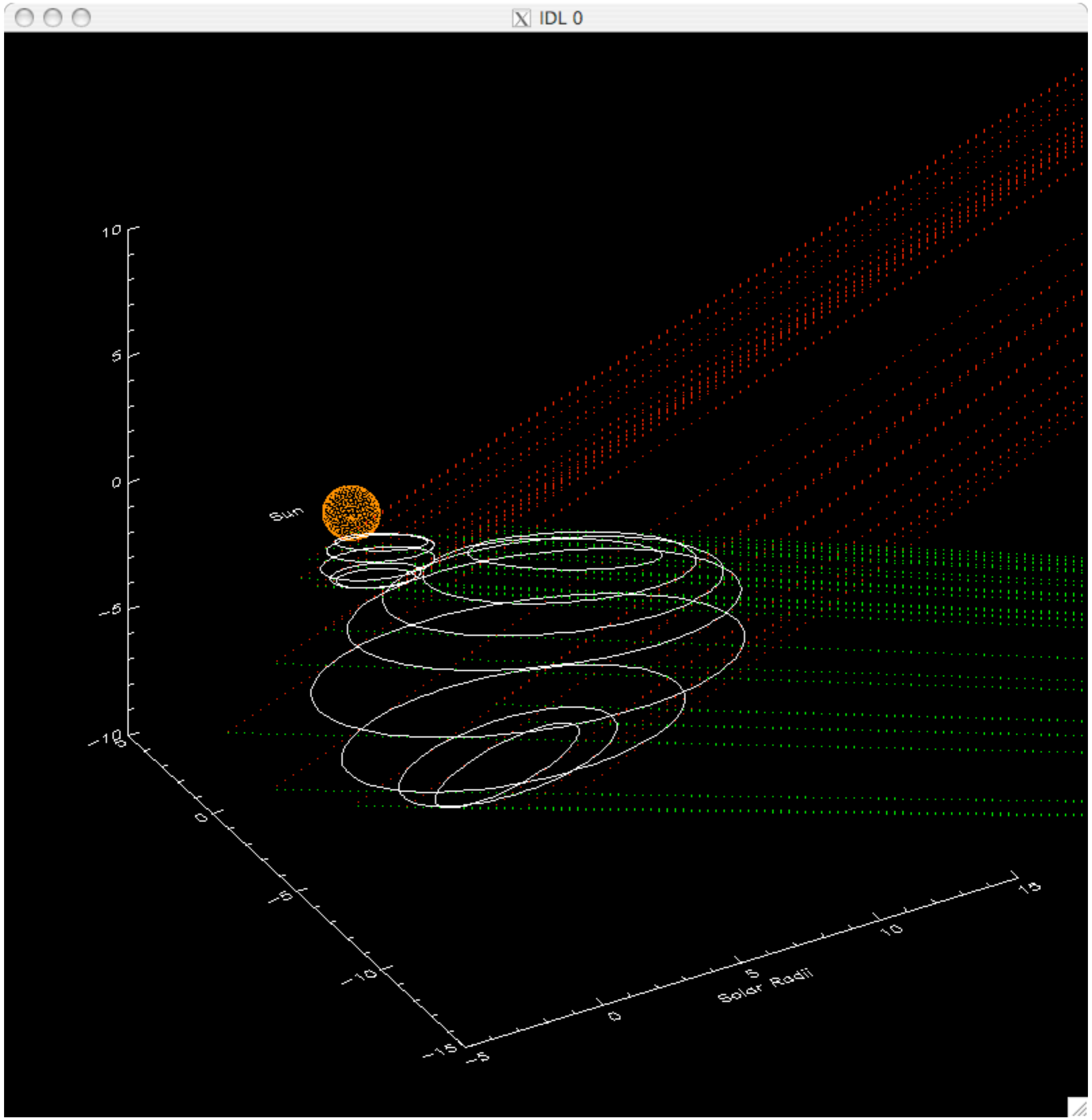
1. Epipolar slice
2. Quadrilateral
3. Isometry
4. Inscribe ellipse
5. Back transform
6. And repeat!



Stereoscopic Analysis

Steps:

1. Epipolar slice
2. Quadrilateral
3. Isometry
4. Inscribe ellipse
5. Back transform
6. And repeat!



Next Steps…

CME’s “true” properties:

1. Source region - true trajectory, deflection.
2. Kinematics - correcting for projection effects.
3. Morphology - structure, expansion.
4. Mass - energy, space weather implications.
5. EUVI (waves?) <--- CORs ---> HI (drag forces?)