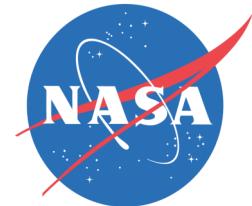




Multiscale Detection and Characterisation of CMEs

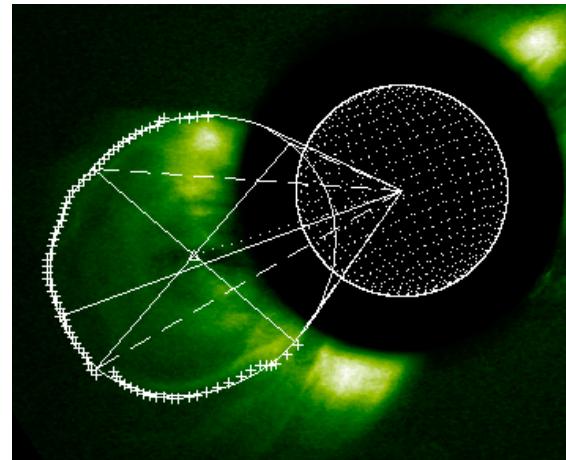


J. P. Byrne¹, P. T. Gallagher¹, C. A. Young² and
R. T. J. McAteer³

¹ Astrophysics Research Group, School of Physics, Trinity College Dublin, Dublin 2, Ireland.

² ADNET Systems Inc., NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA.

³ Catholic University of America, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA.

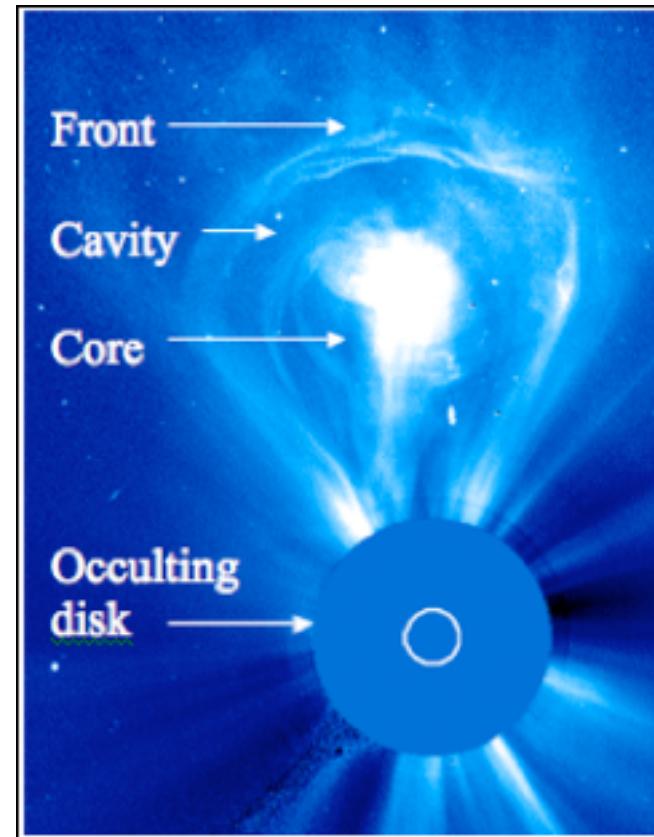


SECCHI-A/COR1 24-Jan-07



Overview

- CME Models
- Image Processing:
Multiscale methods
- CME Morphology &
Kinematics
- Application to LASCO
and STEREO/SECCHI

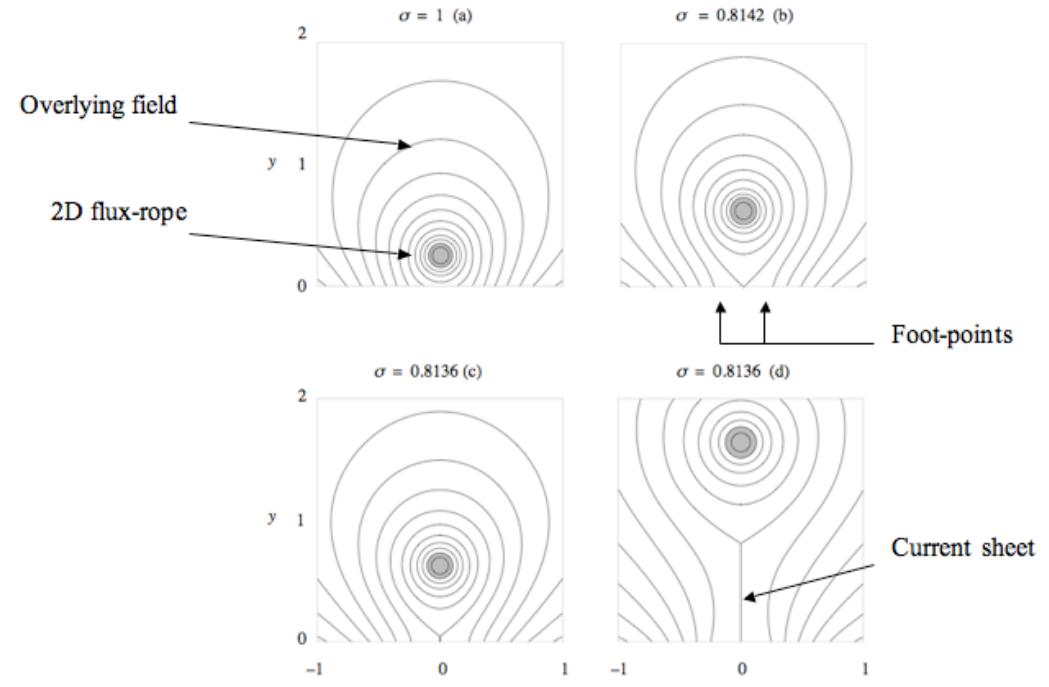


LASCO/C3 27-Feb-00

CME Models

- Magnetic Flux-Rope:

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



- Magnetic Break-out:

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

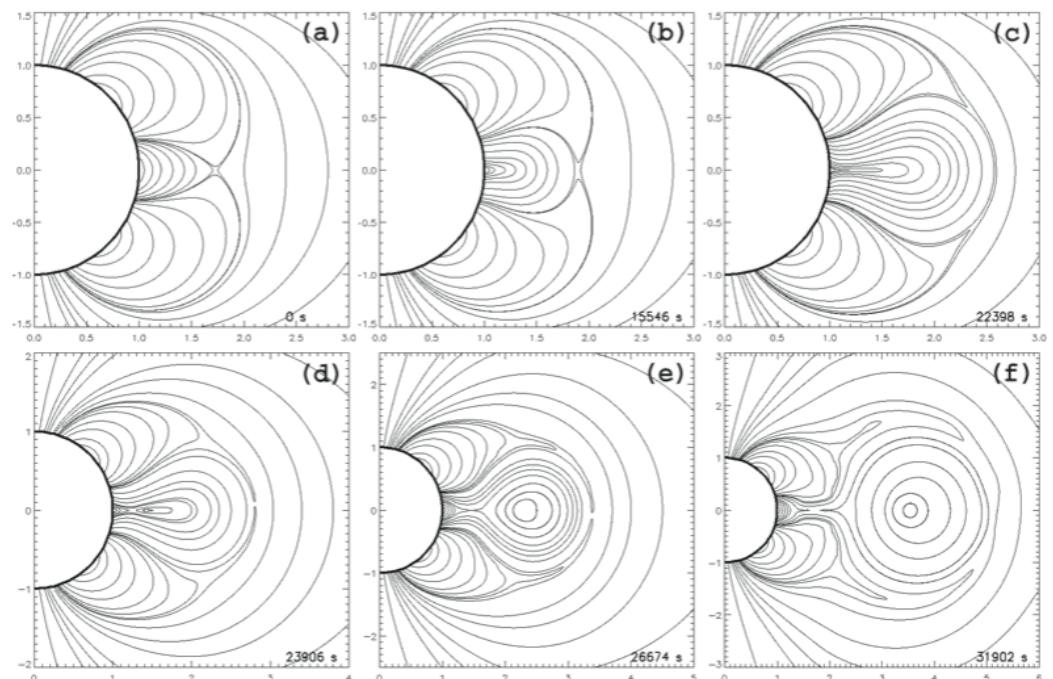
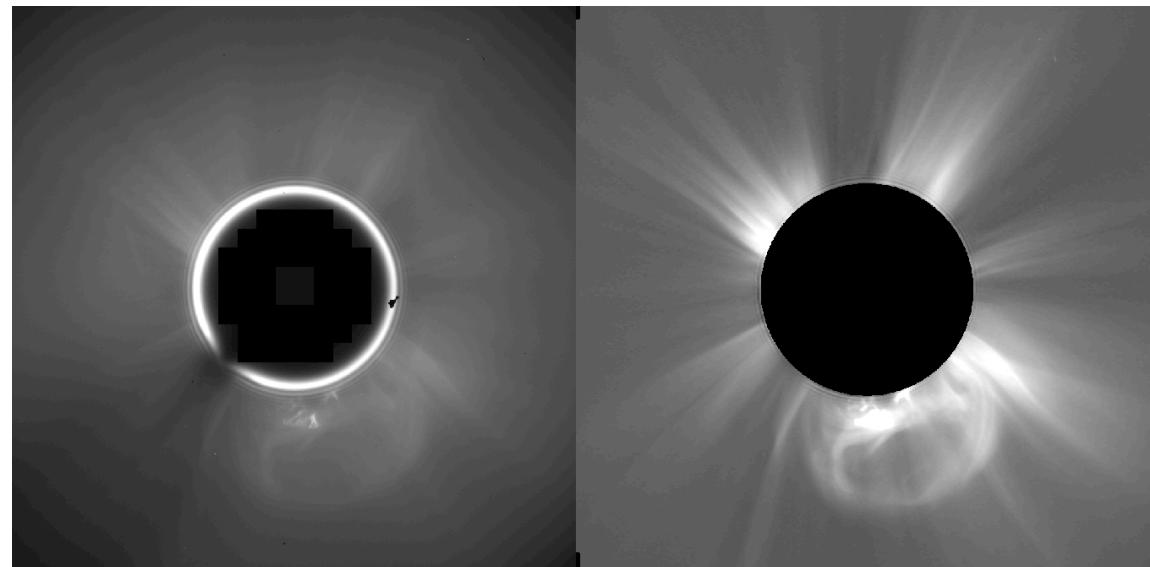


Image Pre-Processing

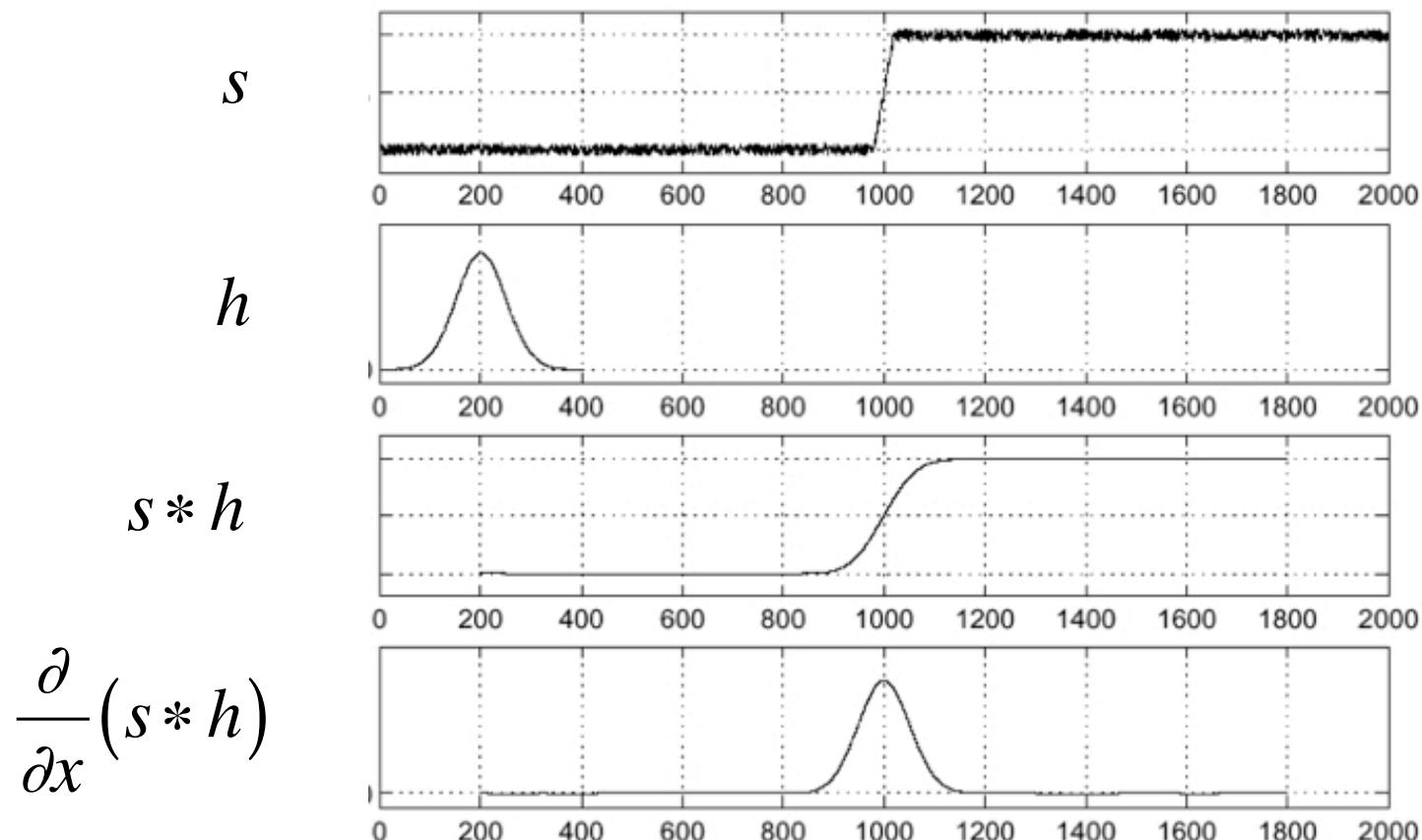
- Normalisation
 - exposure time
 - CCD bias
 - data dropouts
- Background subtraction
- Median filtering
(de-noising)



LASCO/C2 18-Apr-00

Finding the CME Front

Edge Detection:



Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter

4) Non-Maxima Suppression

5) CME Front Characterisation

Kinematics & Morphology

Our Algorithm

Image Pre-Processing



1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter

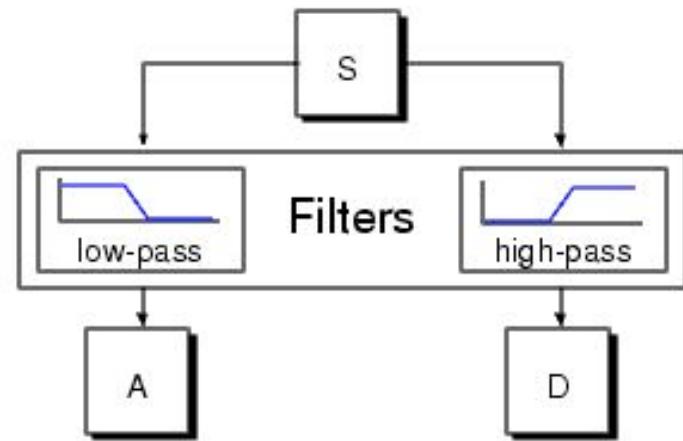
4) Non-Maxima Suppression

5) CME Front Characterisation

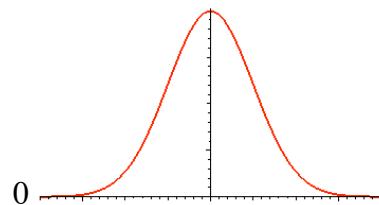
Kinematics & Morphology

1) Multiscale Decomposition

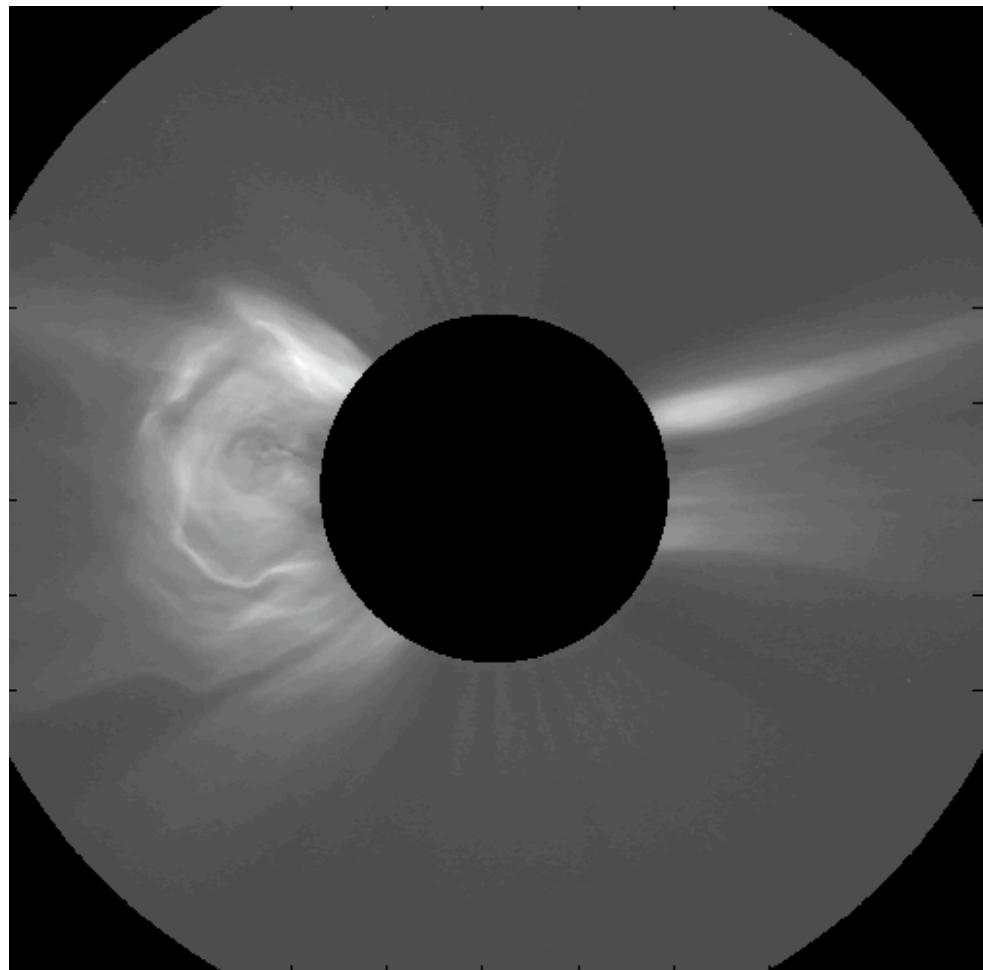
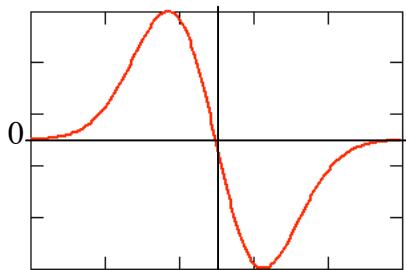
Input: s



Low pass: Approximation



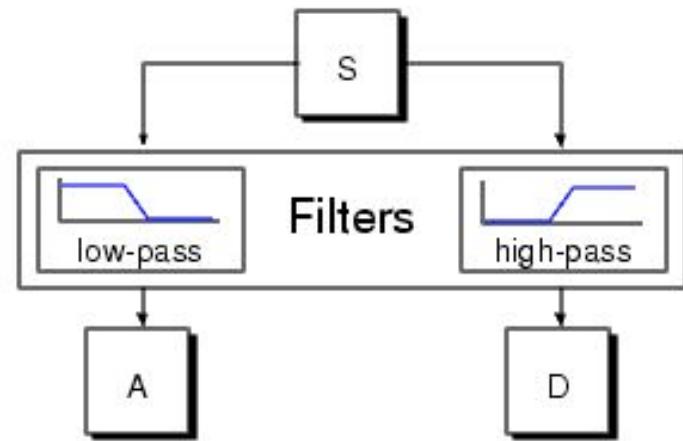
High pass: Detail



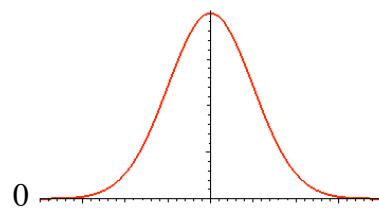
LASCO/C2 24-Jan-07

1) Multiscale Decomposition

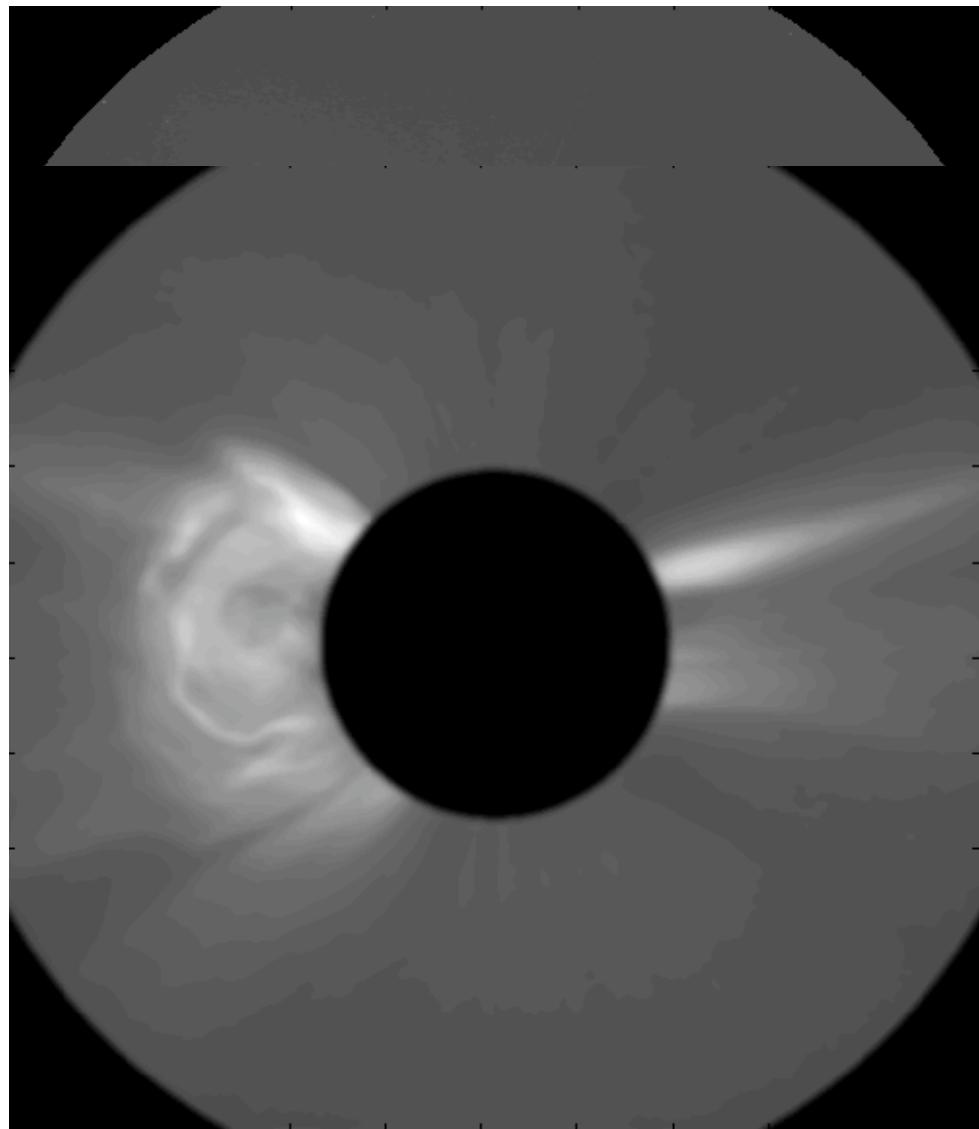
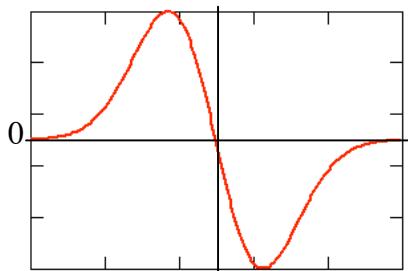
Input: s



Low pass: Approximation

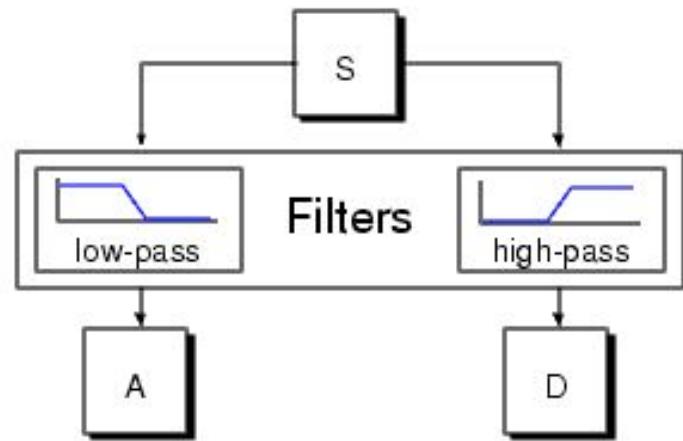


High pass: Detail

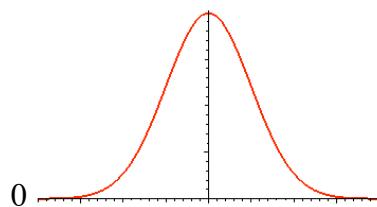


1) Multiscale Decomposition

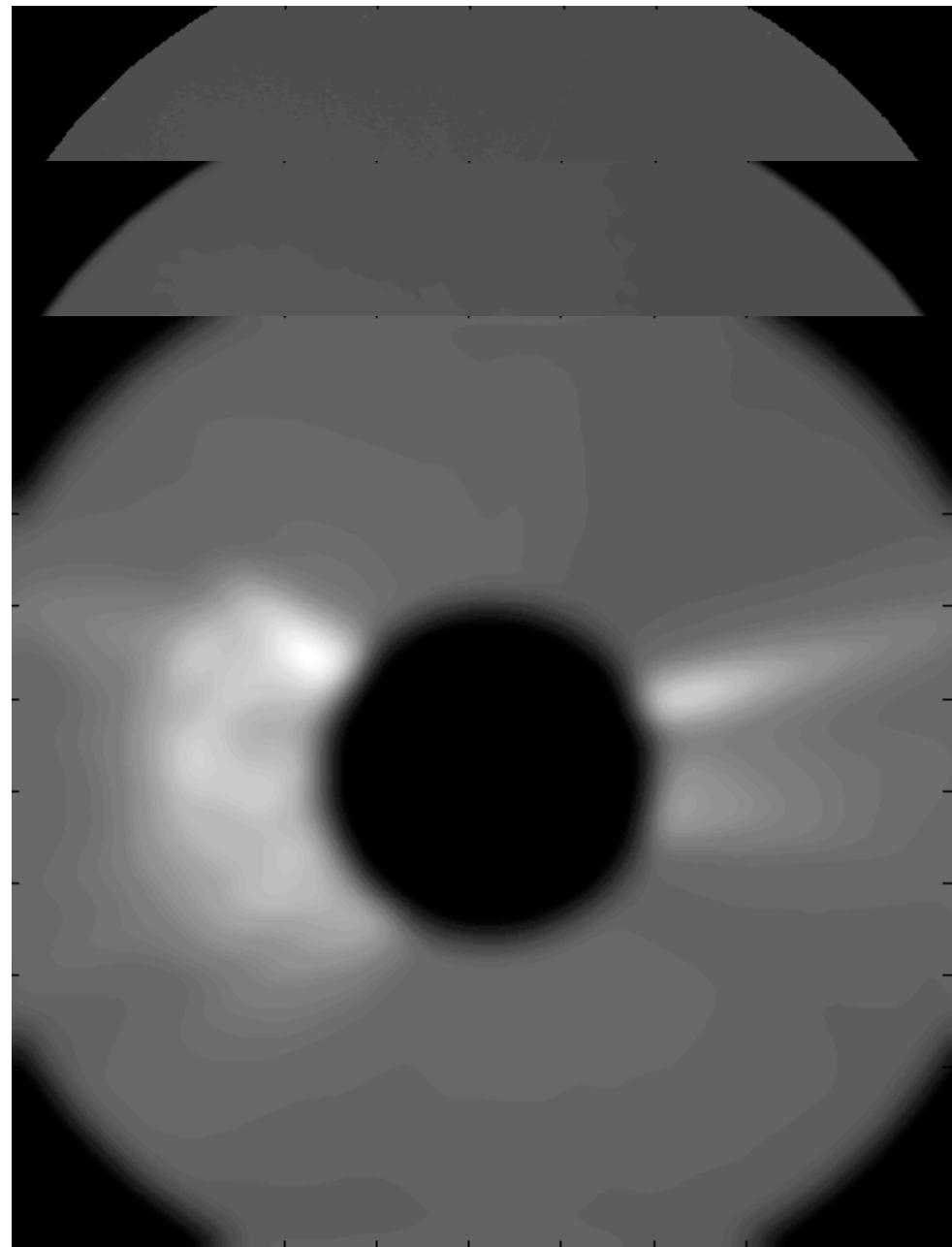
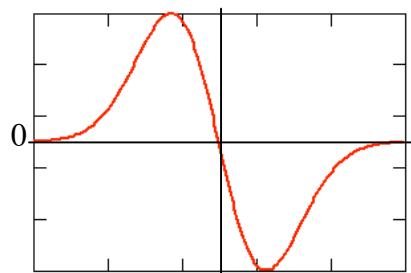
Input: s



Low pass: Approximation

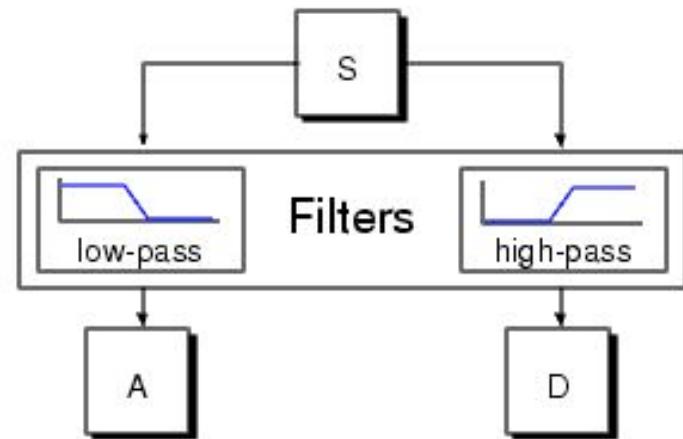


High pass: Detail

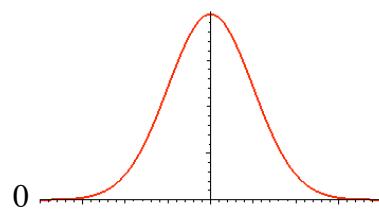


1) Multiscale Decomposition

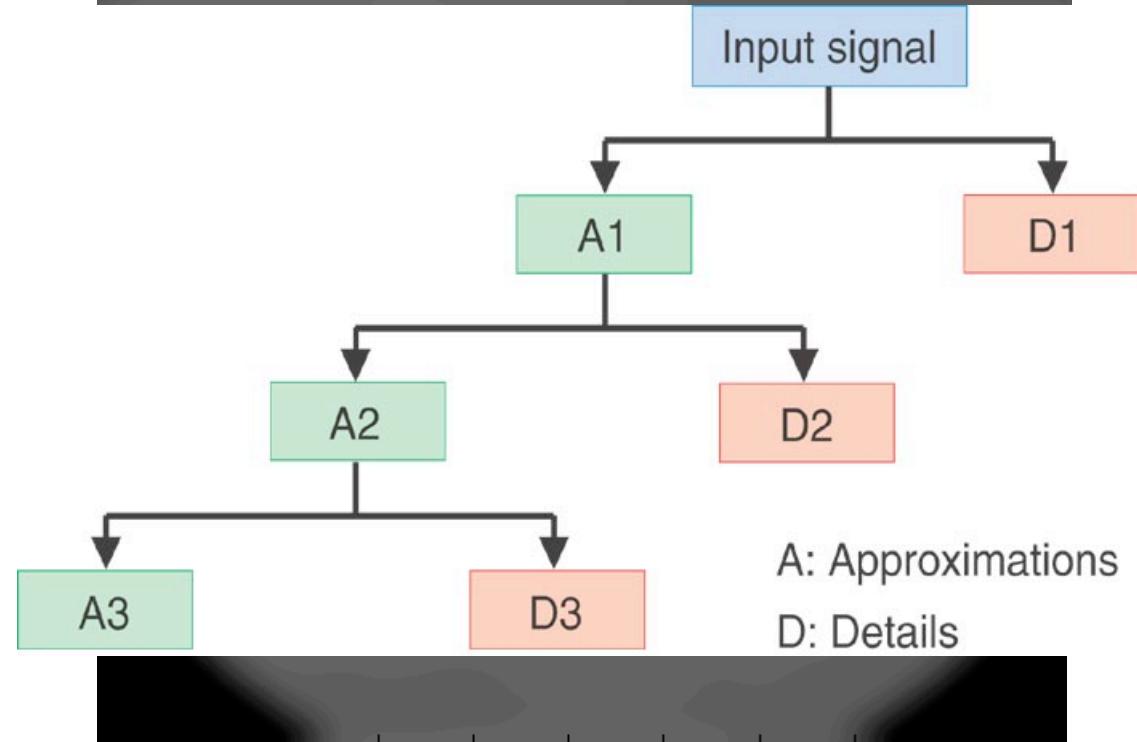
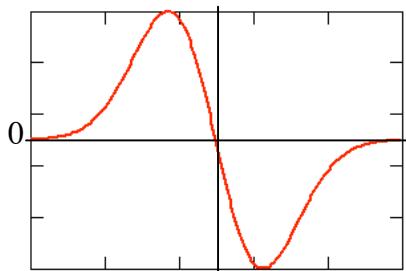
Input: s



Low pass: Approximation

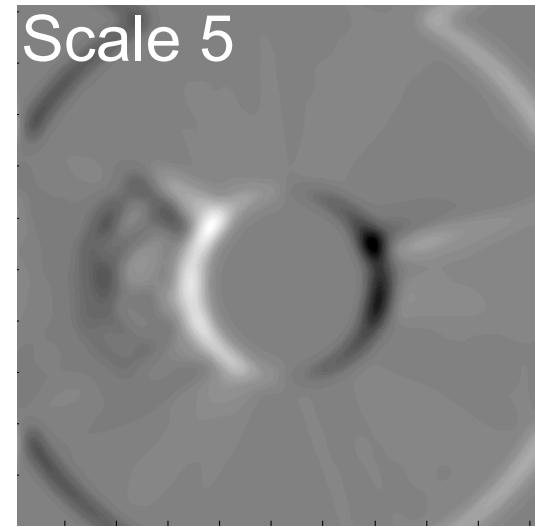
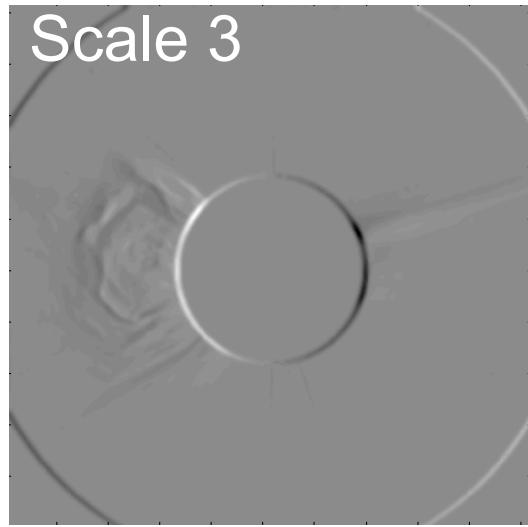
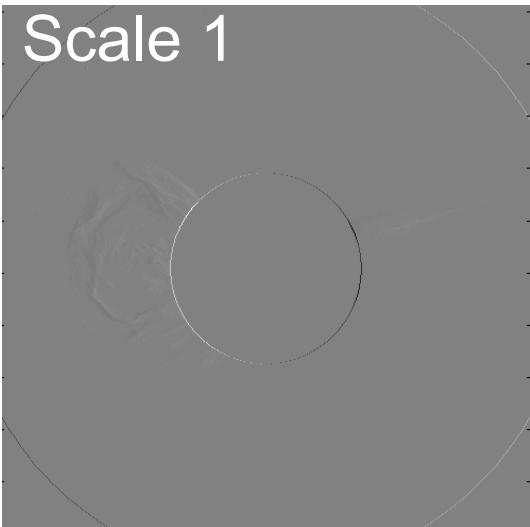


High pass: Detail

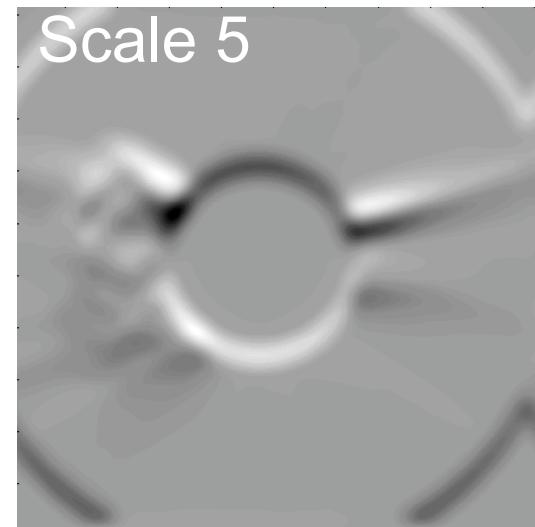
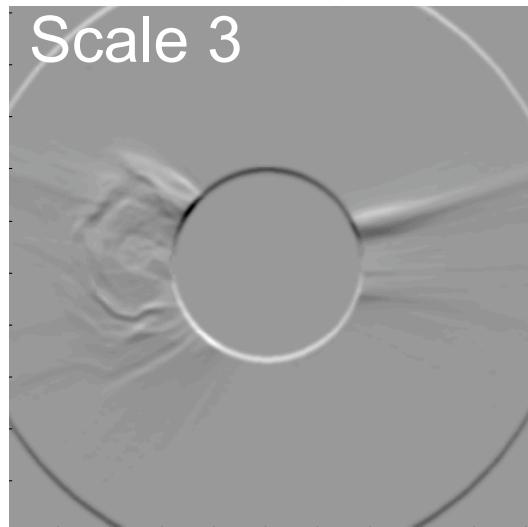
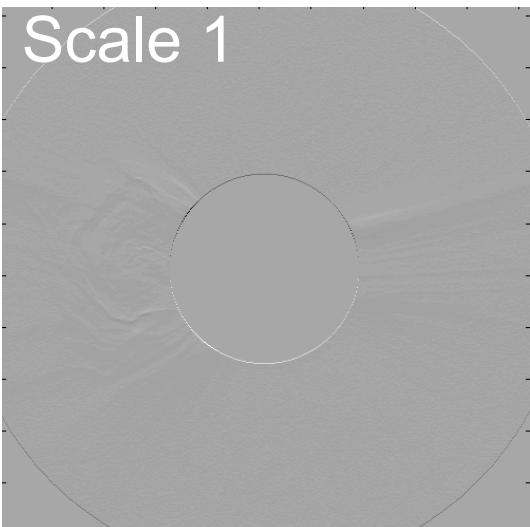


1) Multiscale Decomposition

Horizontal Direction:



Vertical Direction:



Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition



2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter

4) Non-Maxima Suppression

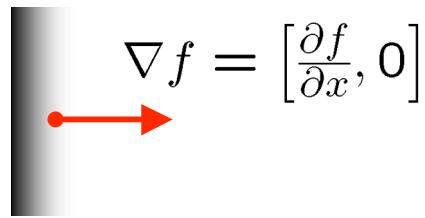
5) CME Front Characterisation

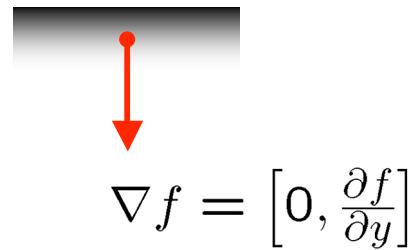
Kinematics & Morphology

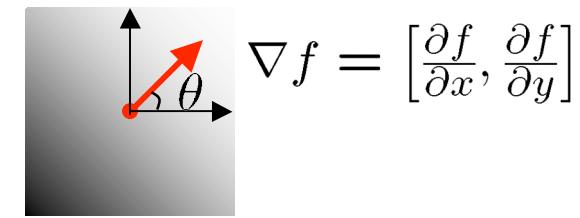
2) Gradient Space Information

- 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:

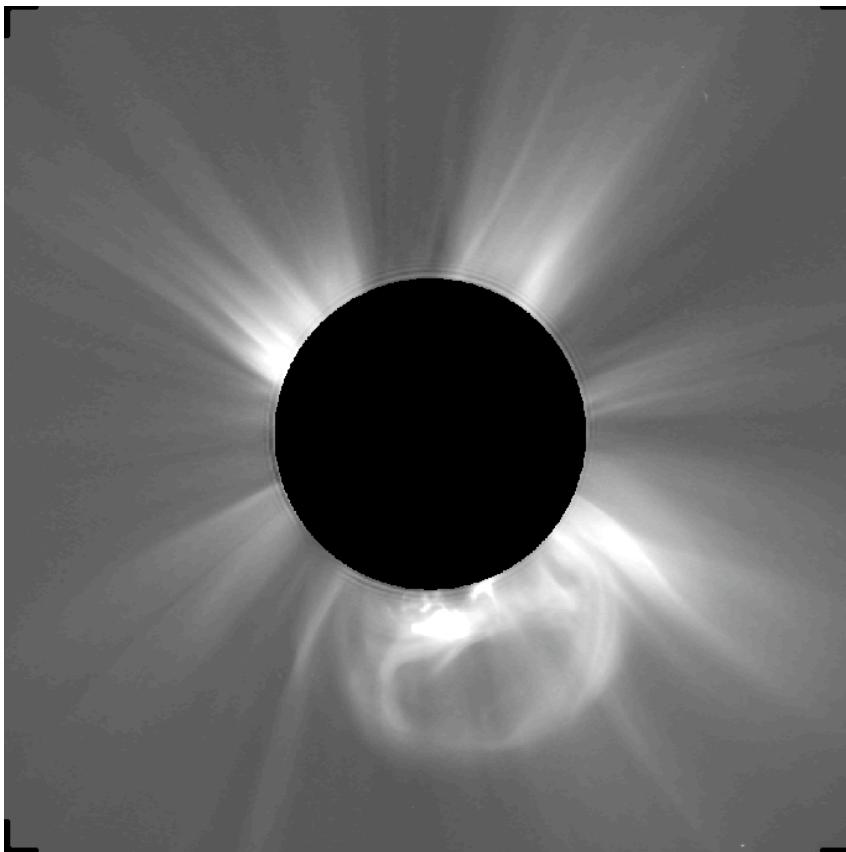
$$\theta = \tan^{-1} \left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x} \right)$$

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

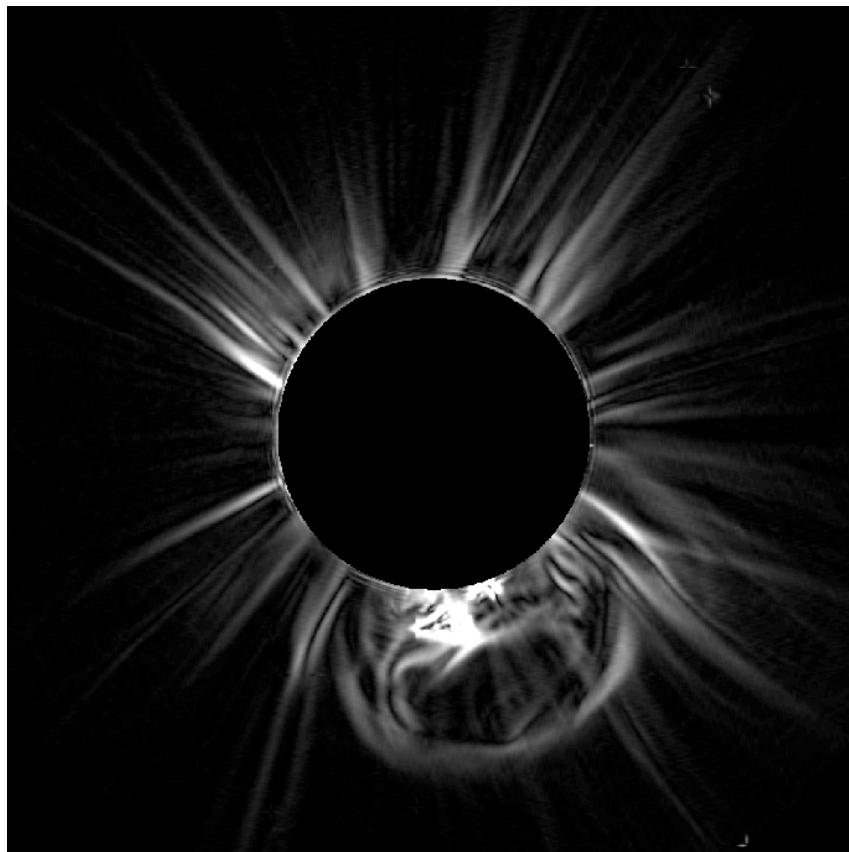
$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x} \right)^2 + \left(\frac{\partial f}{\partial y} \right)^2}$$

2) Gradient Space Information

Original:



Magnitude:

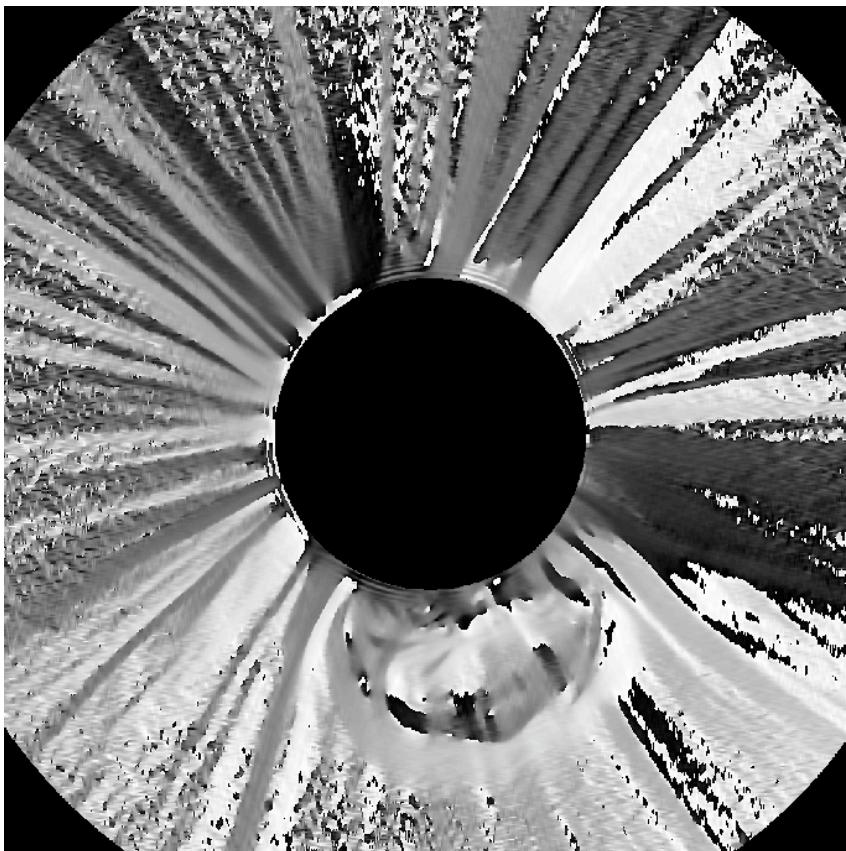


LASCO/C2 18-Apr-00

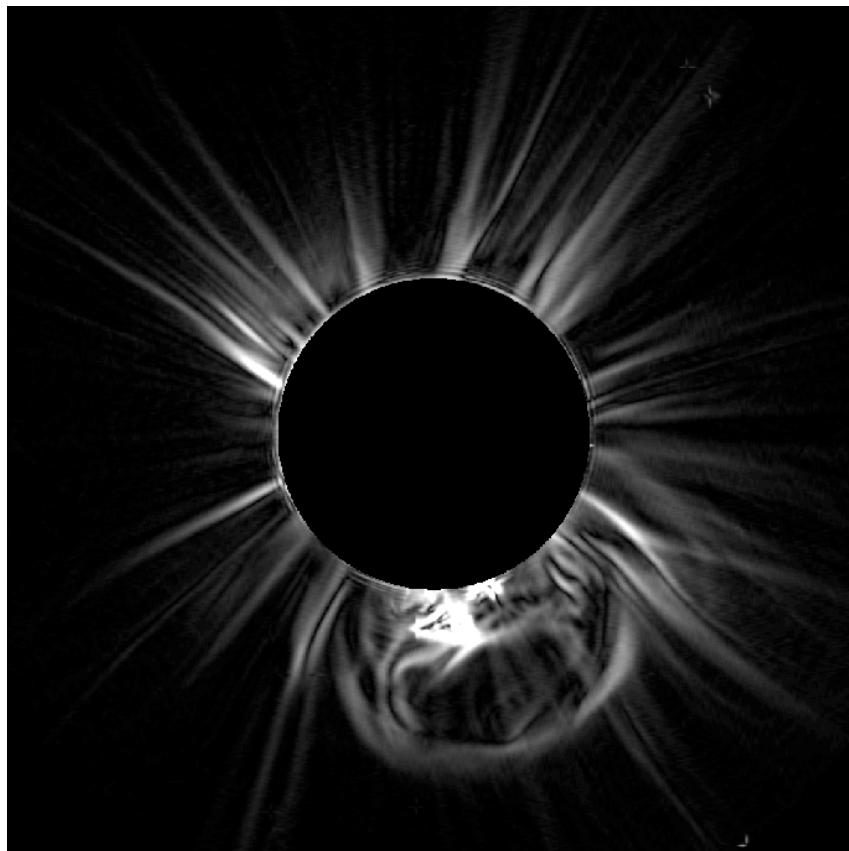
(McAteer et al. 2007)

2) Gradient Space Information

Angle:



Magnitude:

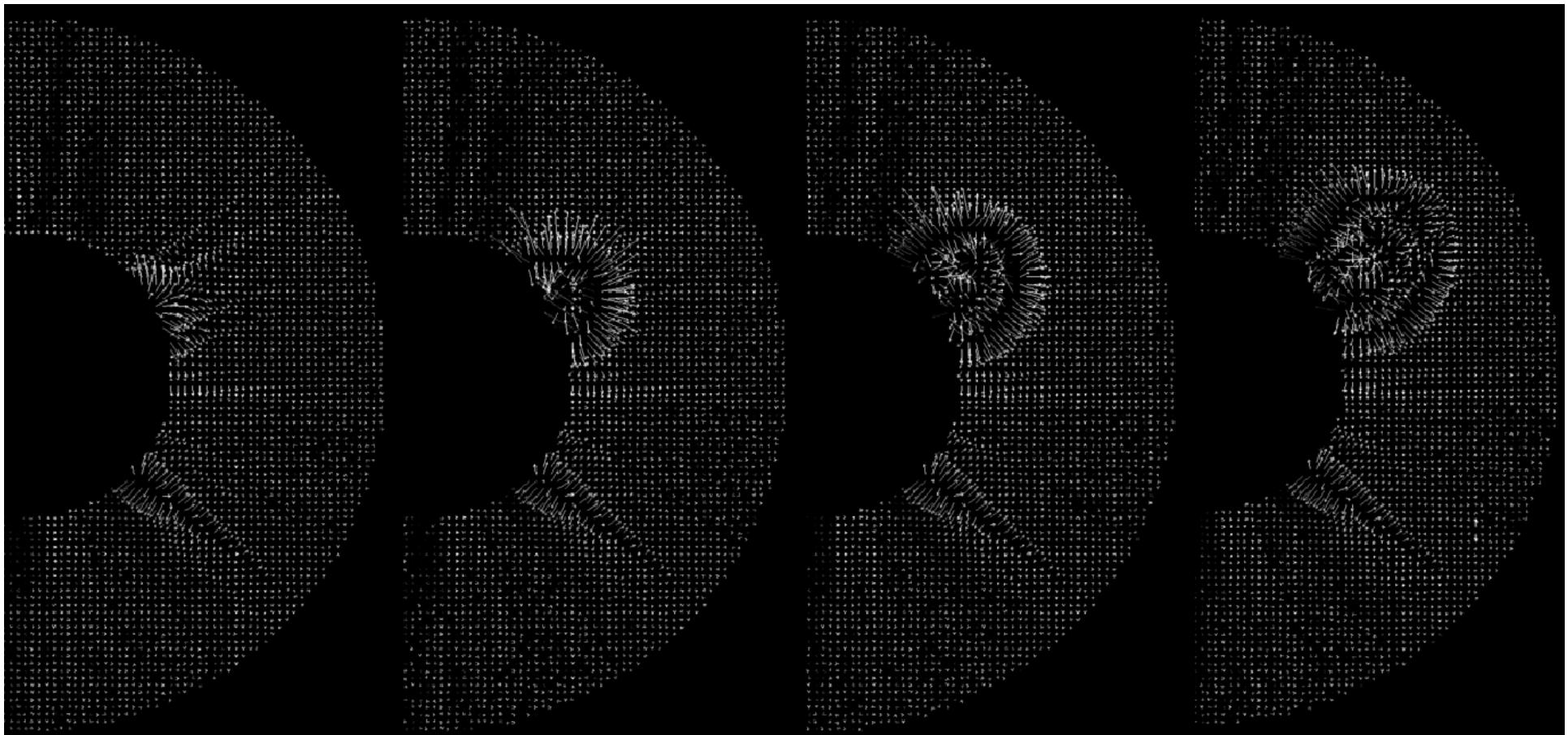


LASCO/C2 18-Apr-00

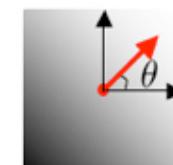
(McAteer et al. 2007)

2) Gradient Space Information

Vector-Arrow Field



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



Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field



3) Spatio-Temporal Filter

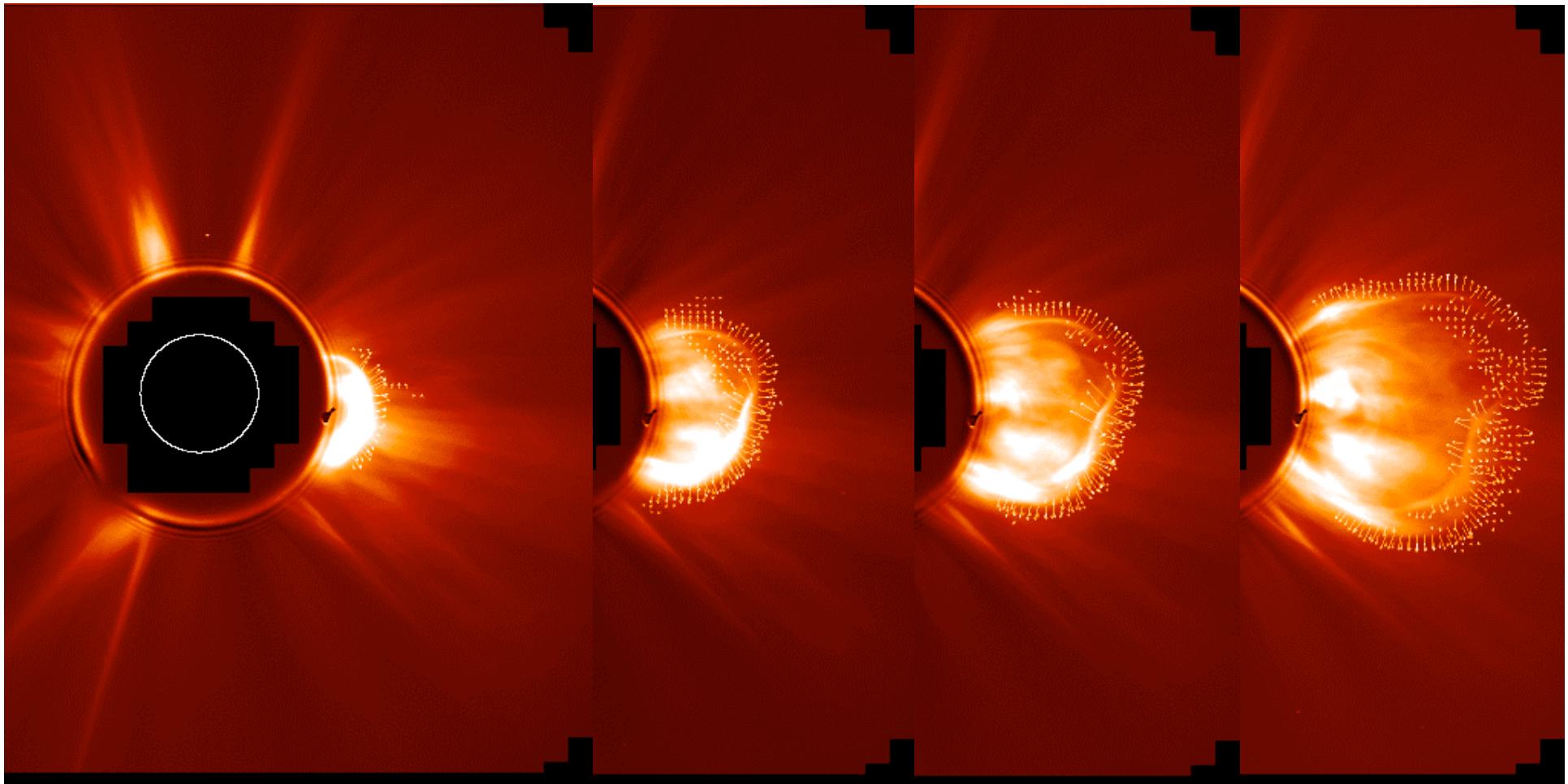
4) Non-Maxima Suppression

5) CME Front Characterisation

Kinematics & Morphology

3) Spatio-Temporal Filter

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



LASCO/C2 18-Jan-00

Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter



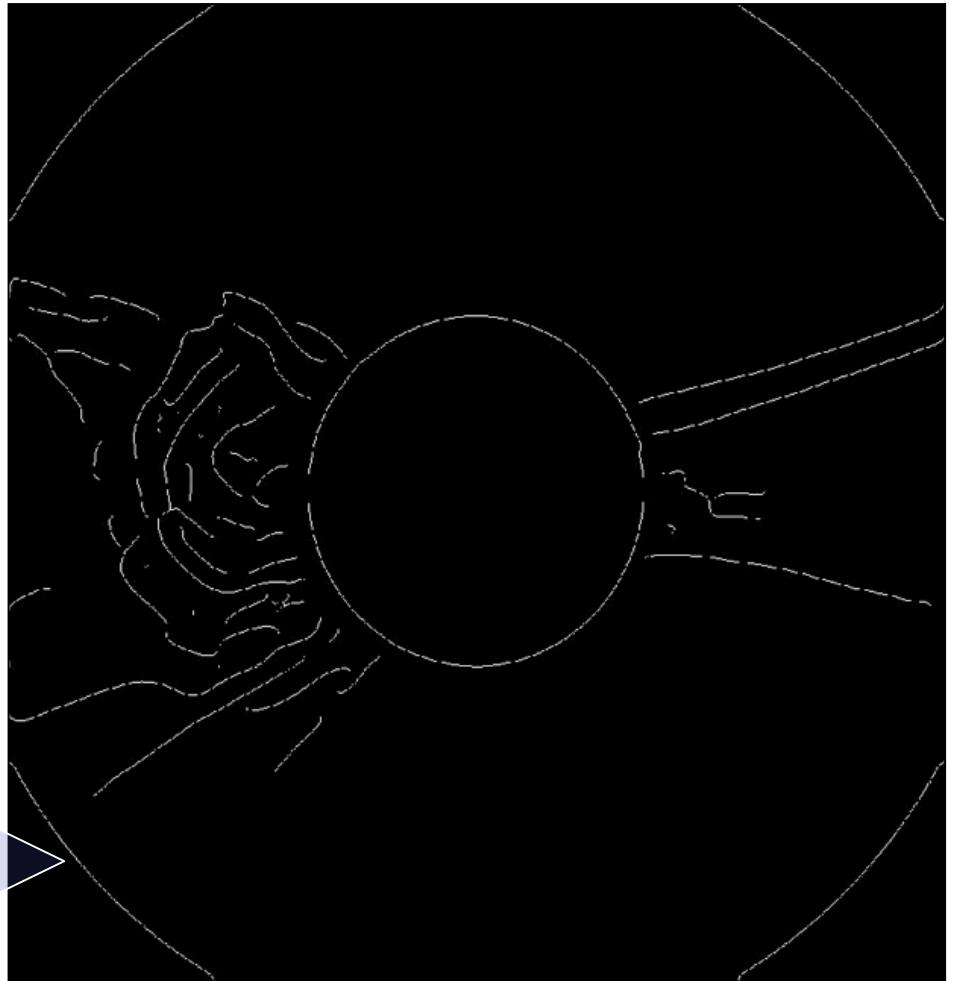
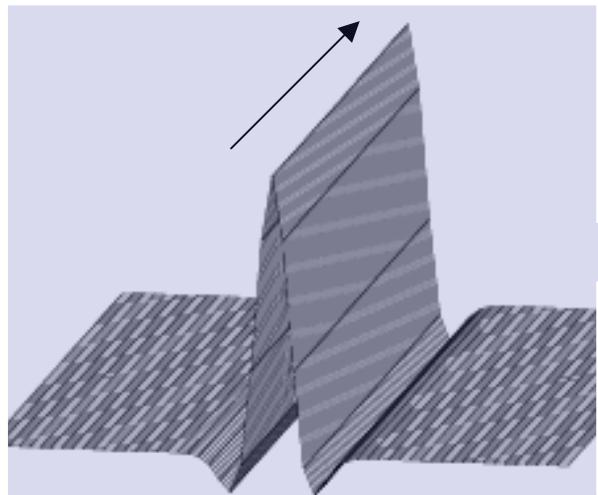
4) Non-Maxima Suppression

5) CME Front Characterisation

Kinematics & Morphology

4) Non-Maxima Suppression

- 1) Nearest-neighbour info.
- 2) Criteria of angle and magnitude from gradients.
- 3) Pixels chained along edges.



LASCO/C2 24-Jan-07

Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter

4) Non-Maxima Suppression



5) CME Front Characterisation

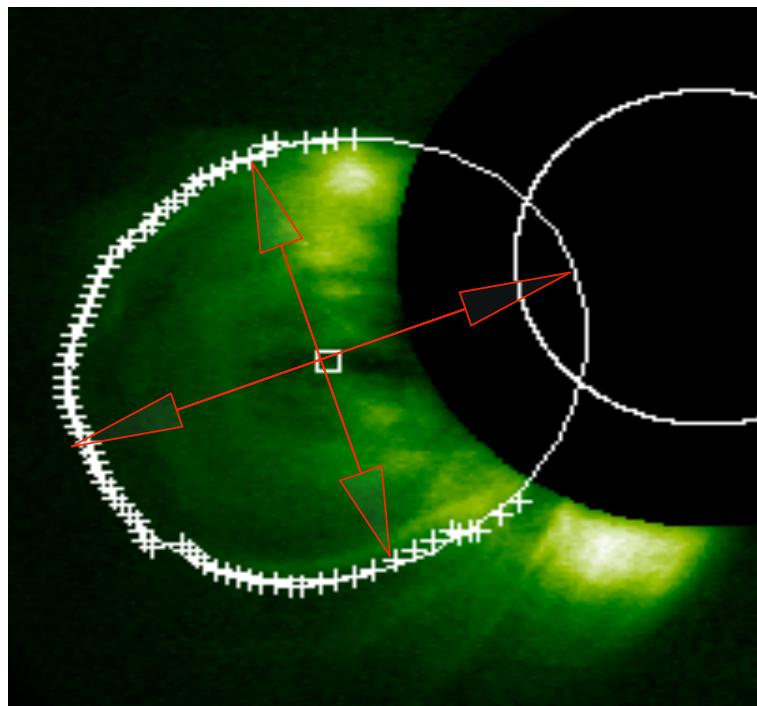
Kinematics & Morphology

5) CME Front Characterisation

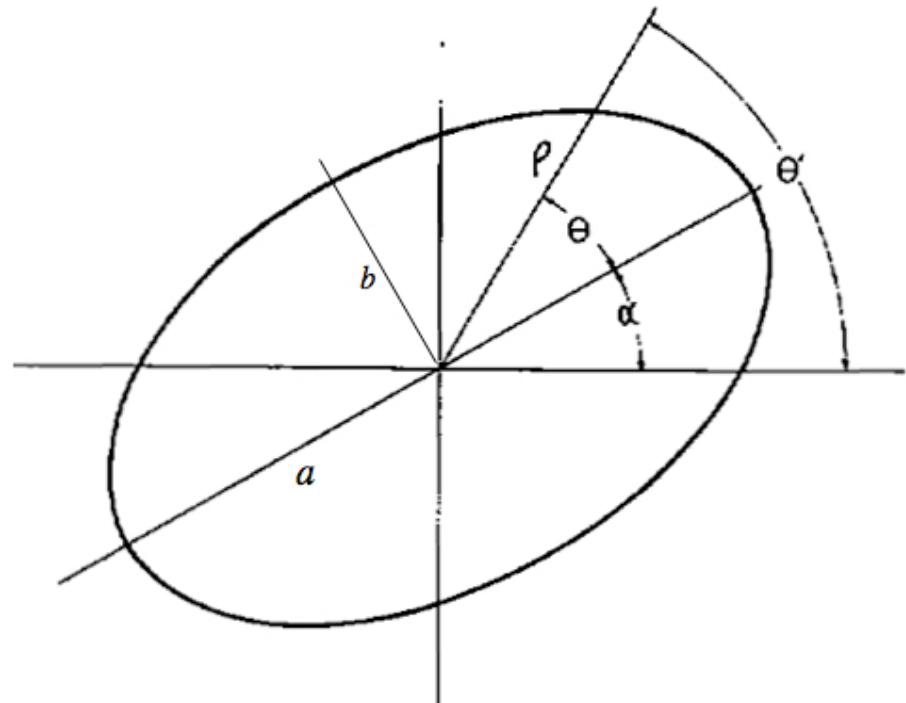
- Ellipse fit
- Height, Width, Curvature, Orientation

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

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

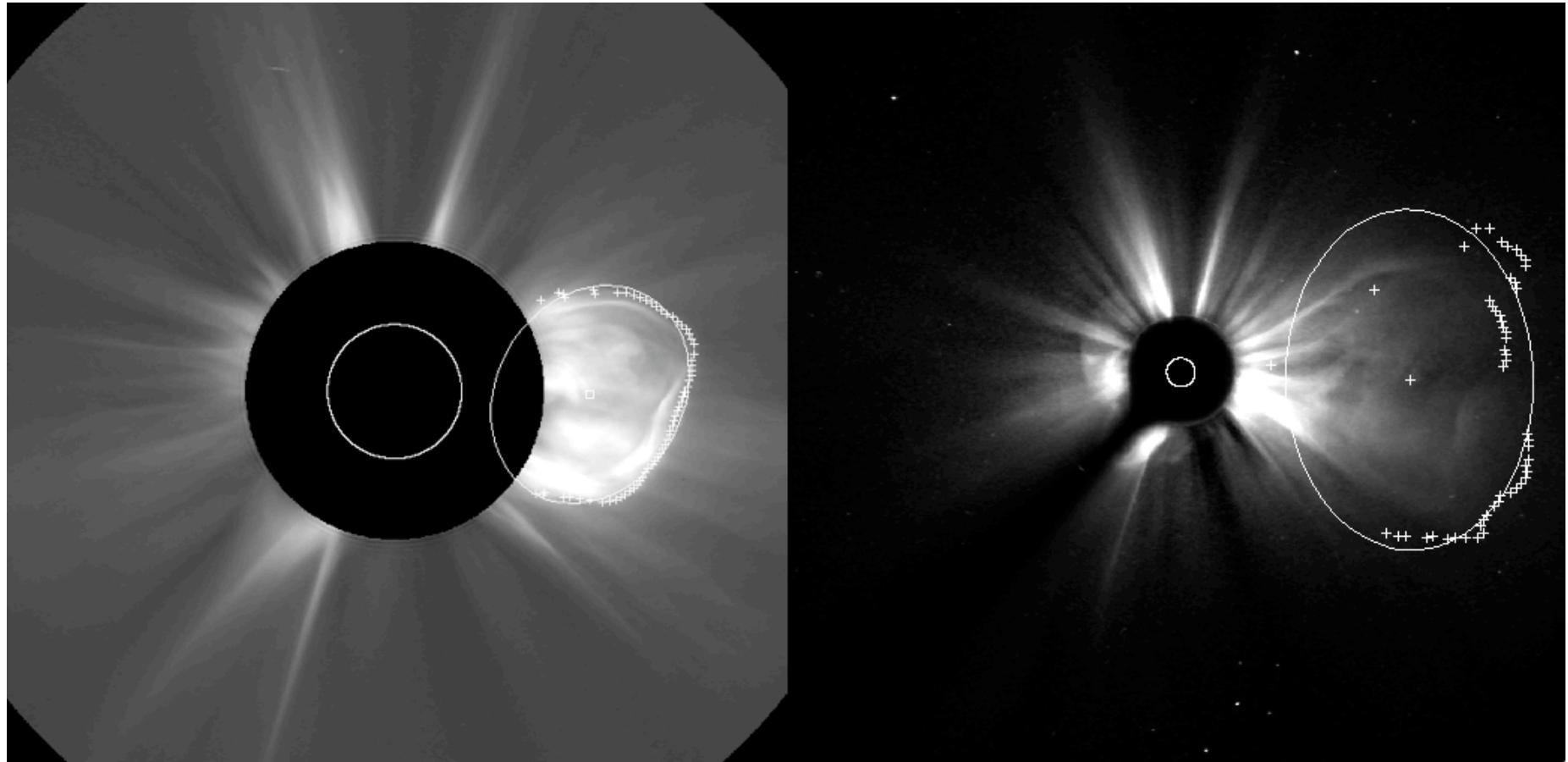


SECCHI/COR1 24-Jan-07



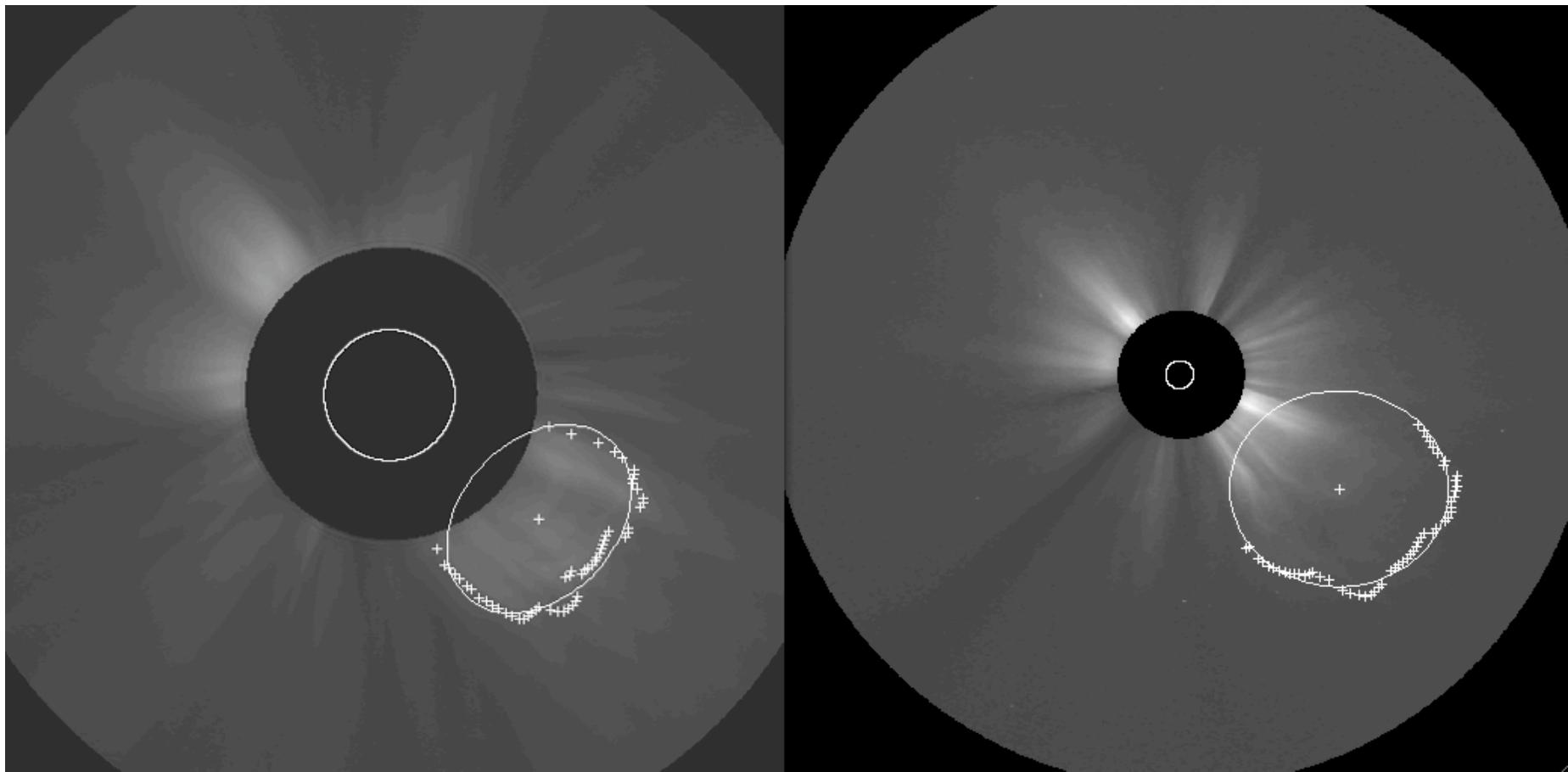
(H.E. Schrank, 1961)

5) CME Front Characterisation



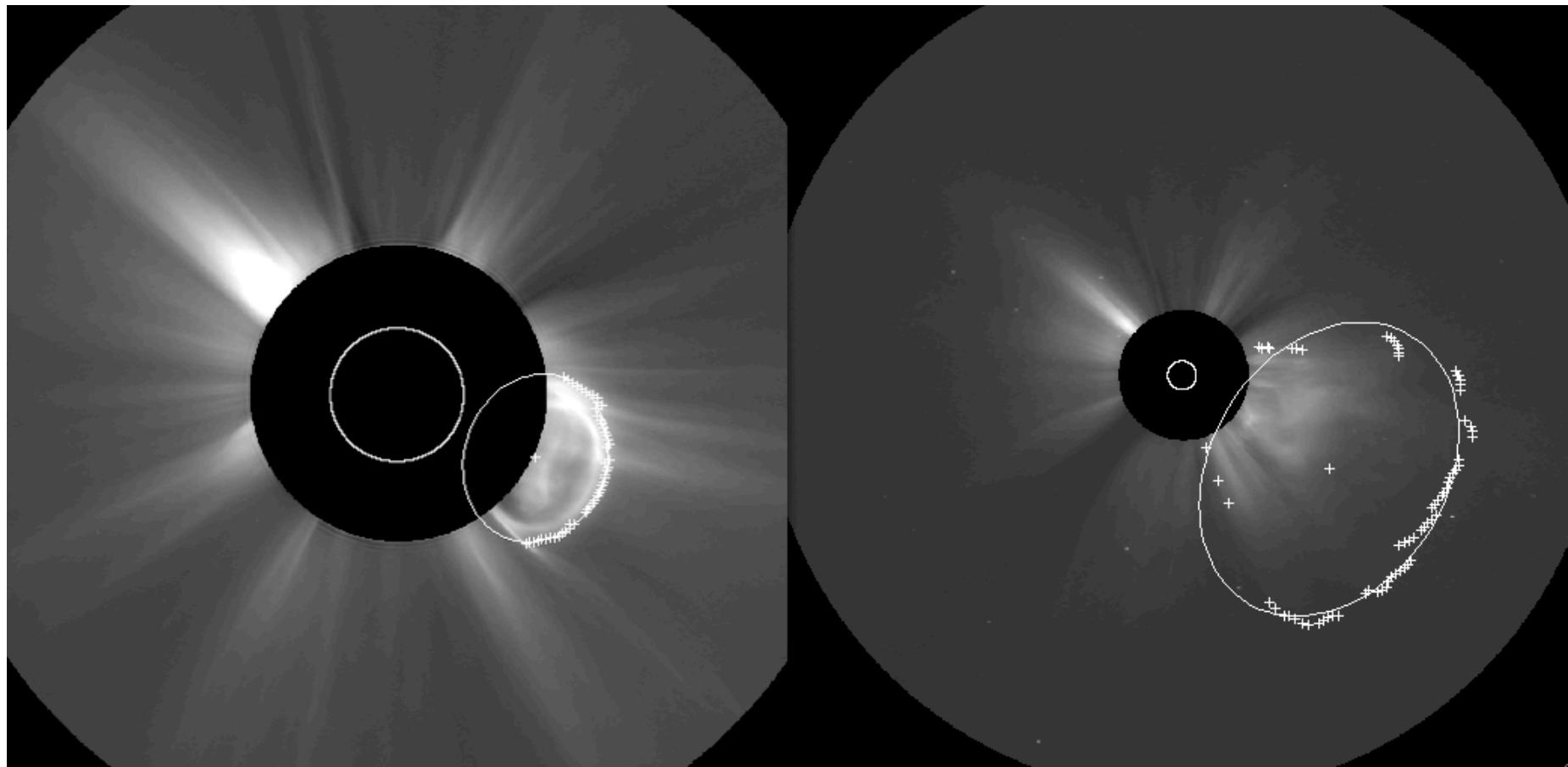
LASCO C2 & C3 18-Jan-00

5) CME Front Characterisation



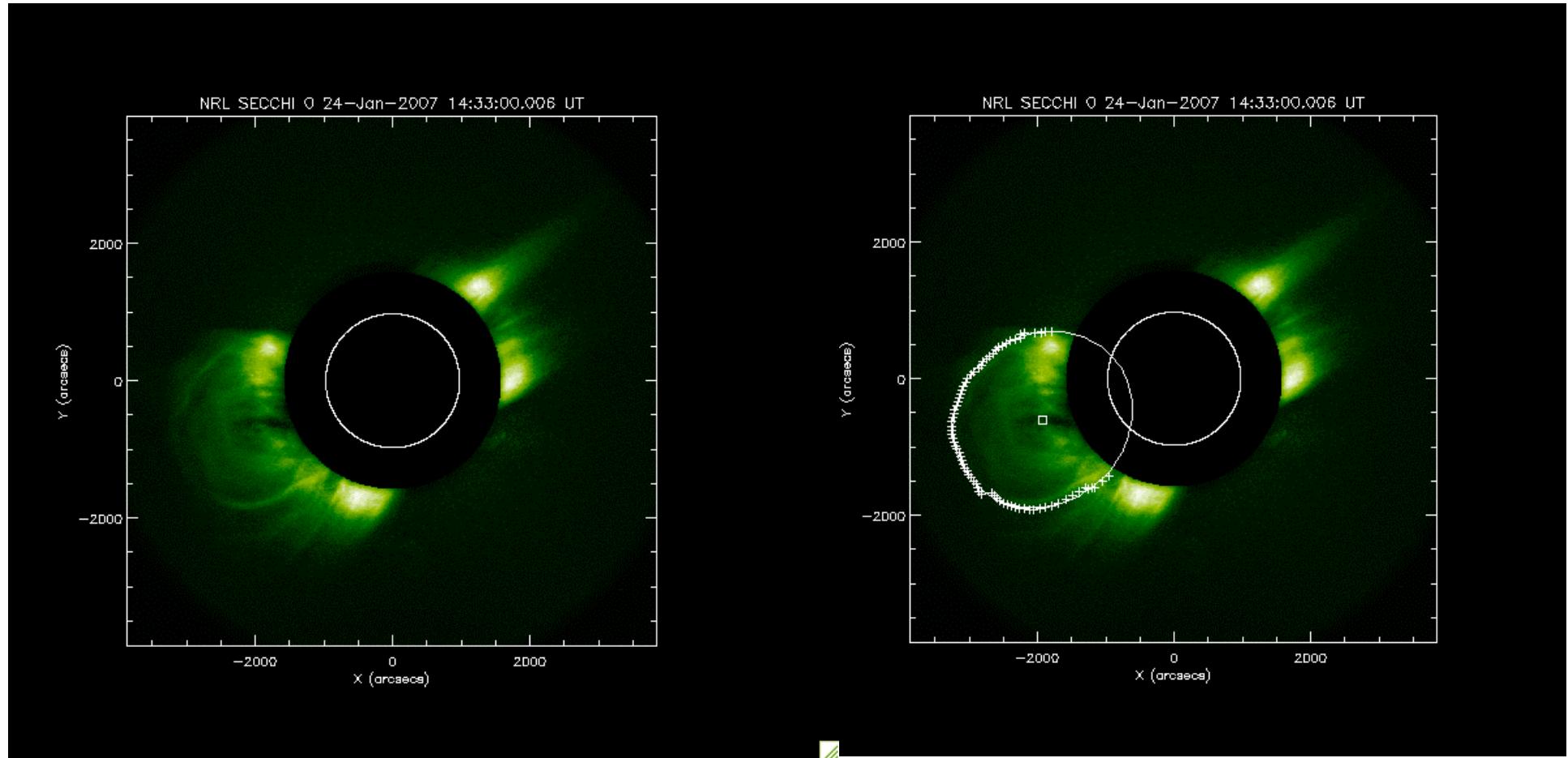
LASCO C2 & C3 19-Apr-00

5) CME Front Characterisation



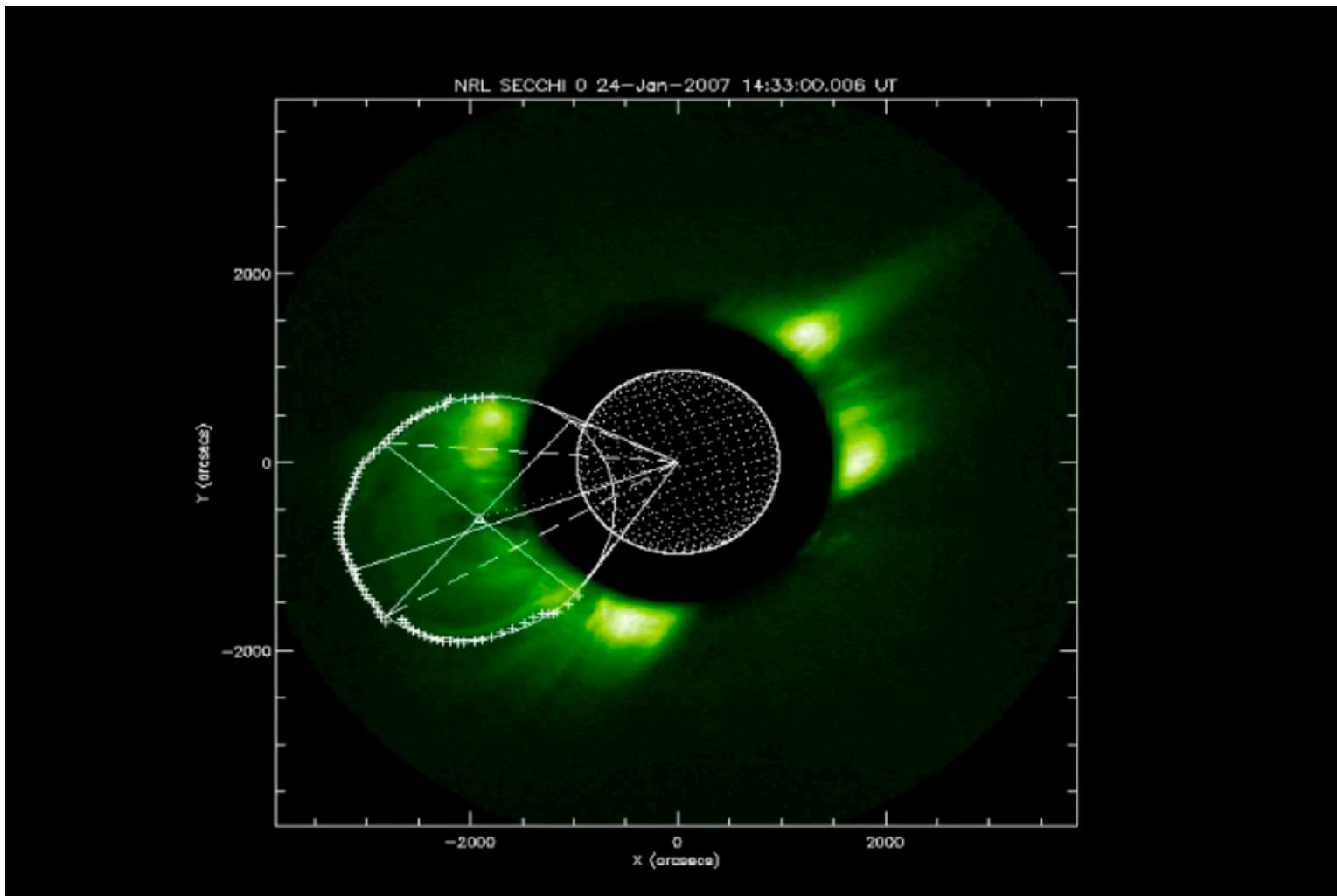
LASCO C2 & C3 23-Apr-01

5) CME Front Characterisation



SECCHI-A COR1 24-Jan-07

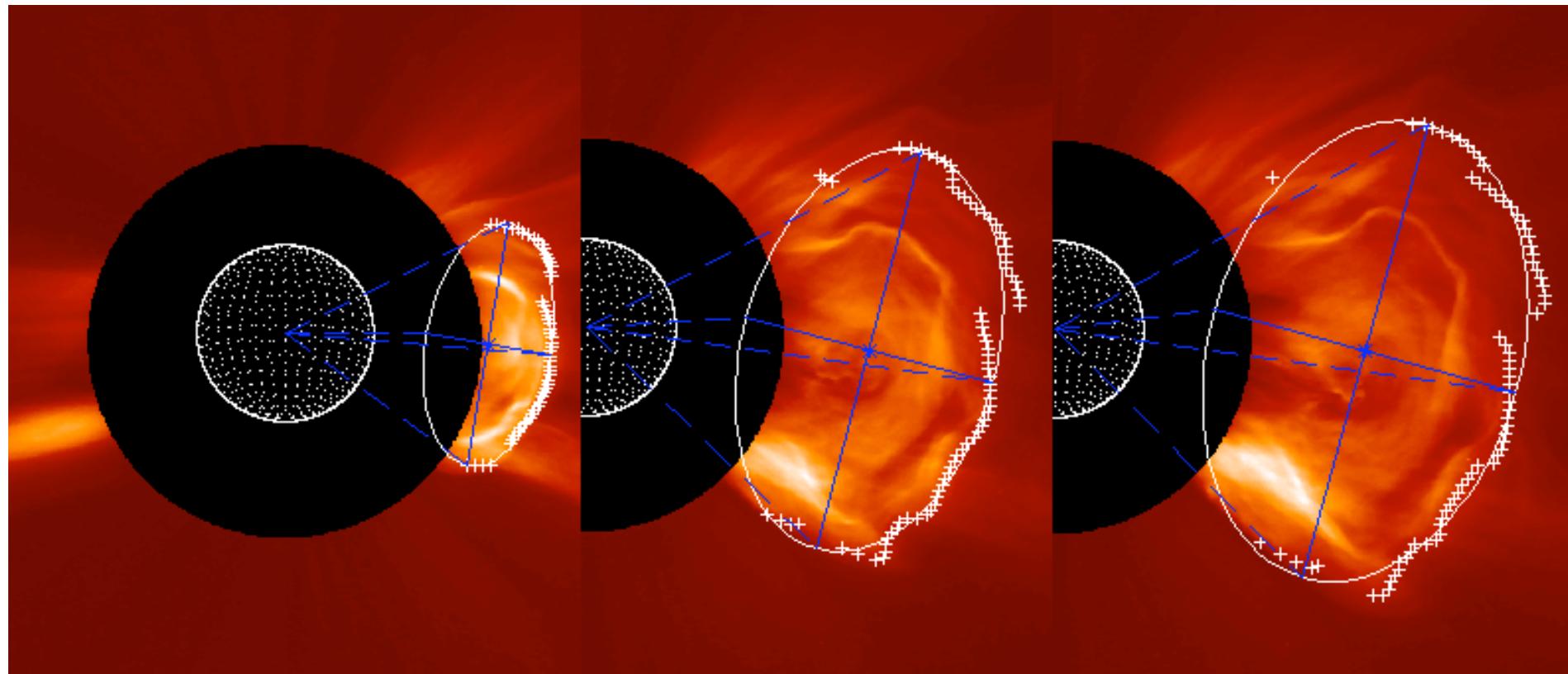
5) CME Front Characterisation



SECCHI-A COR1 24-Jan-07

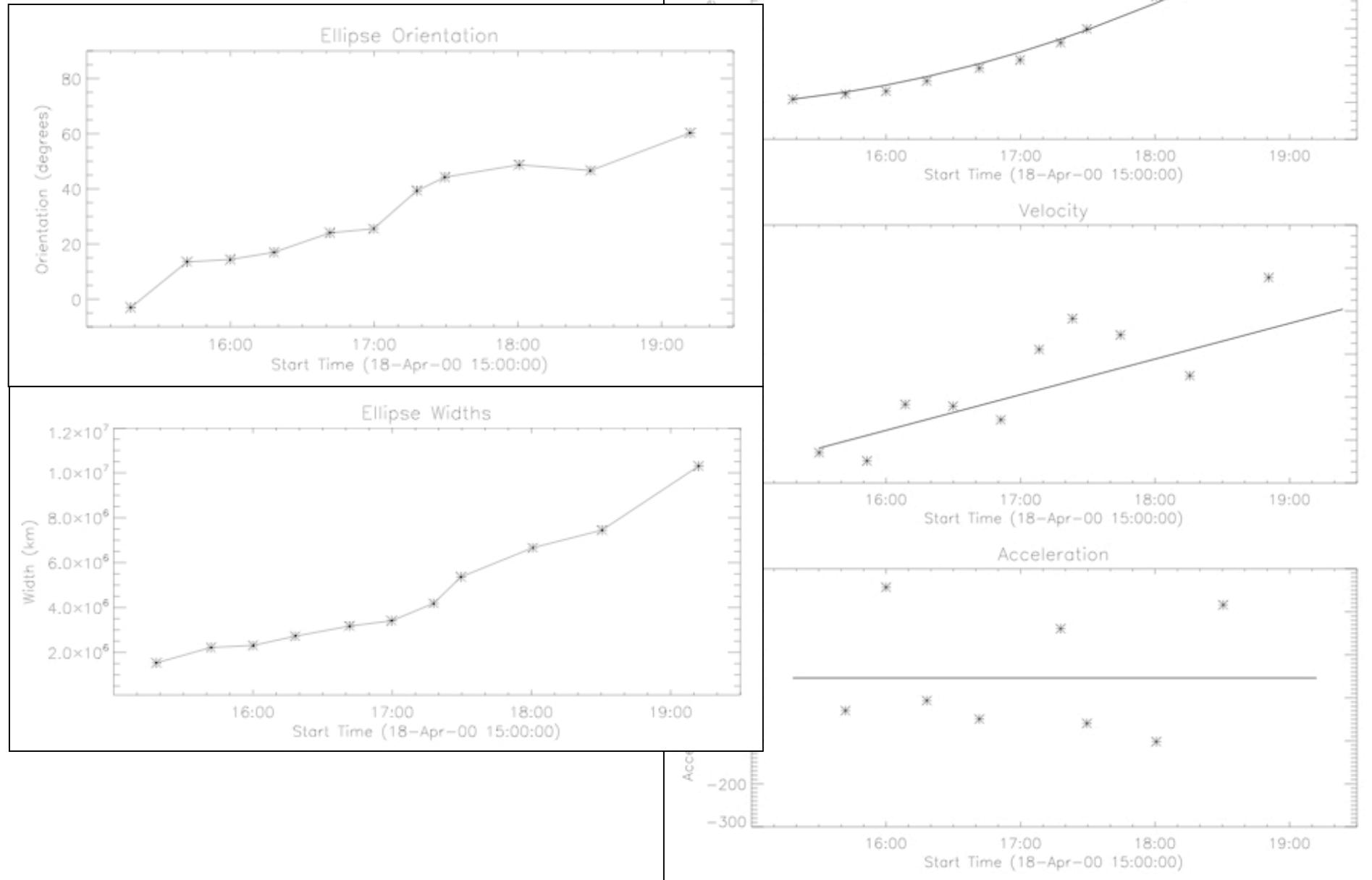
5) CME Front Characterisation

Kinematics & Morphology



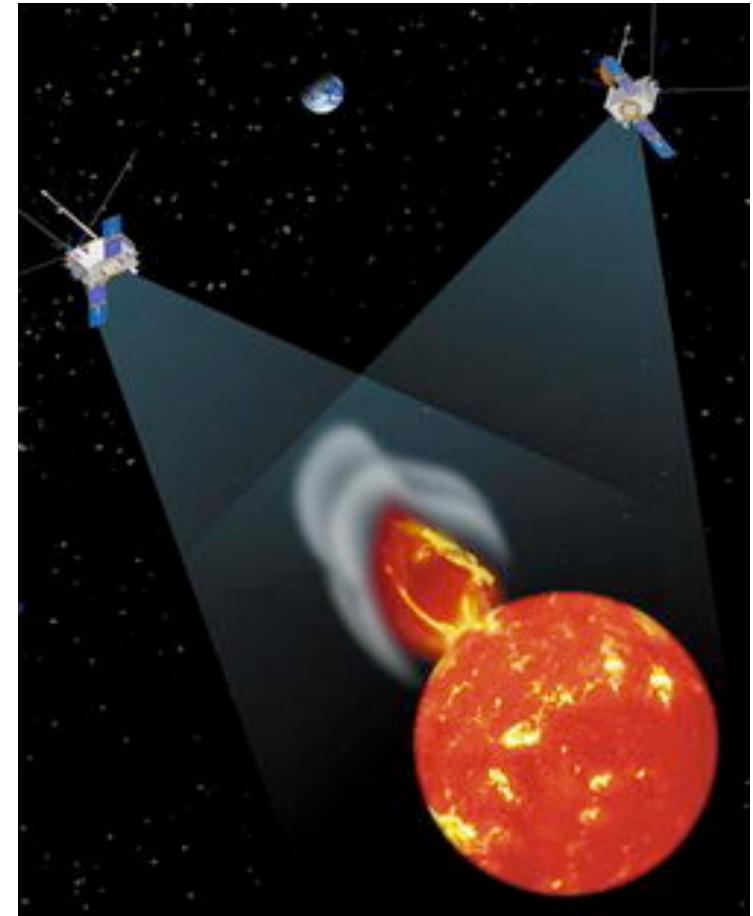
LASCO/C2 24-Jan-07

5) CME Front Characterisation



Next Steps...

- More data; distribution of CME kinematics.
- Multiple view points (STEREO); triangulation / projection effects.
- Automated front detection; space weather forecasting.



STEREO illustration

Thank You

Acknowledgments



NRL:

Angelos Vourlidas, Simon Plunkett.



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jbyrne6@gmail.com

Movie Scripts

- http://www.maths.tcd.ie/~jaydog/Solar/canny_atrous/arrow_01apr04.html
- http://www.maths.tcd.ie/~jaydog/Solar/canny_atrous/automation/20000118_arrows_combined_rebin.html
- http://www.maths.tcd.ie/~jaydog/Solar/canny_atrous/automation/20040401_arrows_combined_rebin.html
- http://www.maths.tcd.ie/~jaydog/Solar/CME_ellipse_movies/20070124/C2_movie_ell.html
- http://www.maths.tcd.ie/~jaydog/Solar/CME_ellipse_movies/20070124/C3_movie_ell.html