ADVANCED IMAGE PROCESSING FOR STEREO

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STEREO SWG - Pasadena, CA - Feb. 2009

We are developing **advanced image processing methods** to extract the evolving **morphology and kinematics of CMEs** and to **compare** these results **with** as yet unconfirmed predictions of **theory**.

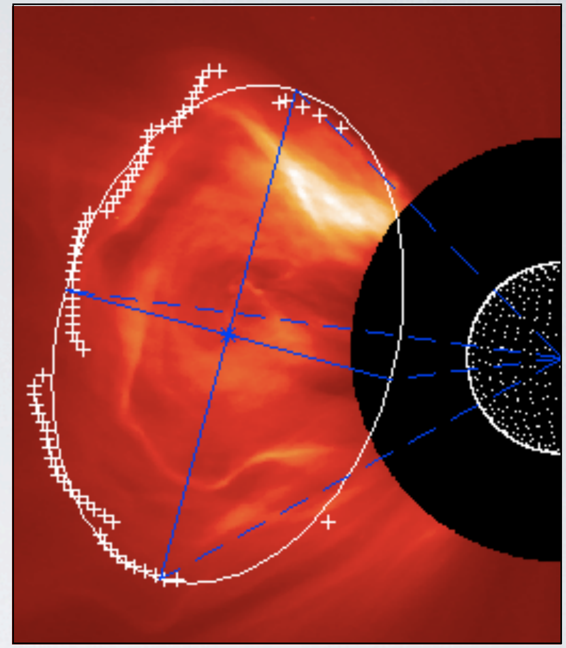
OVERVIEW

- Motivation
- CME models
- Multiscale methods

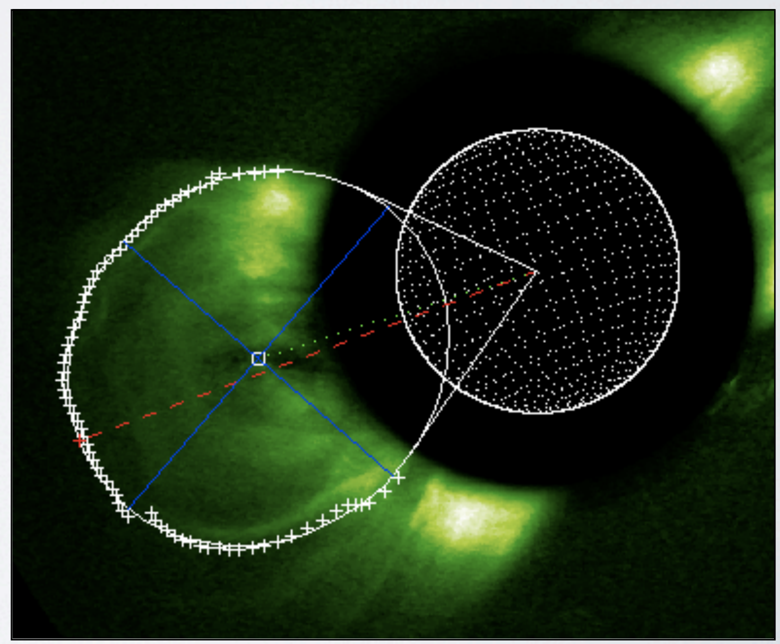
    Background Subtraction

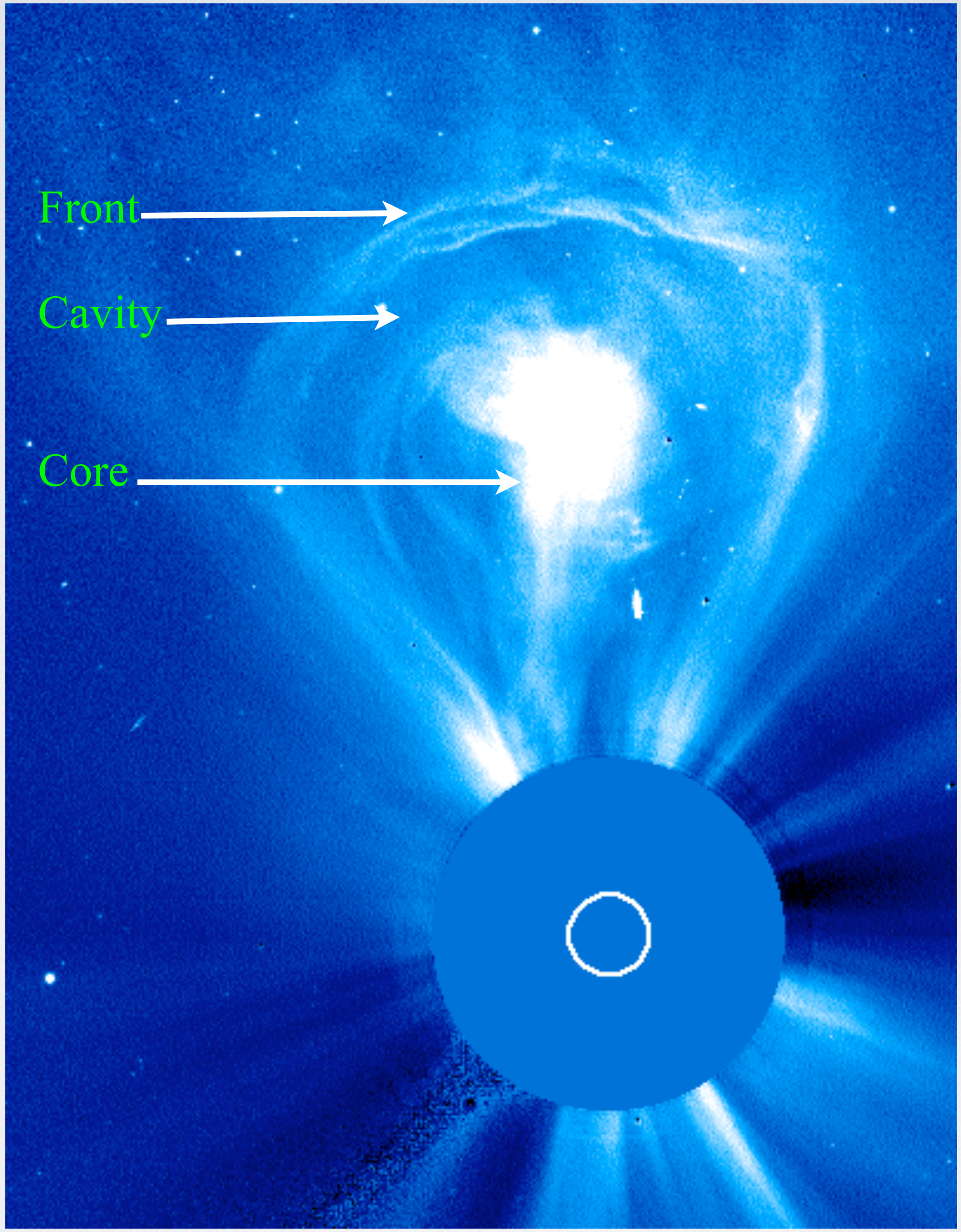
    Edge Detection

- CME Morphology & Kinematics
- Current Work



LASCO/C2 & SECCHI/COR1-A
24-Jan-07




Front
Cavity
Core

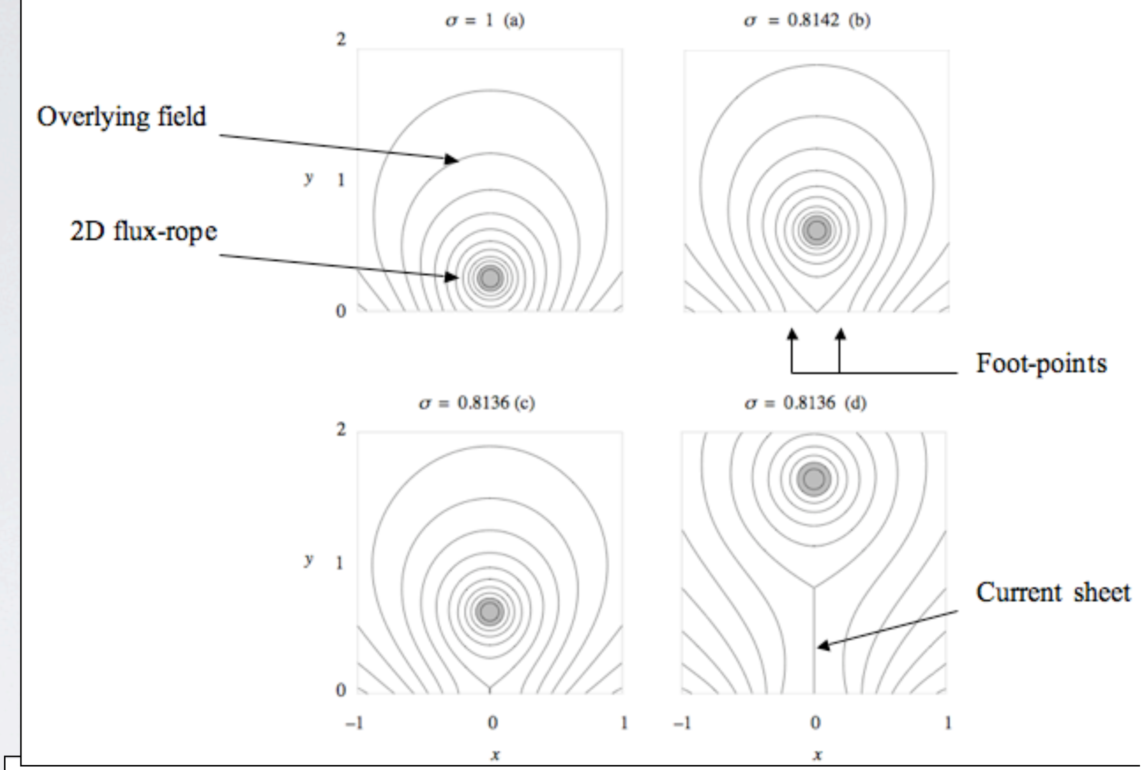
CME MODELS

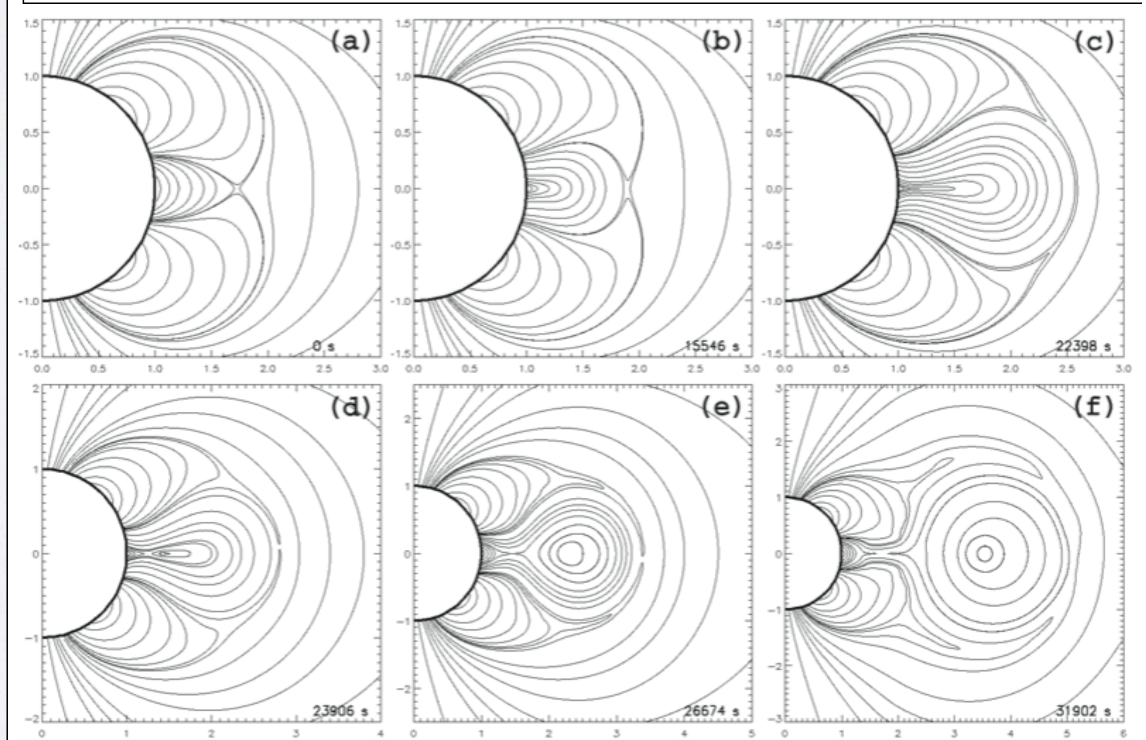
- Magnetic Flux-Rope:

  -*Forbes & Priest, 1990*
  - *Chen & Krall, 2003*

- Magnetic Break-out:

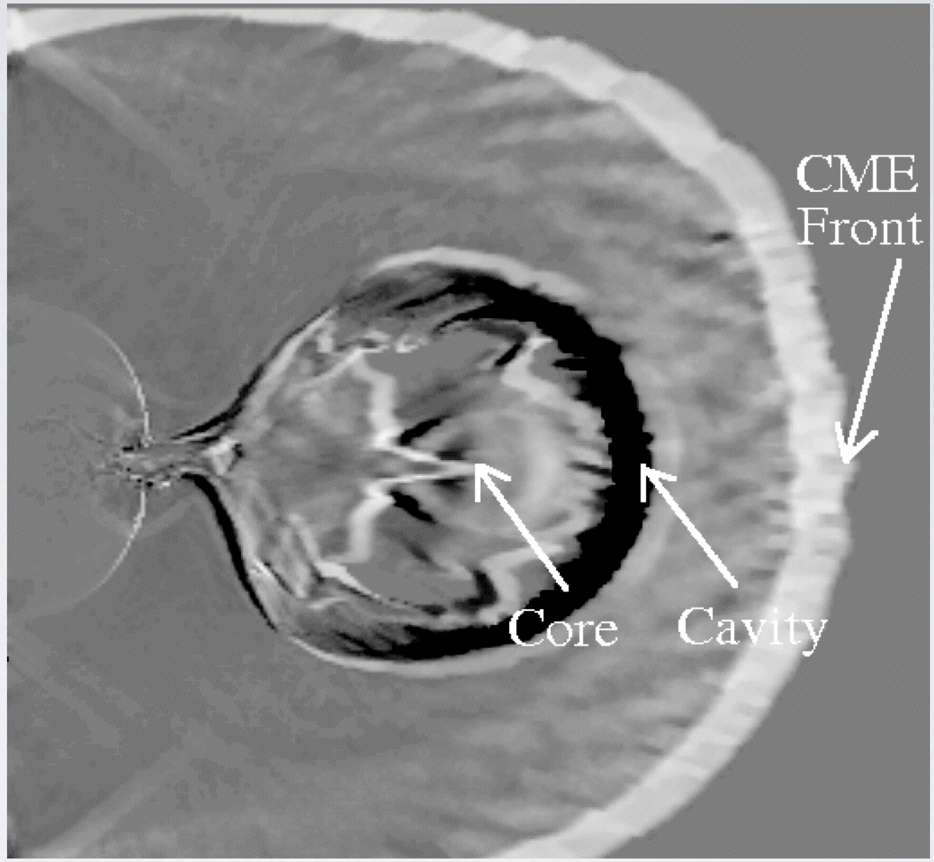
  -*Antiochos et al. 1999*
  - *Lynch et al. 2004*

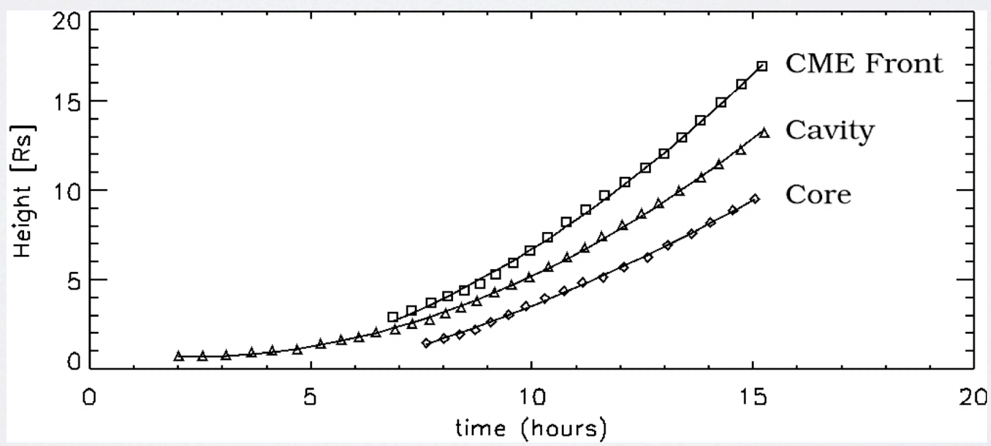




Break-out Simulation:

-Lynch et al. 2006





WHY MULTISCALE?

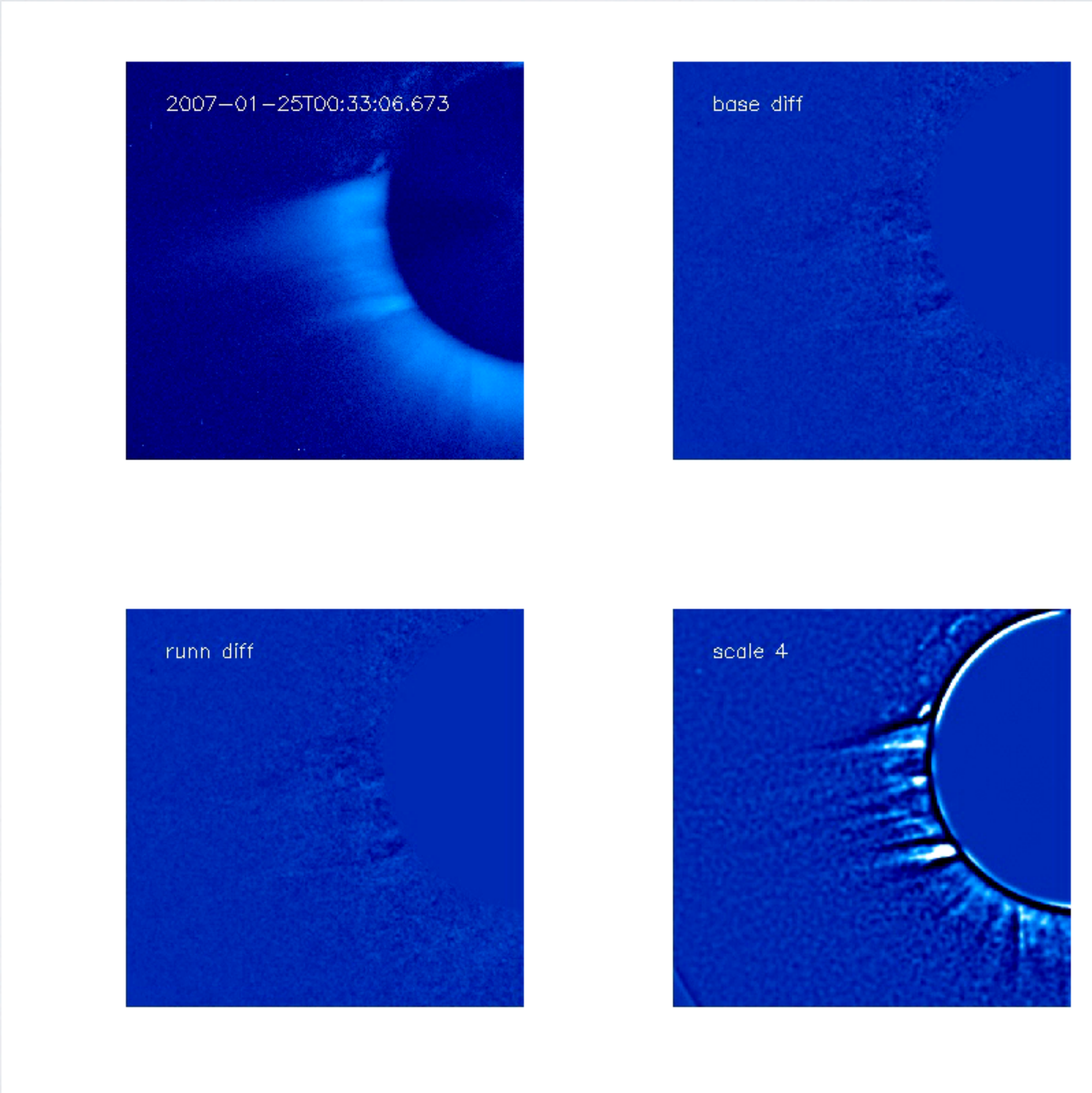
- Computational analysis seeks representations of signals as linear combinations of basis, frame, dictionary, element (i.e. sines, cosines, wavelets, etc.):

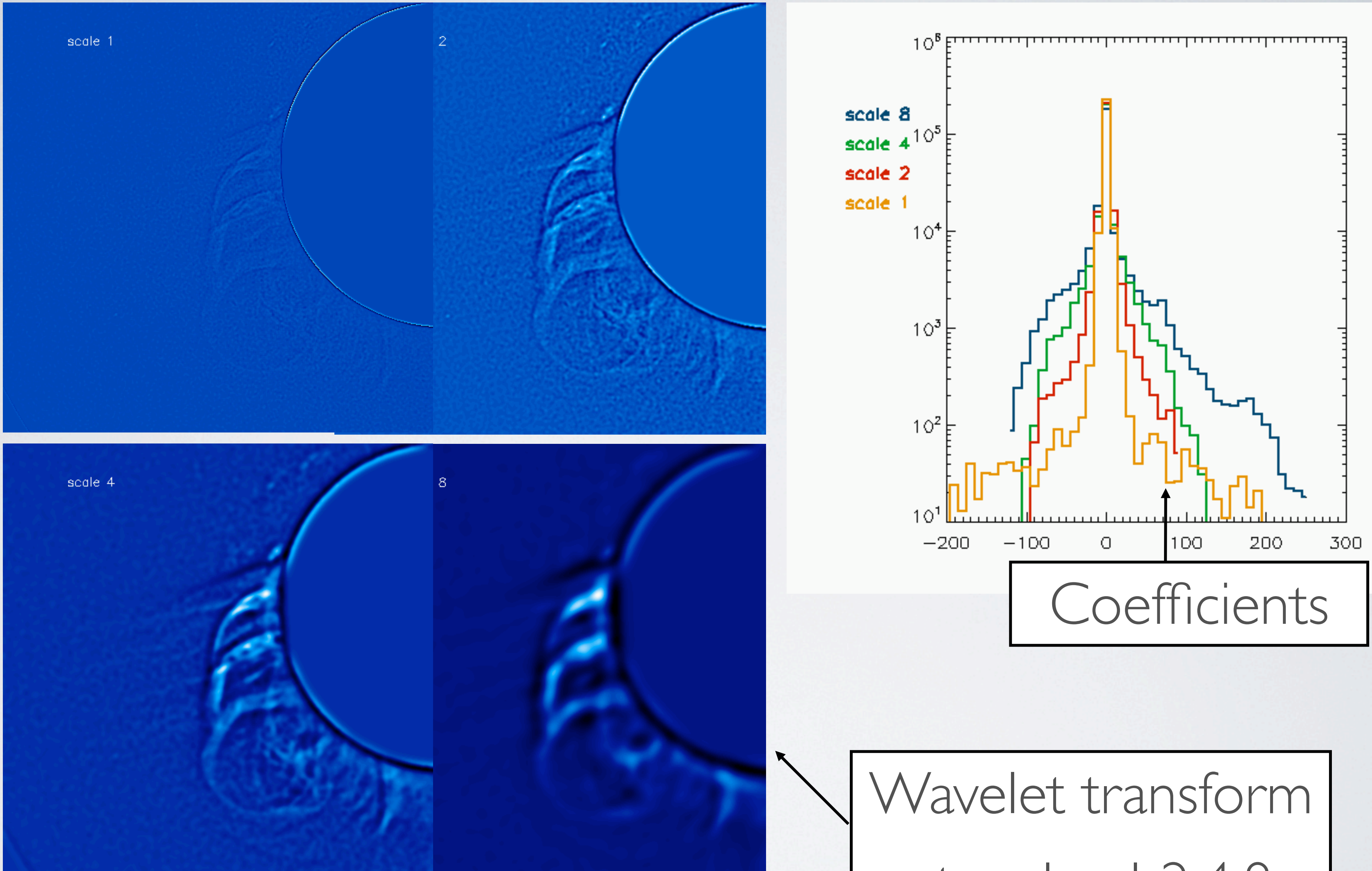
$$f = \sum_k \underbrace{a_k}_{\text{coefficients}} \underbrace{\mathbf{b}_k}_{\text{basis, frame}}$$

- Analysis of the signal is through the statistical properties of the coefficients.
- The analyzing functions (basis, frame elements) should extract features of interest.
- Approximation theory wants to exploit the sparsity of the coefficients.

- Why do we need sparsity?
  - Data compression
  - Feature extraction
  - Feature detection
  - Image restoration (e.g., deconvolution)

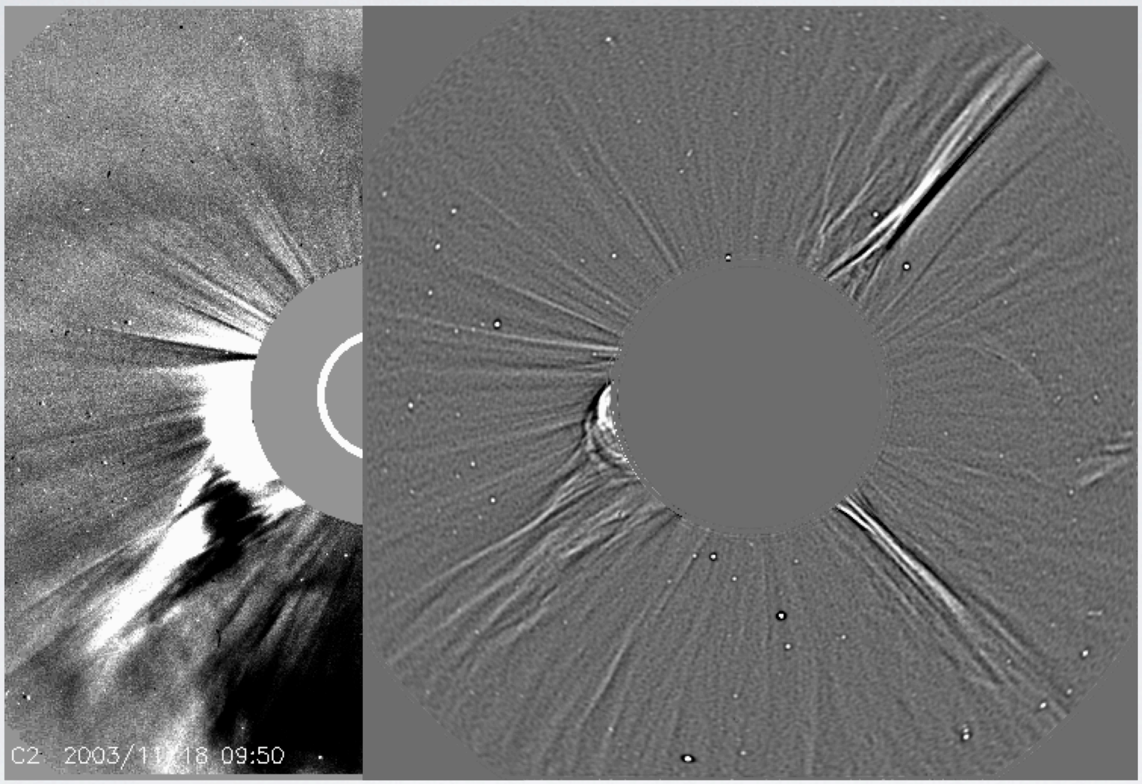
BACKGROUND SUBTRACTION



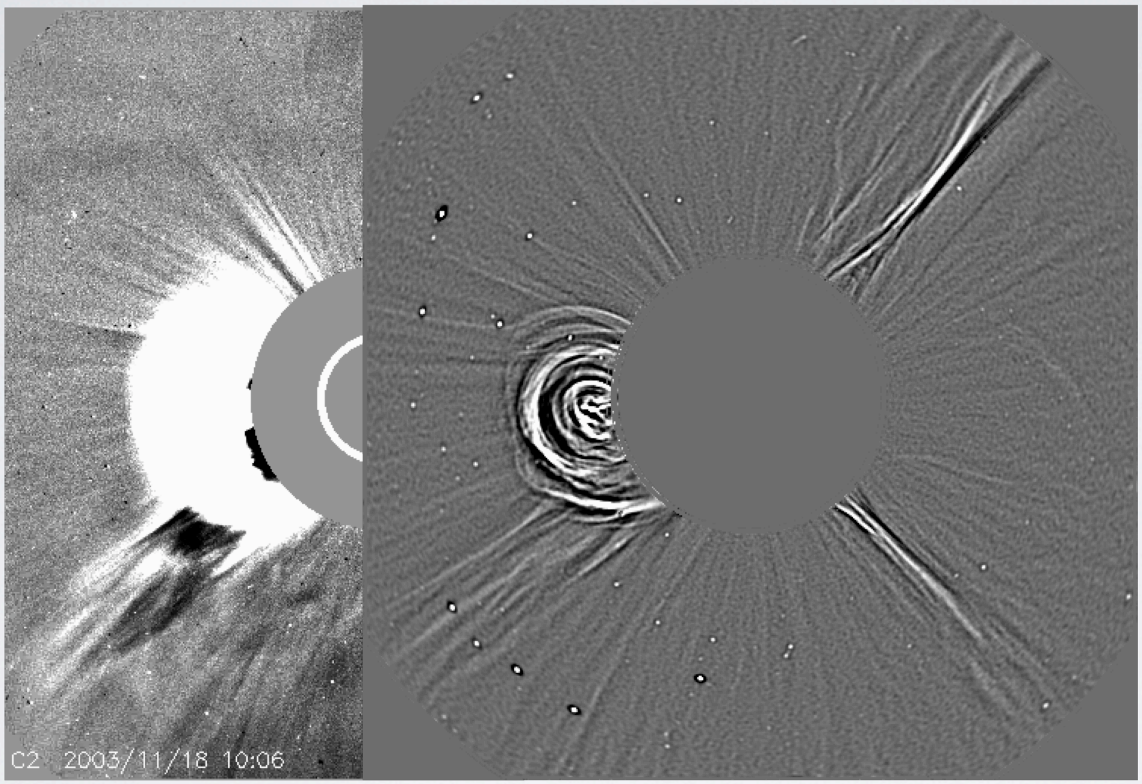


Coefficients

Wavelet transform at scales 1,2,4,8



Stenborg 2003



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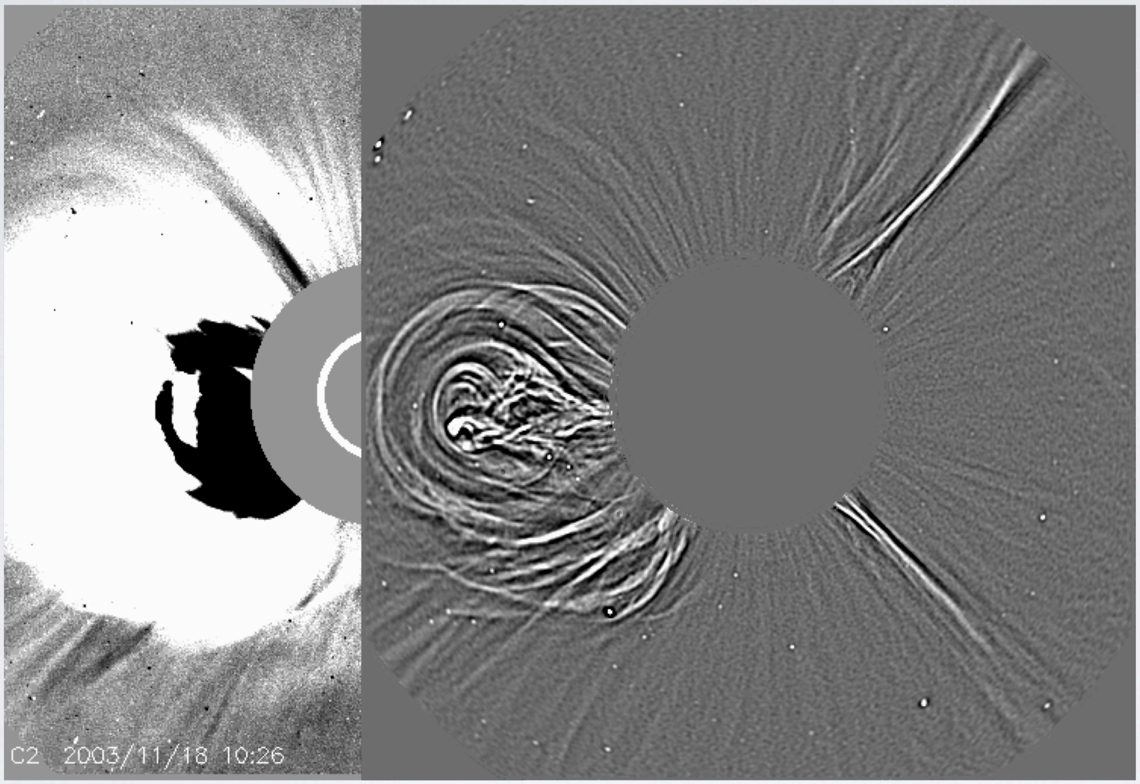

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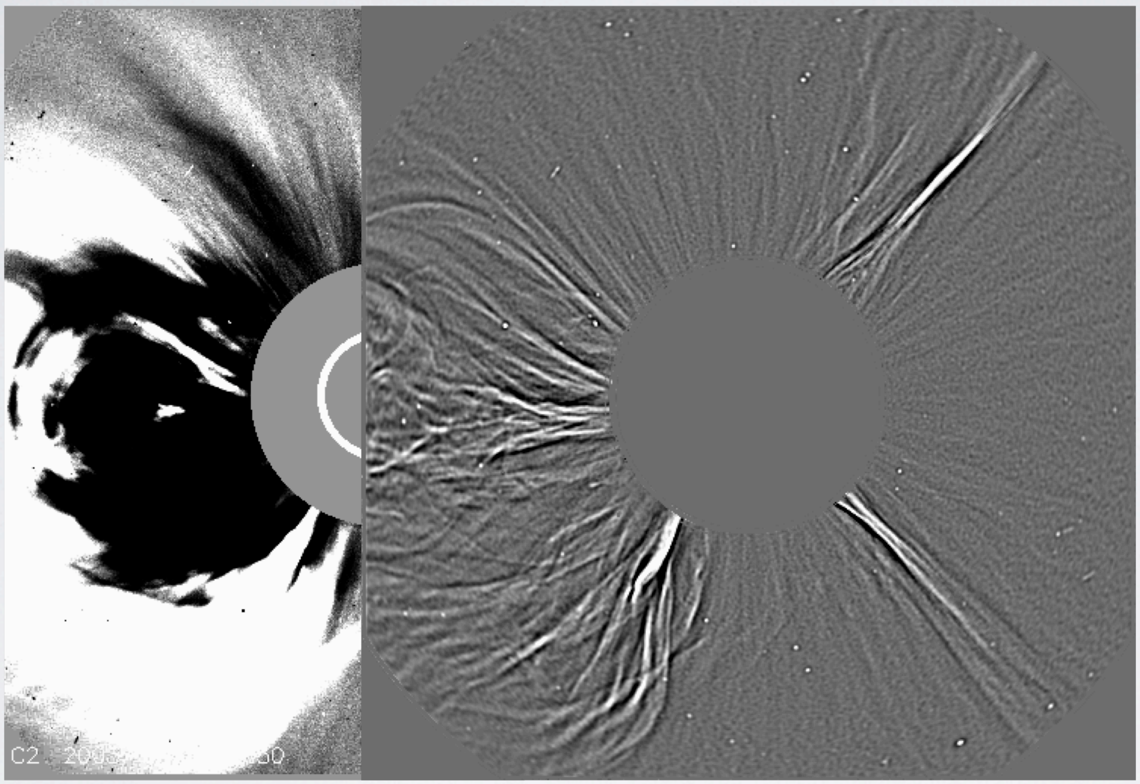
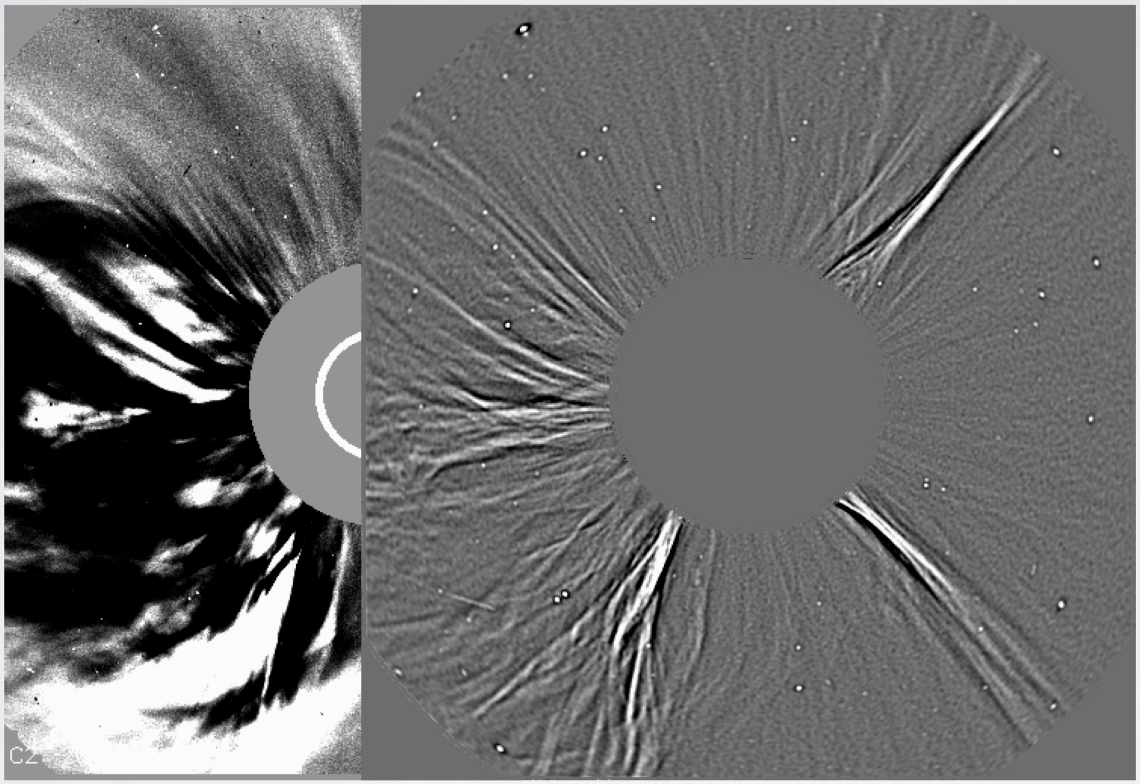
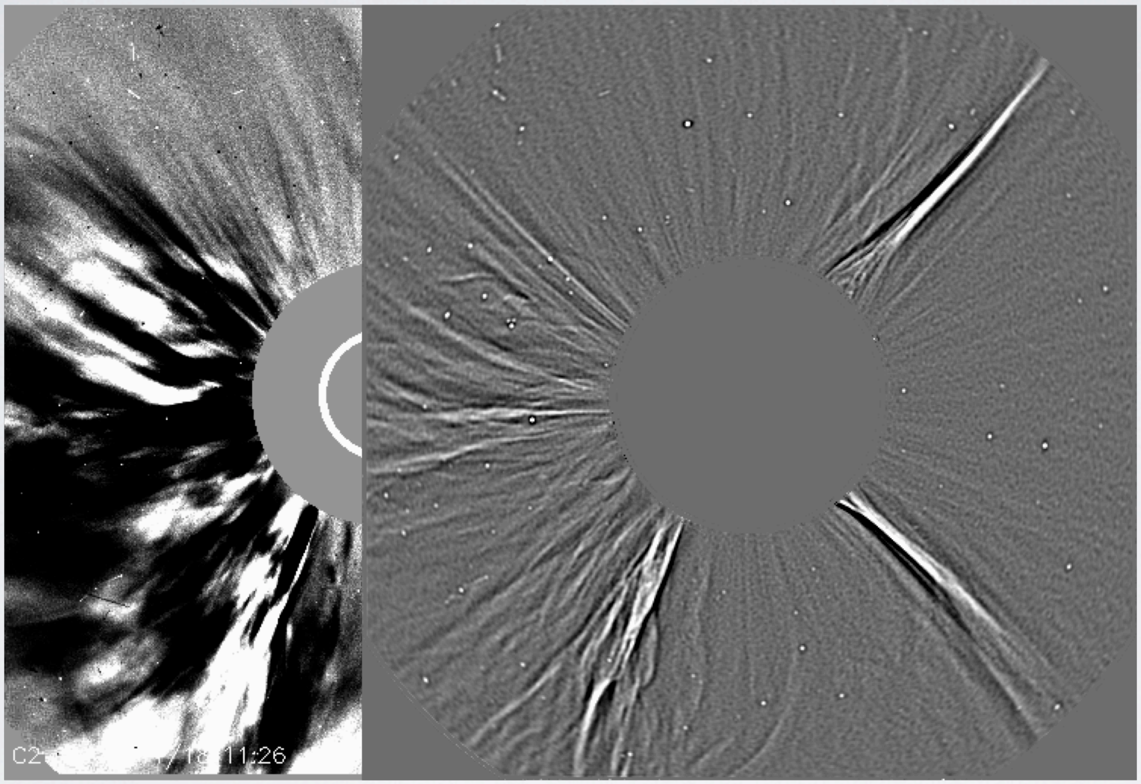


Stenborg 2003



Stenborg 2003



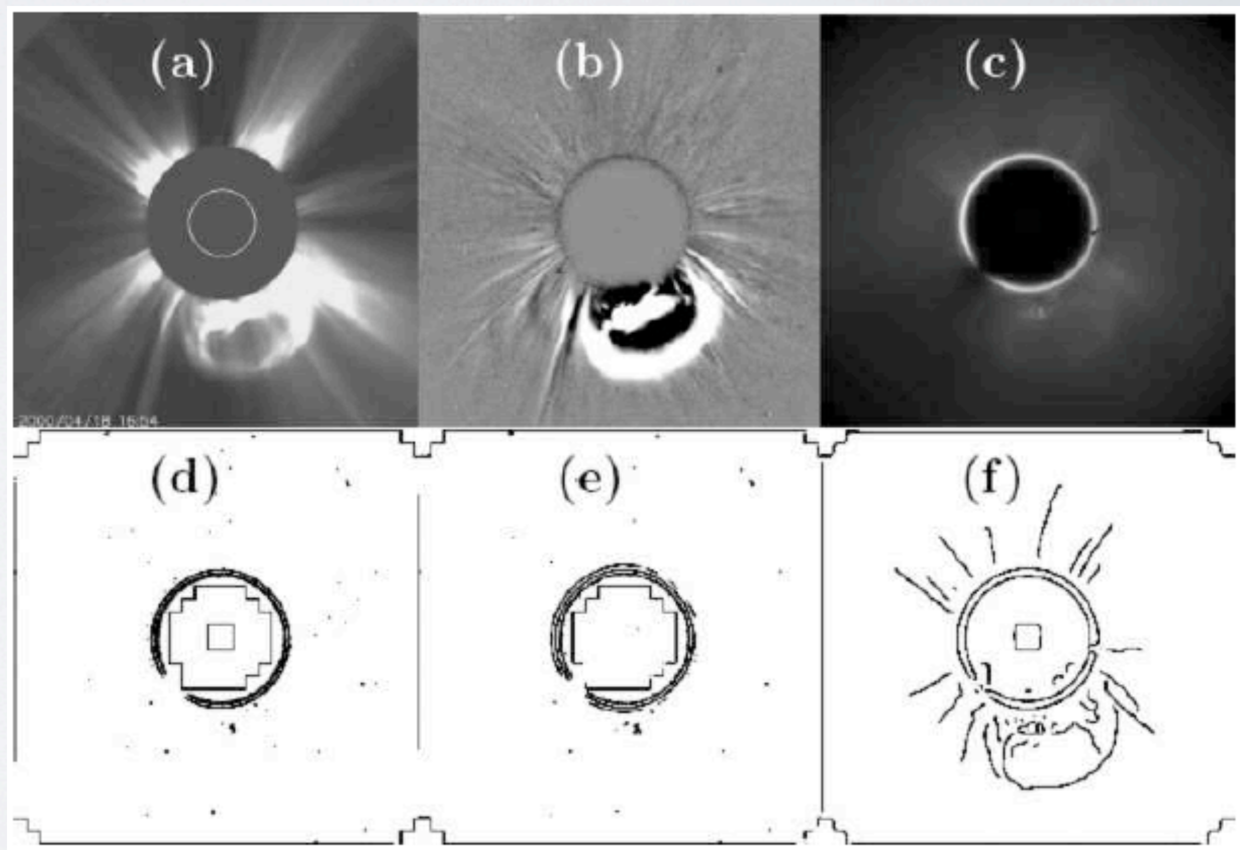
Stenborg 2003

MULTISCALE EDGE DETECTION

Described in "Multiscale Edge Detection in the Corona, Young and Gallagher, Solar Physics, 2008."

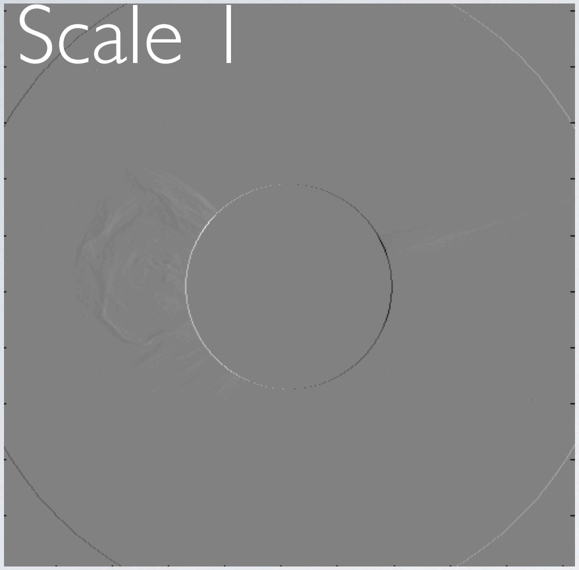
Gradient edge detection

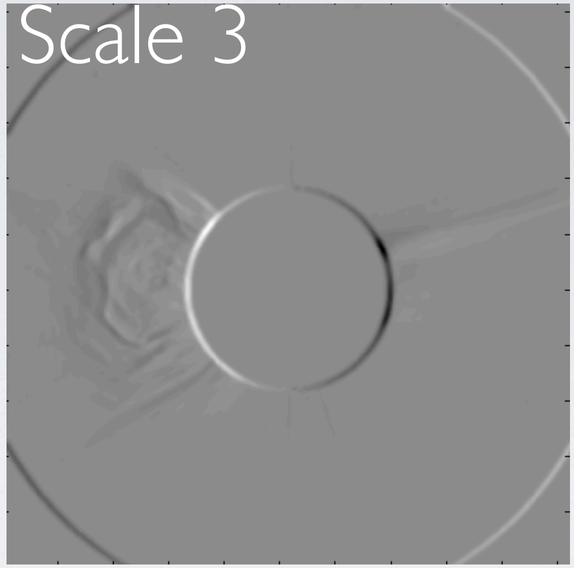
(a) LASCO C2
(b) Running Difference
(c) Raw Image
(d) Roberts
(e) Sobel
(f) MS edge detector

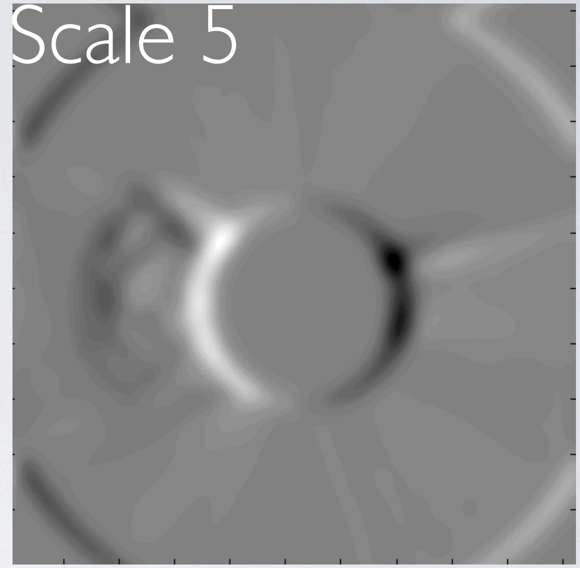


Multiscale Decomposition

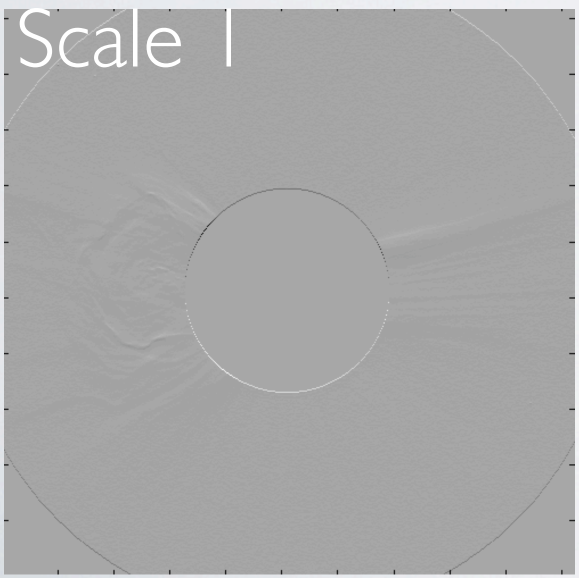
Horizontal Direction:

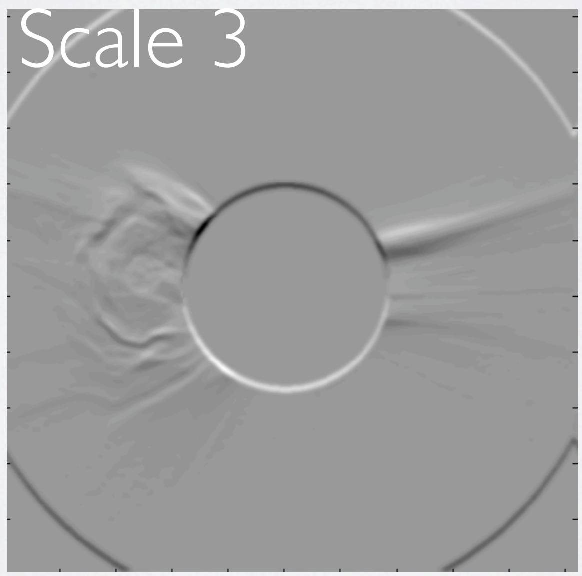


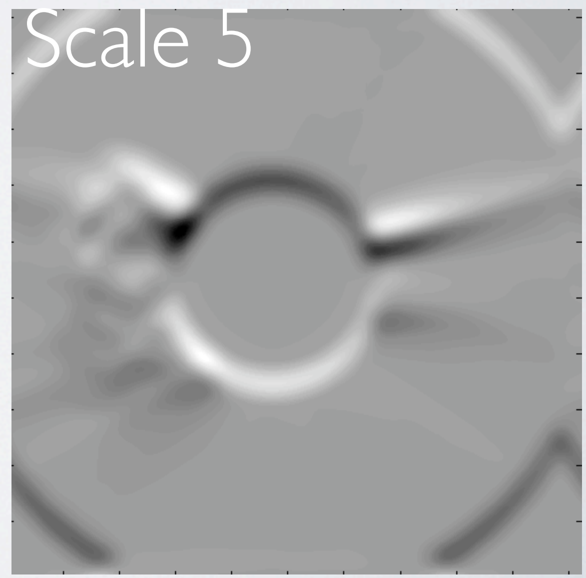




Vertical Direction:





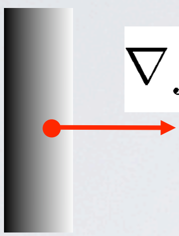


Gradient Space Information

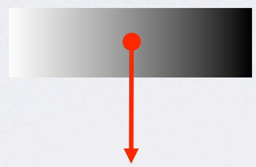
- The gradient of an image:

$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

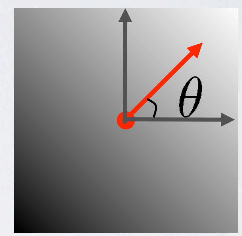
- The gradient points in the direction of most rapid change in intensity



$$\nabla f = \left[\frac{\partial f}{\partial x}, 0\right]$$



$$\nabla f = \left[0, \frac{\partial f}{\partial y}\right]$$



$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

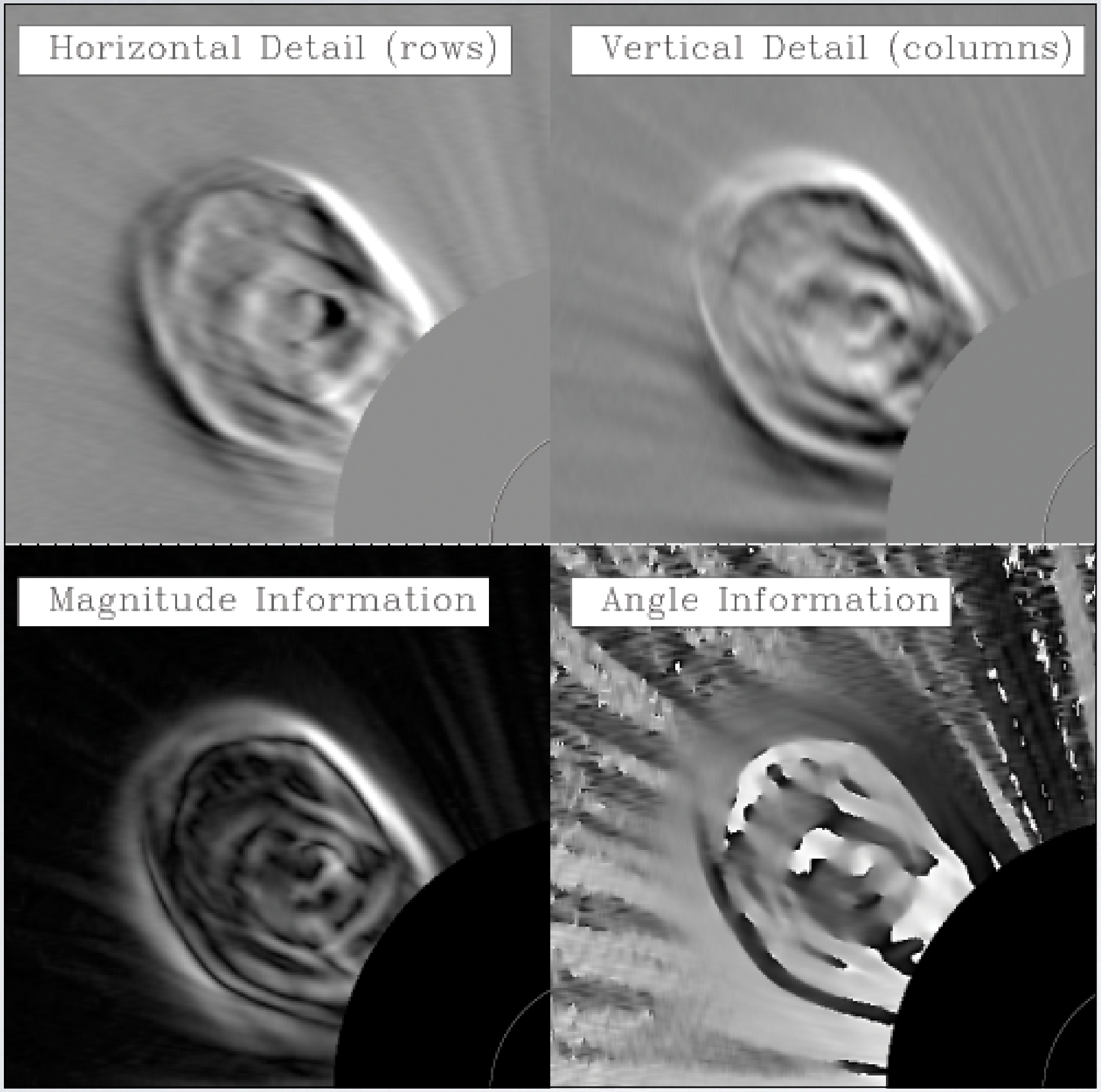
- The gradient direction is given by:

$$\theta = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right)$$

- The *edge strength* is given by the gradient magnitude:

$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

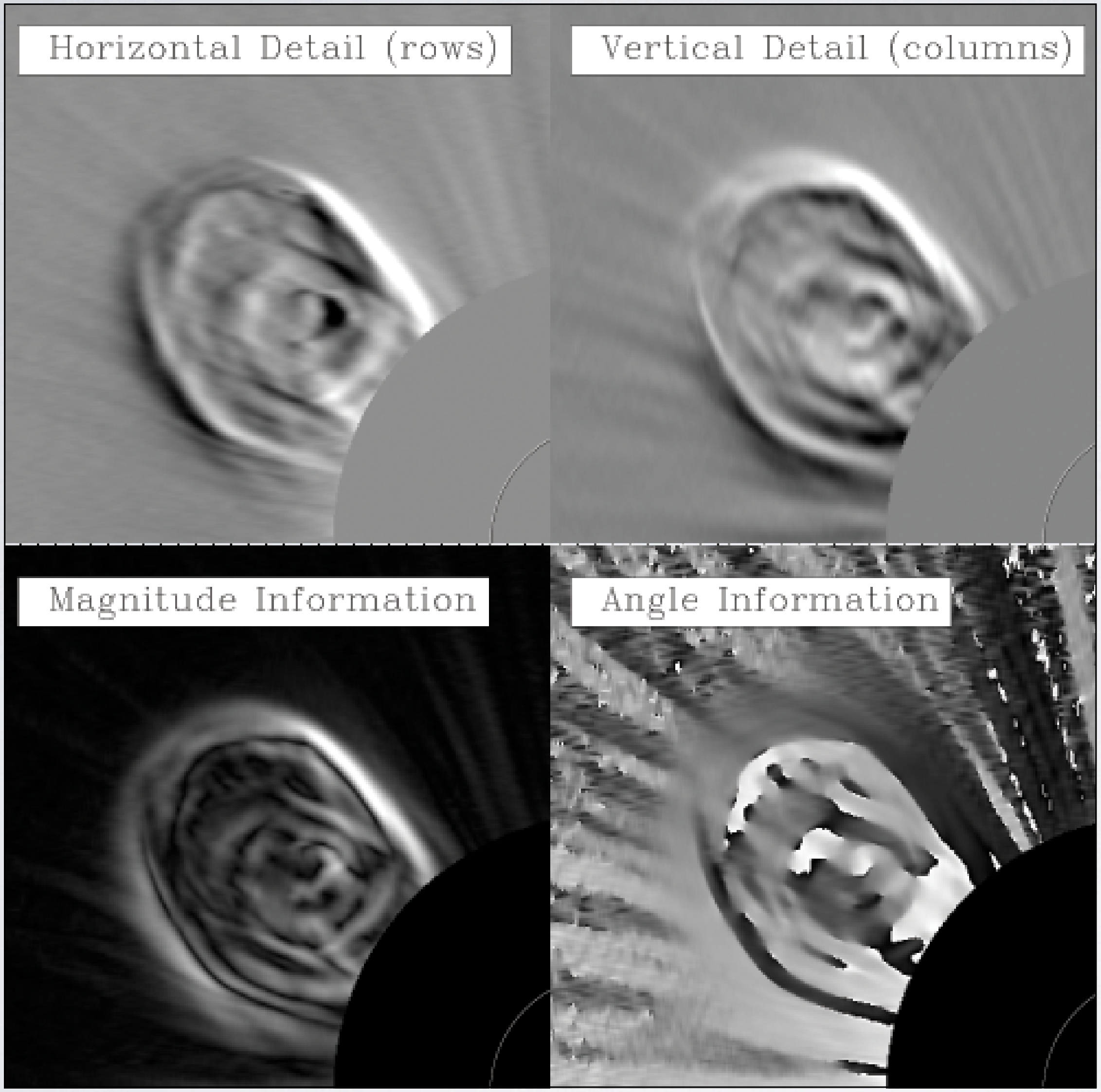
Gradient Space Information



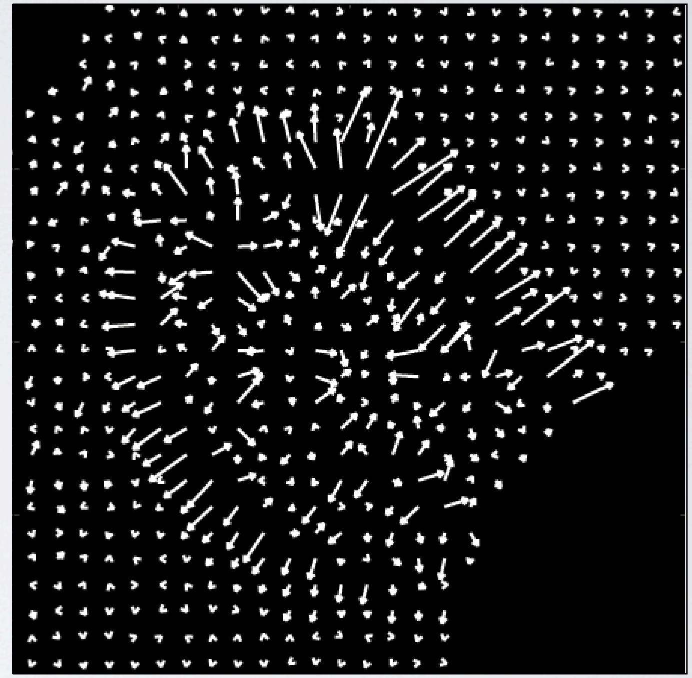
C2 01-Apr-04

Gradient Space Information

Vector-Arrow Field

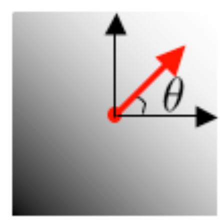


C2 01-Apr-04



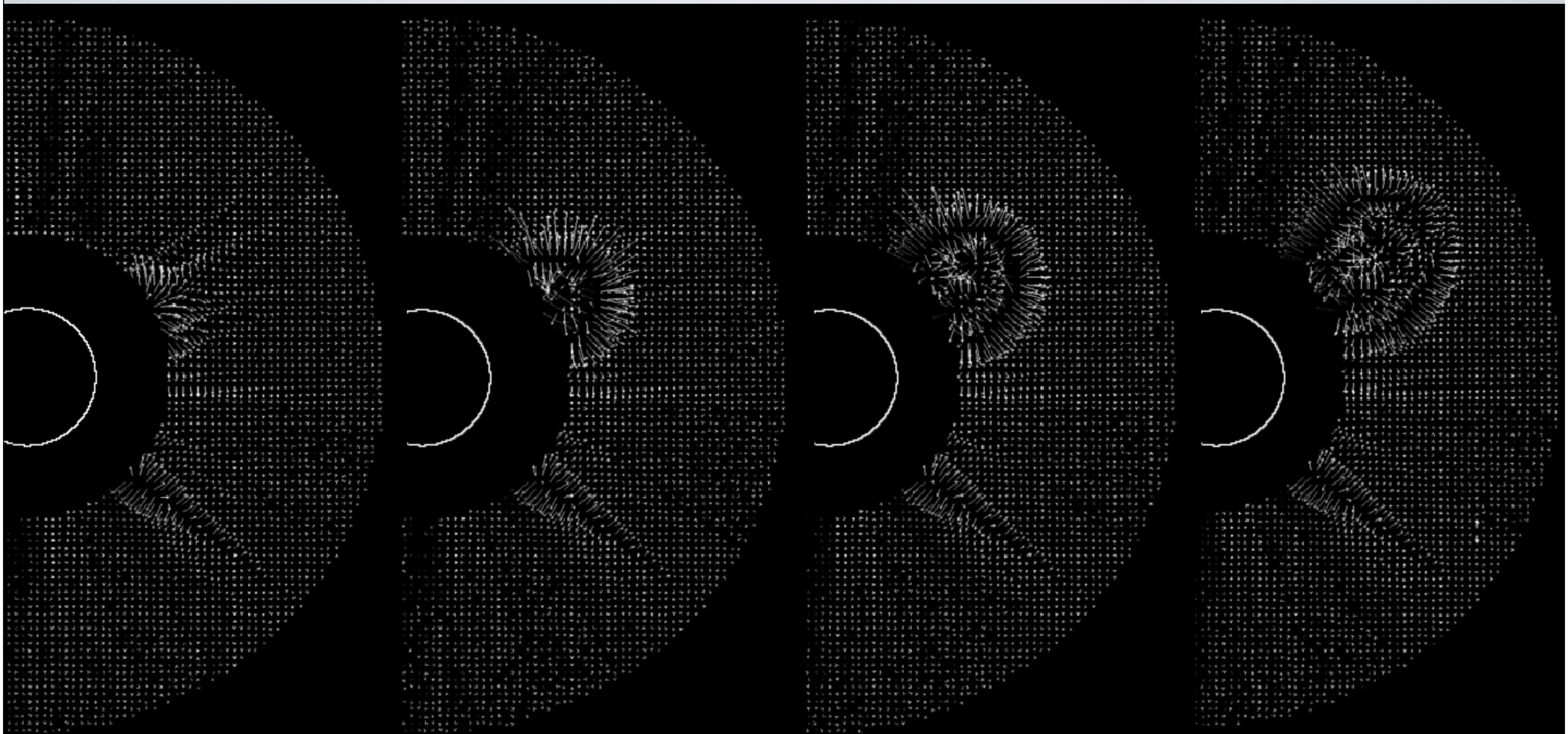
Vectors with magnitude: $\|\nabla f\|$

and inclination angle θ

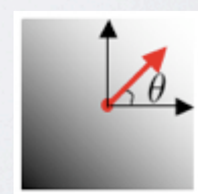


$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

Spatio-Temporal Filter

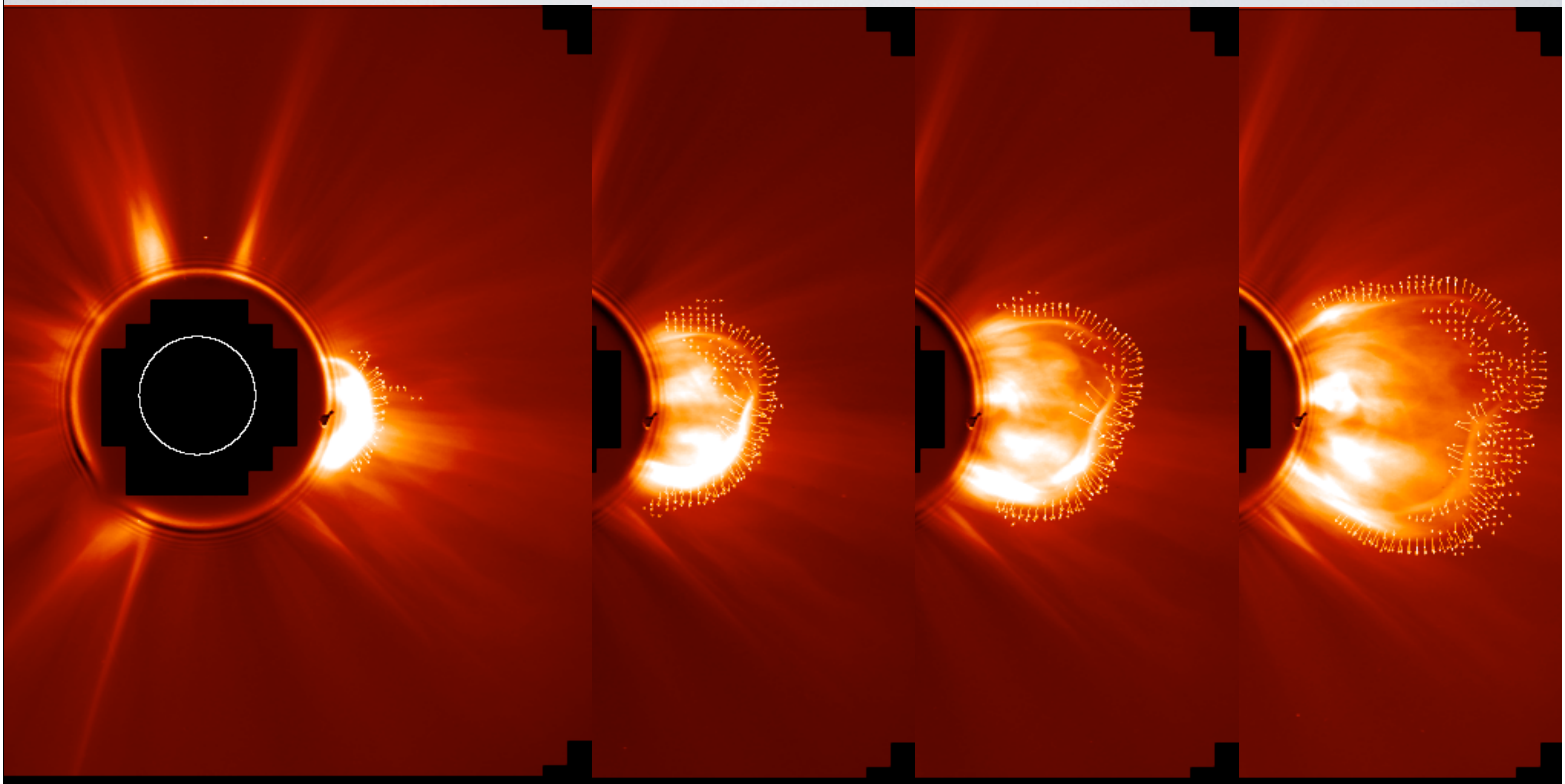


Vector-arrows corresponding to the magnitude and inclination angle of the Scale 5 decomposition of a LASCO/C2 CME on 01-Apr-04.



Spatio-Temporal Filter

Degrees of Freedom: Scale, Magnitude & Angle … in Space & Time



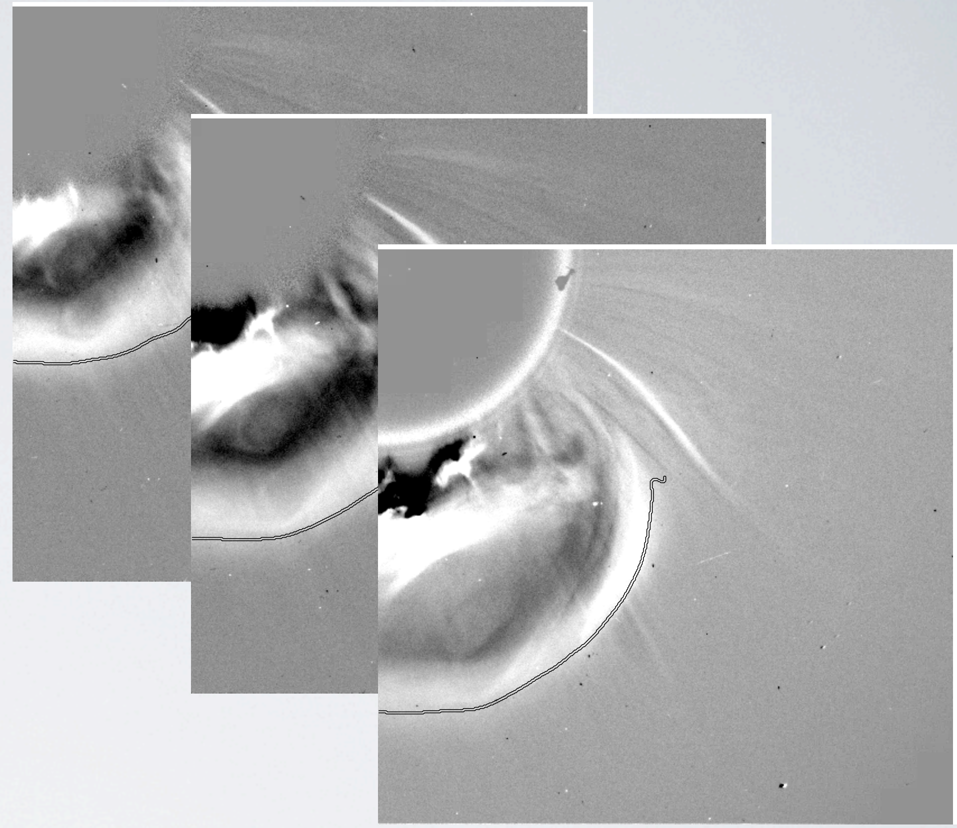
LASCO/C2 18-Jan-00

Non-Maxima Suppression

1) Nearest-neighbour info.

2) Criteria of angle and magnitude from gradients.

3) Pixels chained along edges.

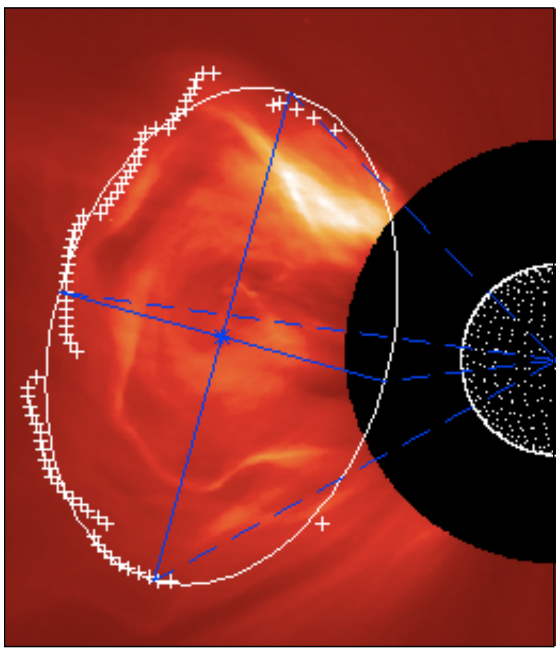


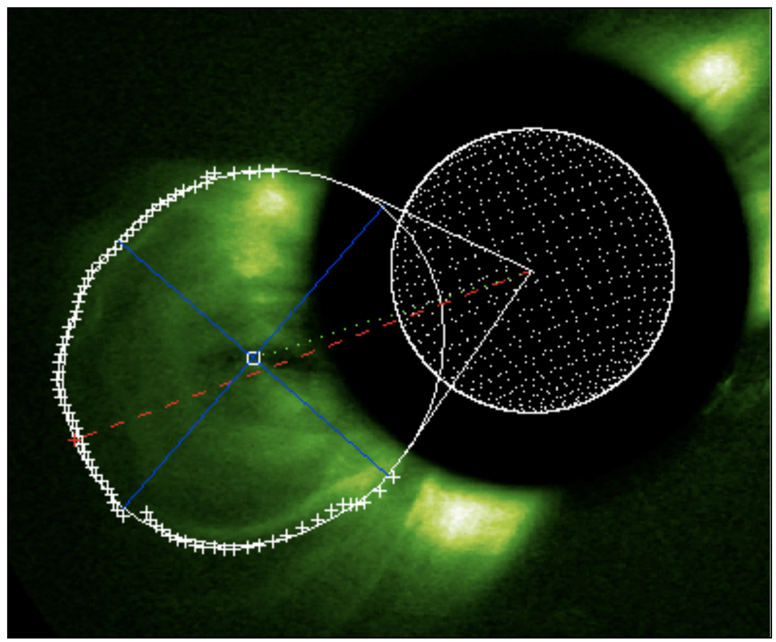
X Y Mag Angle Edges

LASCO/C2 18-Apr-00

CME FRONT CHARACTERIZATION

Described in "The kinematics of coronal mass ejections using multiscale methods", Byrne, Gallagher, McAteer and Young, A&A, 2009.





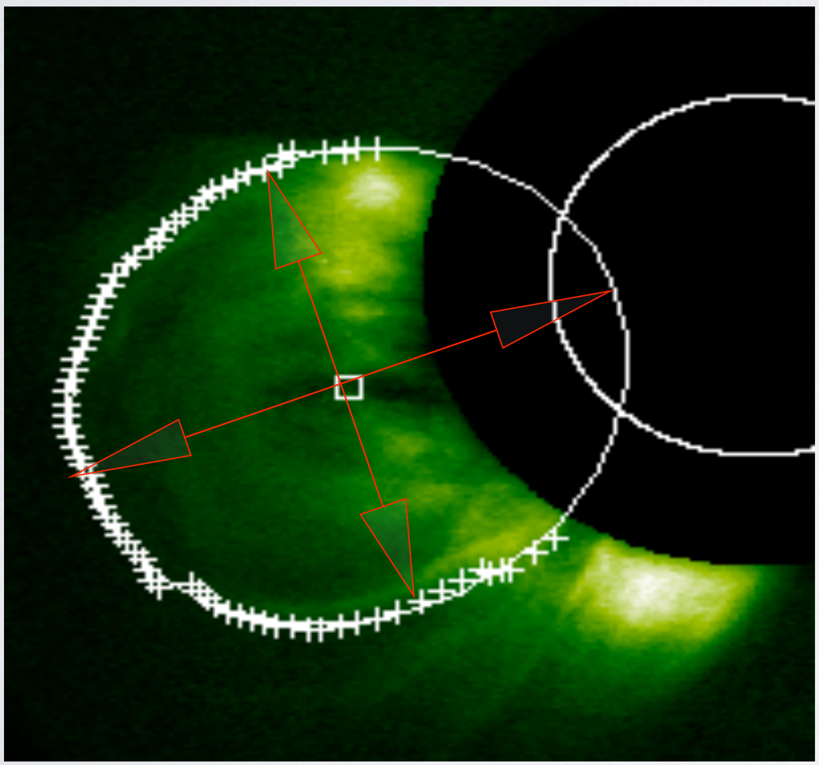
LASCO/C2 &
SECCHI/COR1-A
24-Jan-07

MORPHOLOGY

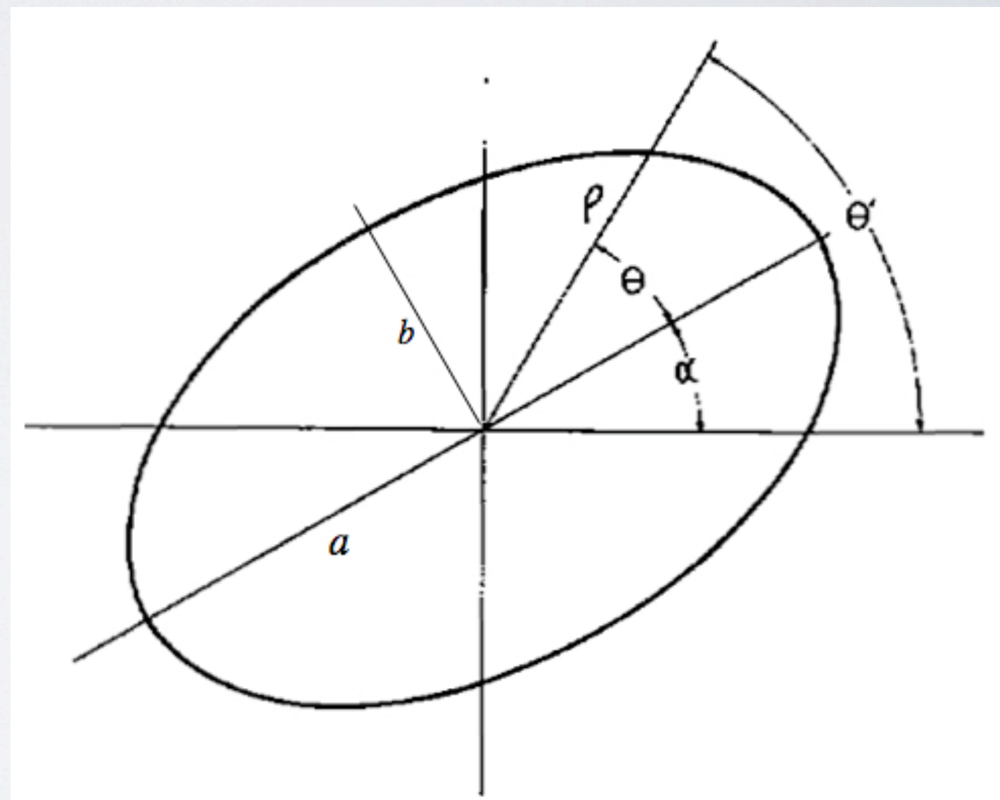
- Ellipse fit
- Height, Width, Curvature, Orientation

$$\frac{\rho^2\cos^2\theta}{a^2}+\frac{\rho^2\sin^2\theta}{b^2}=1$$

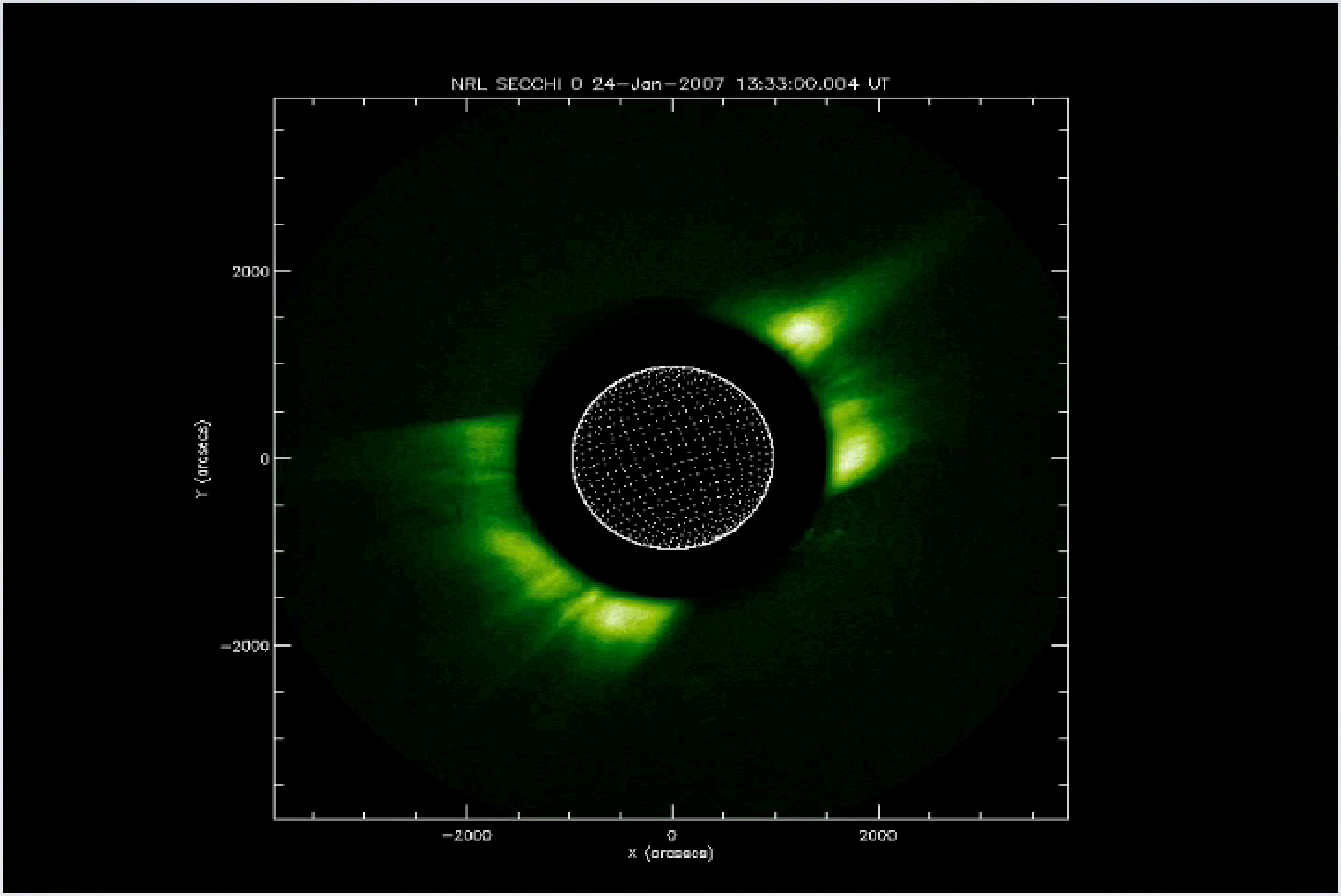
$$\rho^2=\frac{a^2b^2}{\left(\frac{a^2+b^2}{2}\right)-\left(\frac{a^2-b^2}{2}\right)\cos(2\theta'-2\alpha)}$$



SECCHI/COR1 24-Jan-07

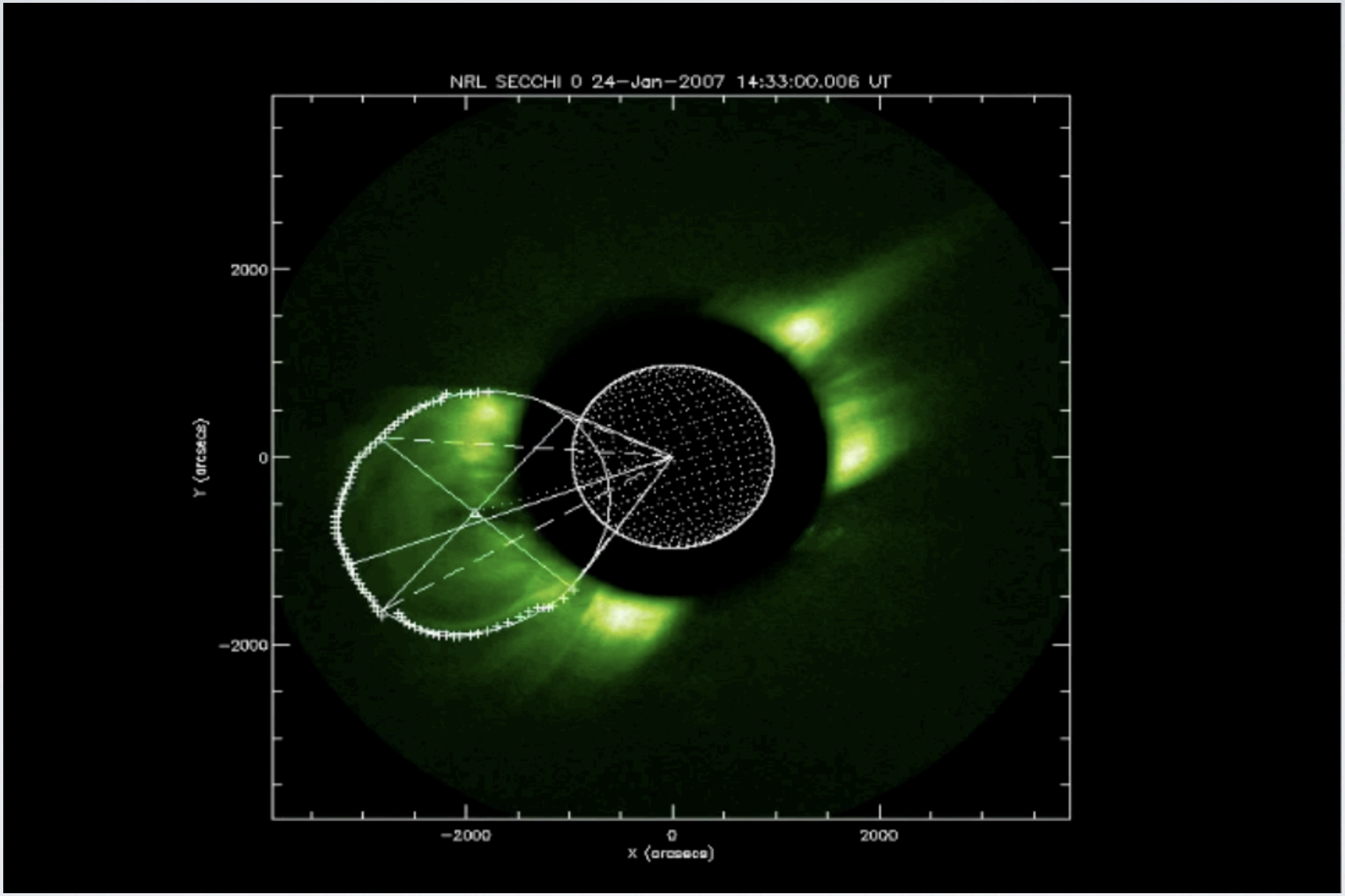


MORPHOLOGY



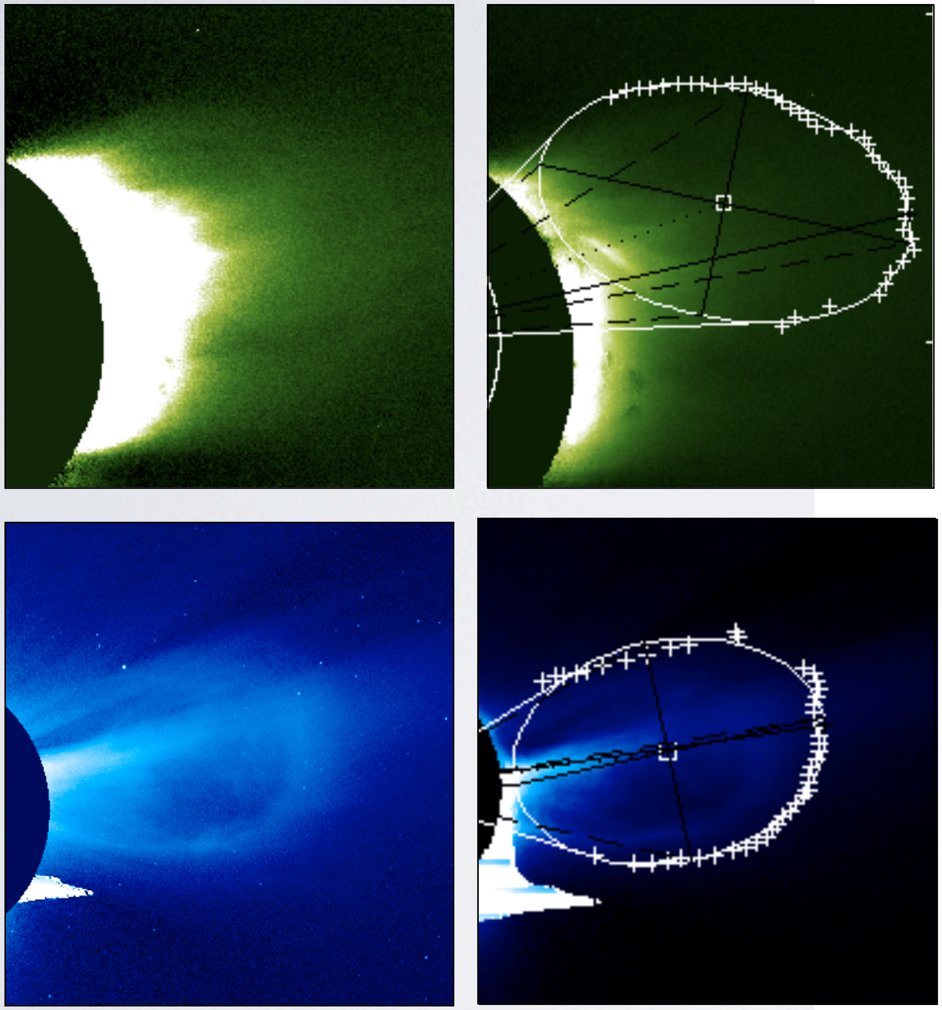
SECCHI/COR1-A 24-Jan-07

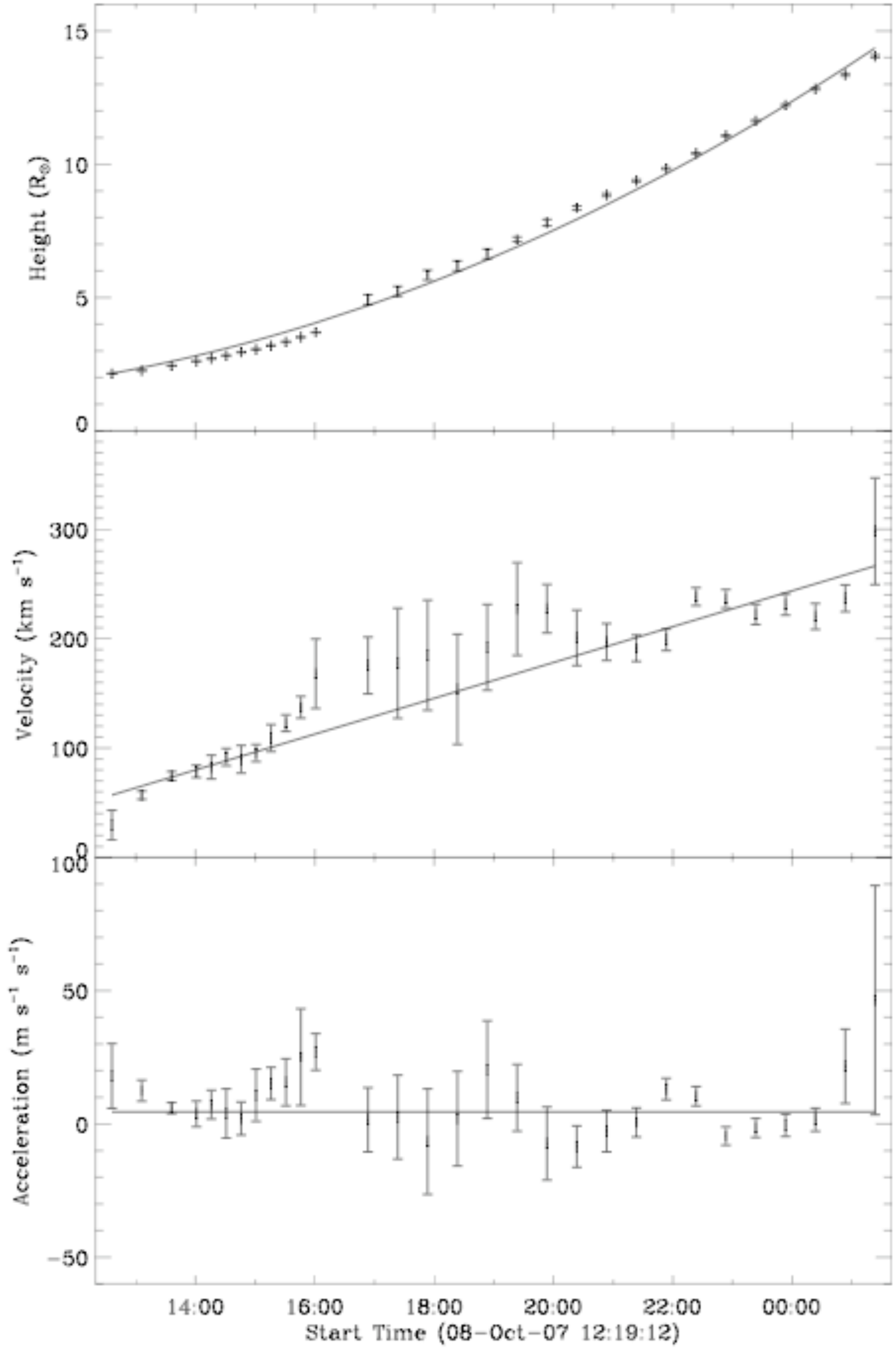
MORPHOLOGY



SECCHI/COR1-A 24-Jan-07

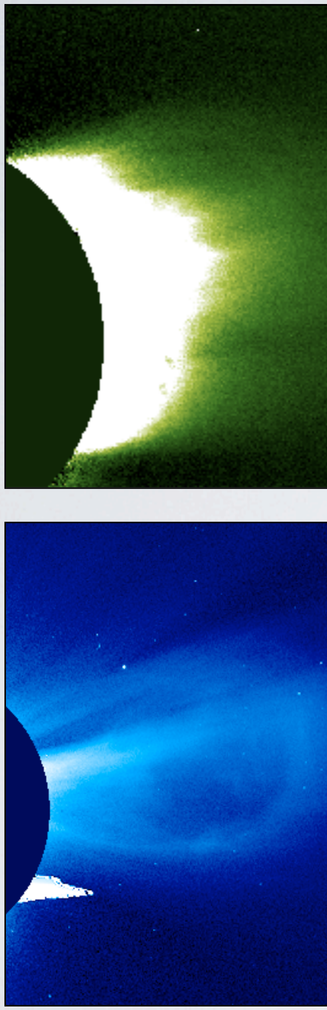
Kinematics & Morphology

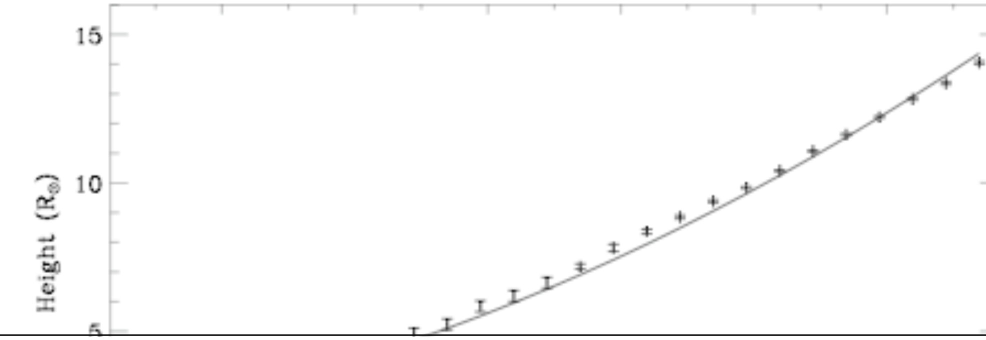


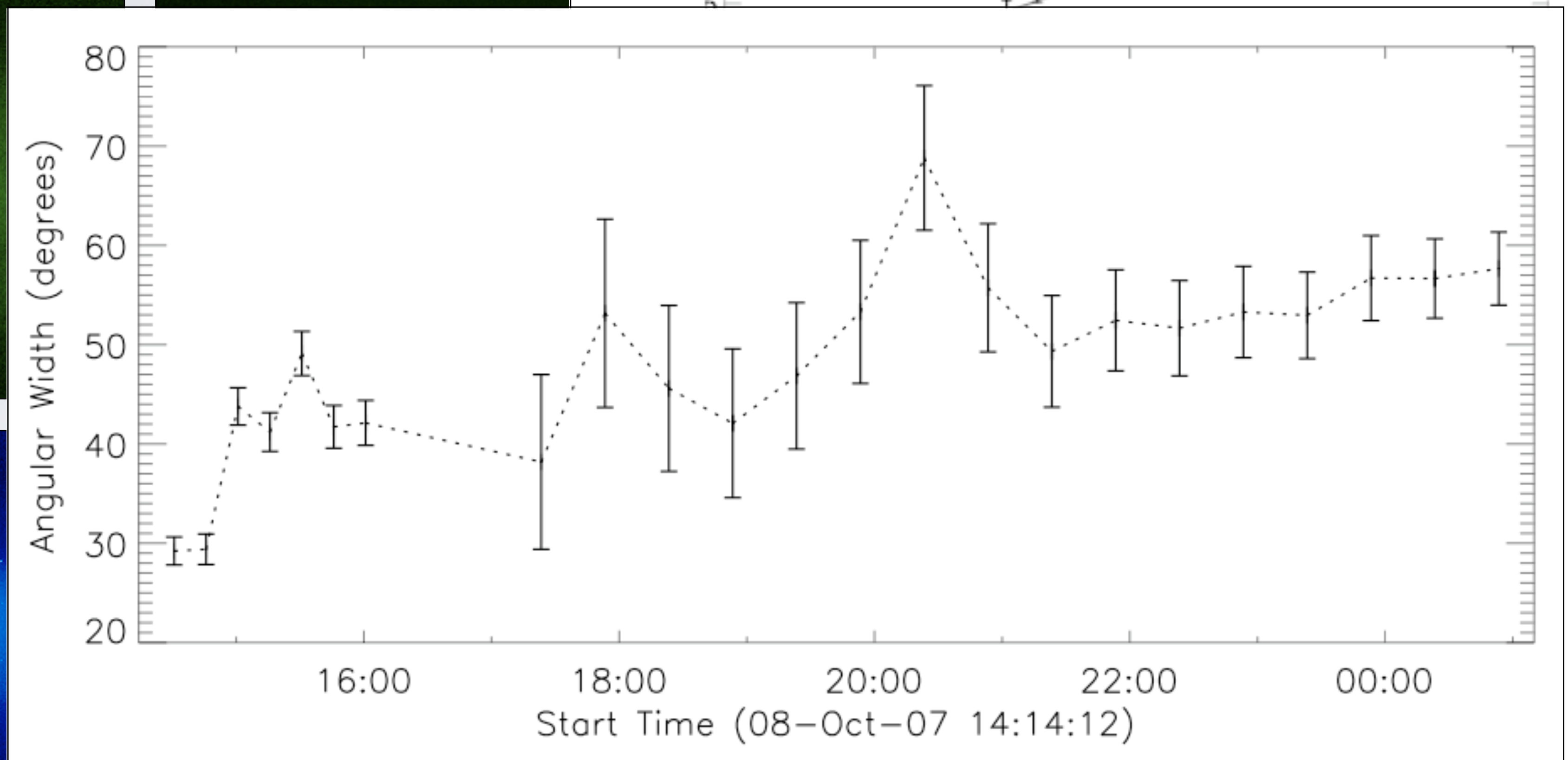


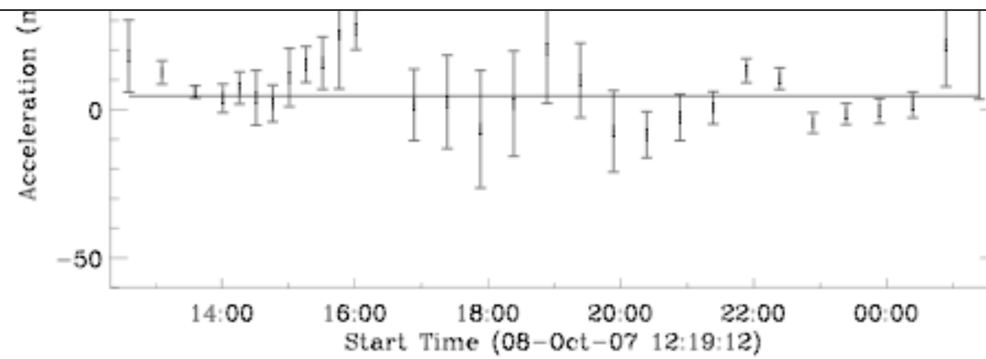
SECCHI 08-Oct-07

Kinematics & Morphology









SECCHI 08-Oct-07

CURRENT WORK

- testing a basic toolkit for IDL - 1D and 2D wavelets
- developing additional multiscale transforms - e.g. ridglets and curvelets
- developing improved fitting methods for height-time, velocity and acceleration