The Kinematics and Morphologies of Coronal Mass Ejections using Multiscale Methods

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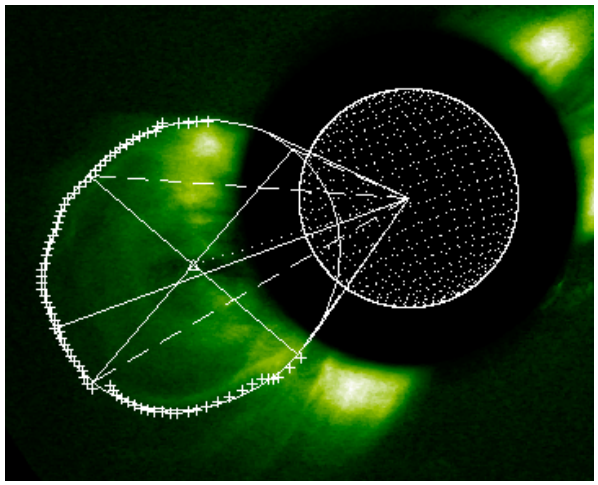
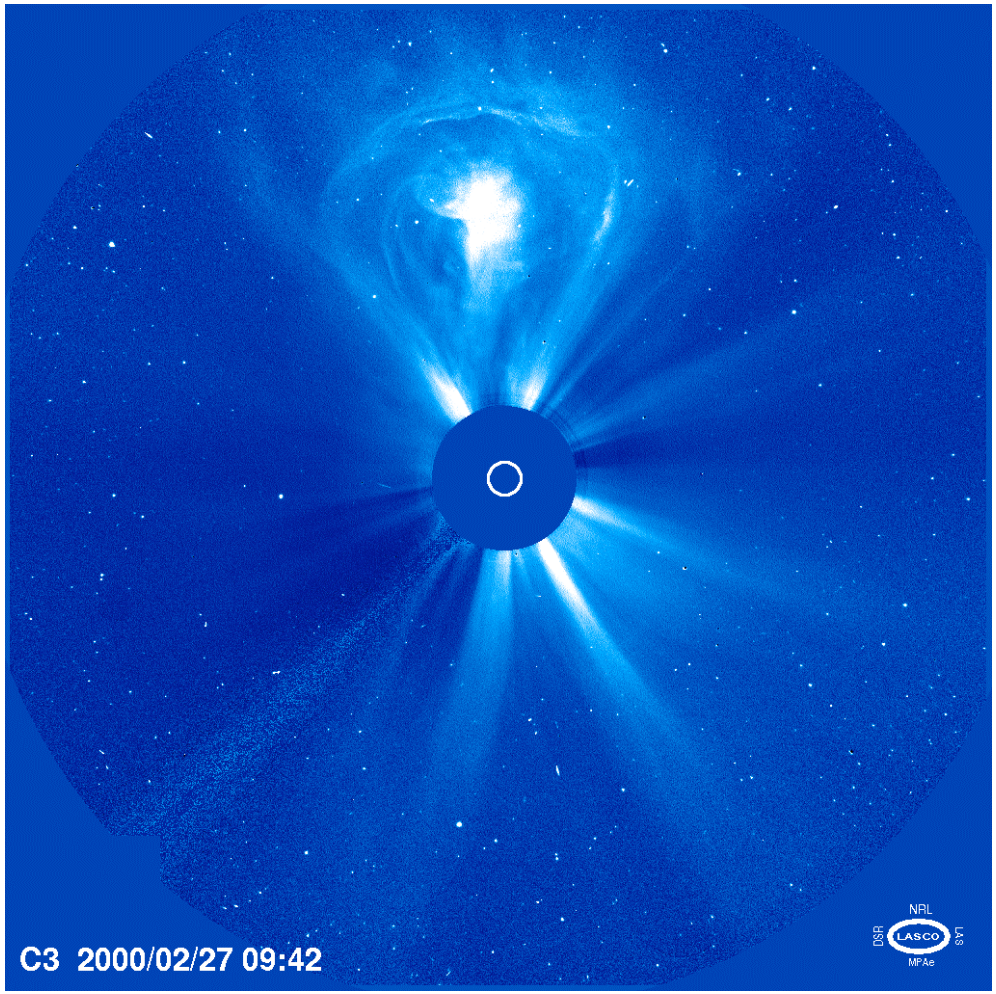


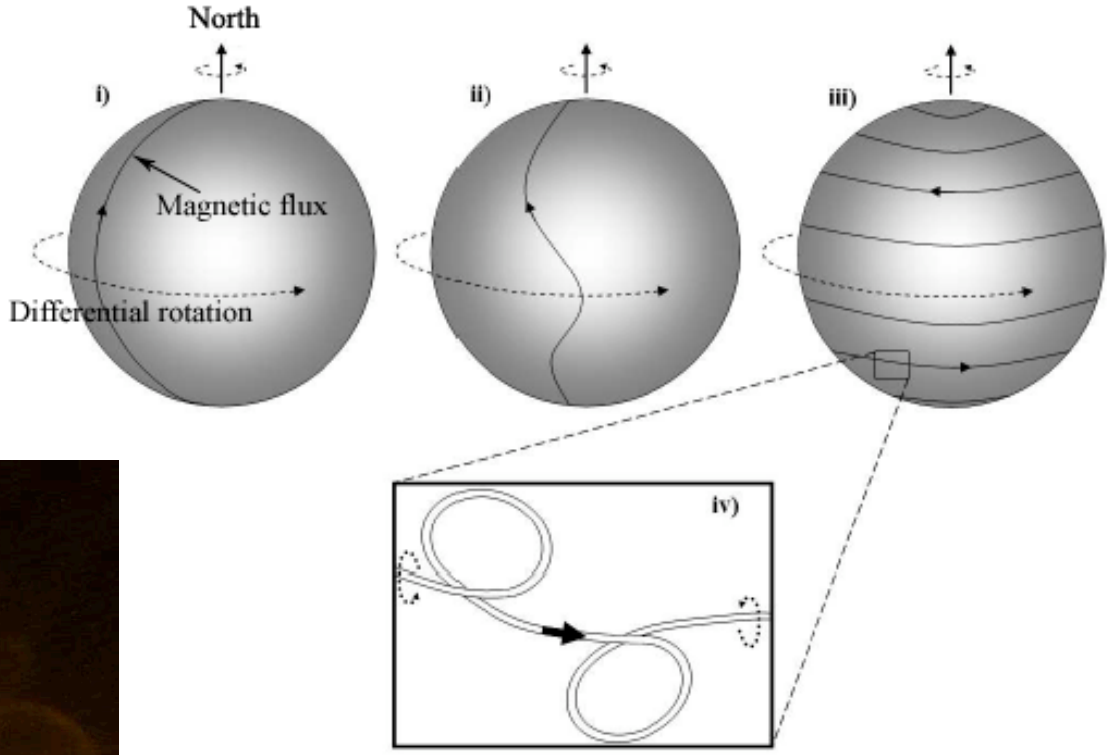
STEREO/Cor1 24-Jan-07

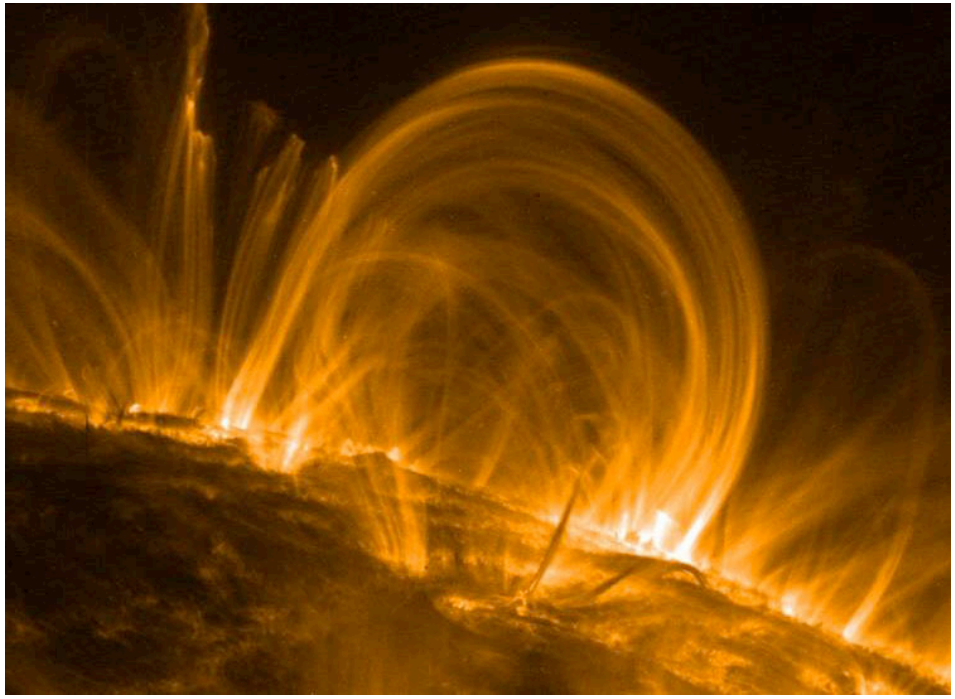
Overview

- Coronal mass ejections
  - Solar corona
  - Observations
  - CME models
- Image processing: multiscale methods
- Application to spacecraft data:
  - LASCO & SECCHI
  - CME Kinematics



Solar Corona

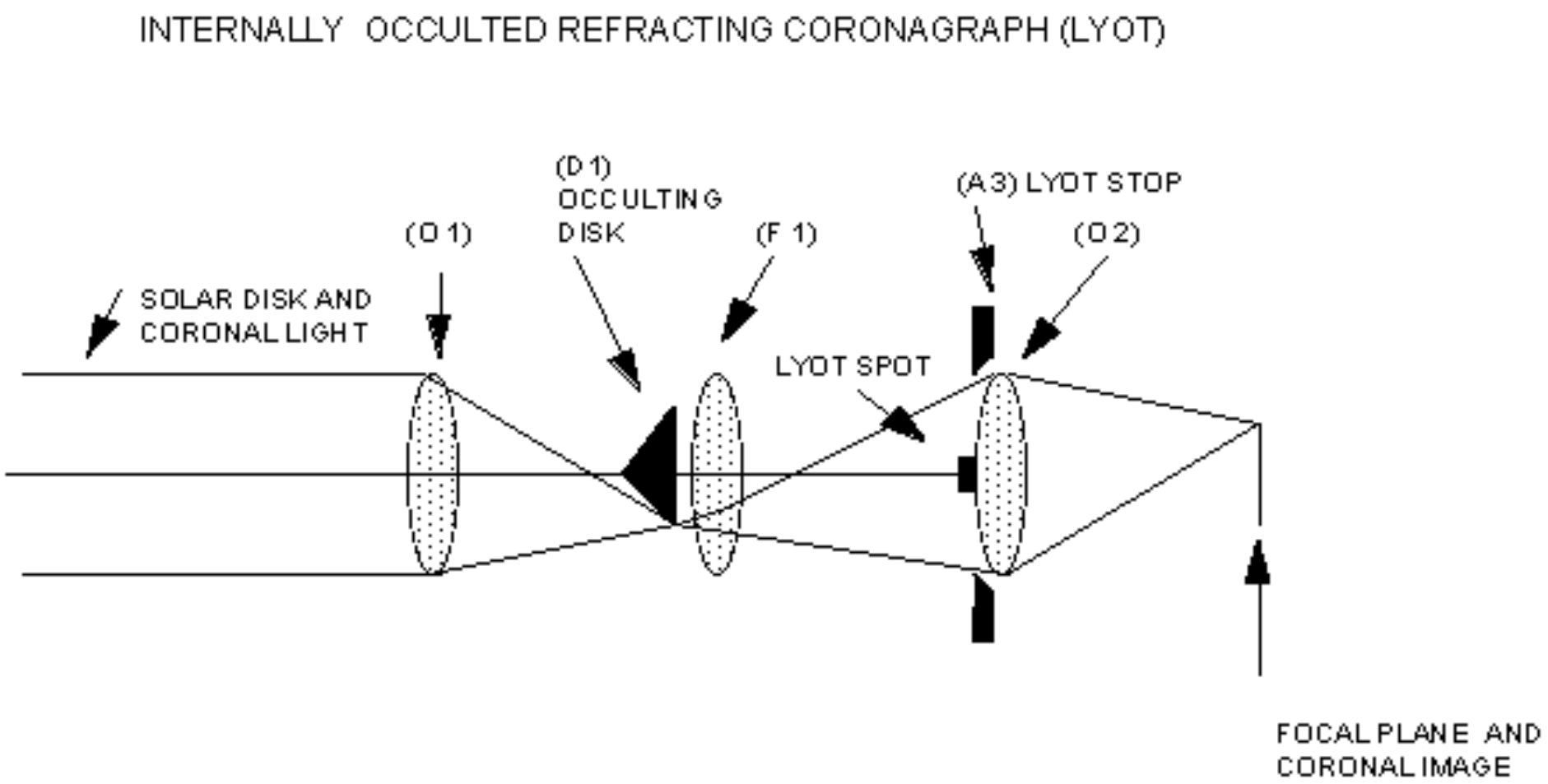




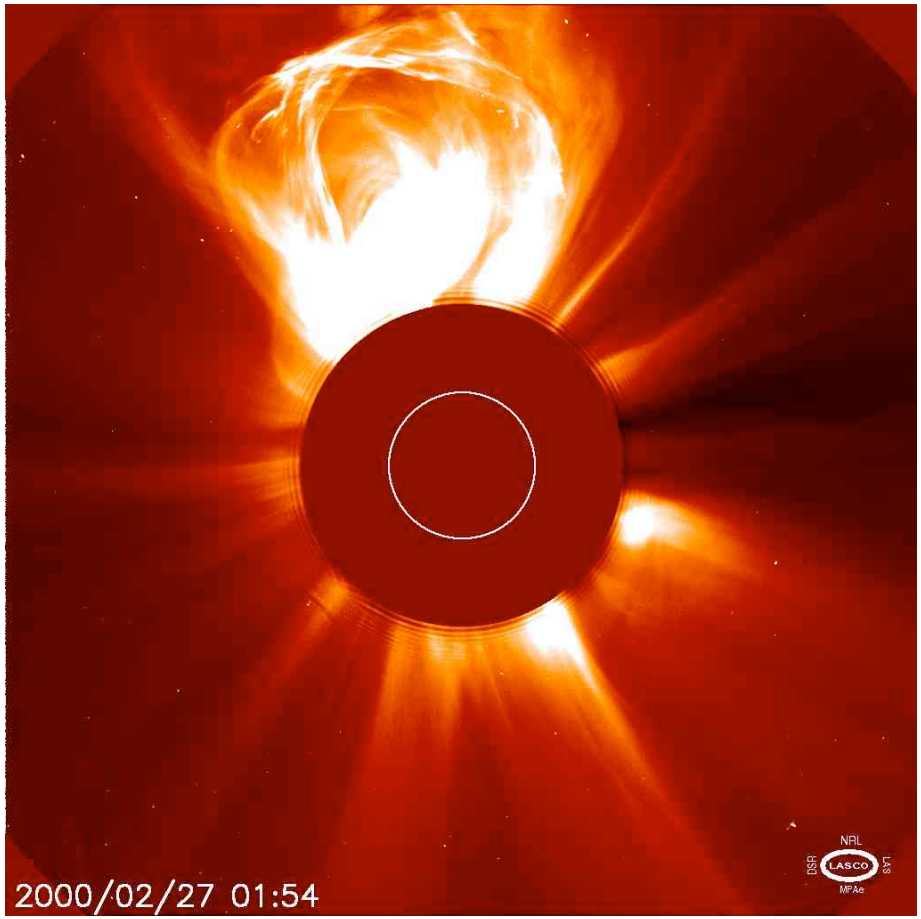
Above, coronal loops observed by Trace.

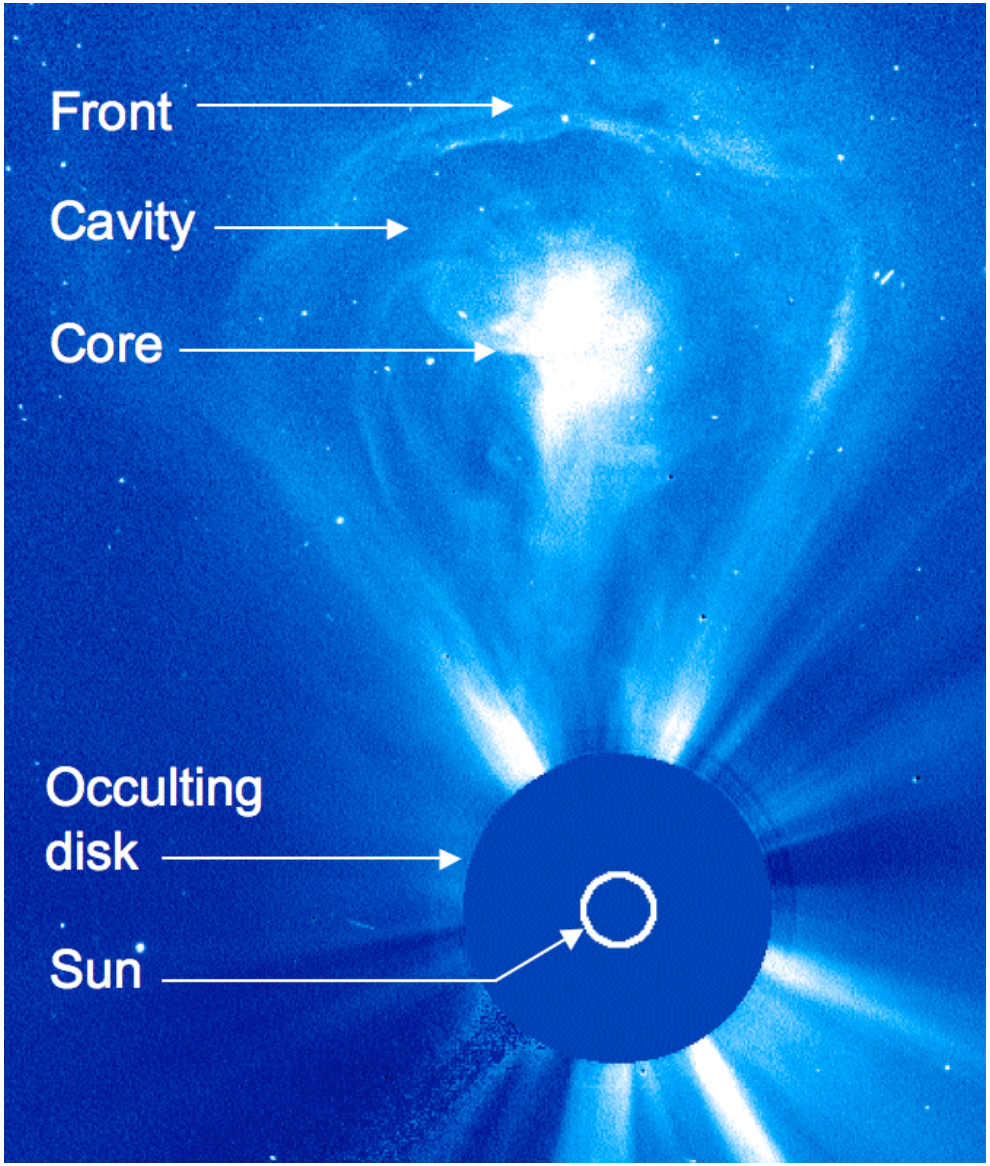
Right, the solar corona during an eclipse.

Observations: Coronagraph



Observations: CMEs

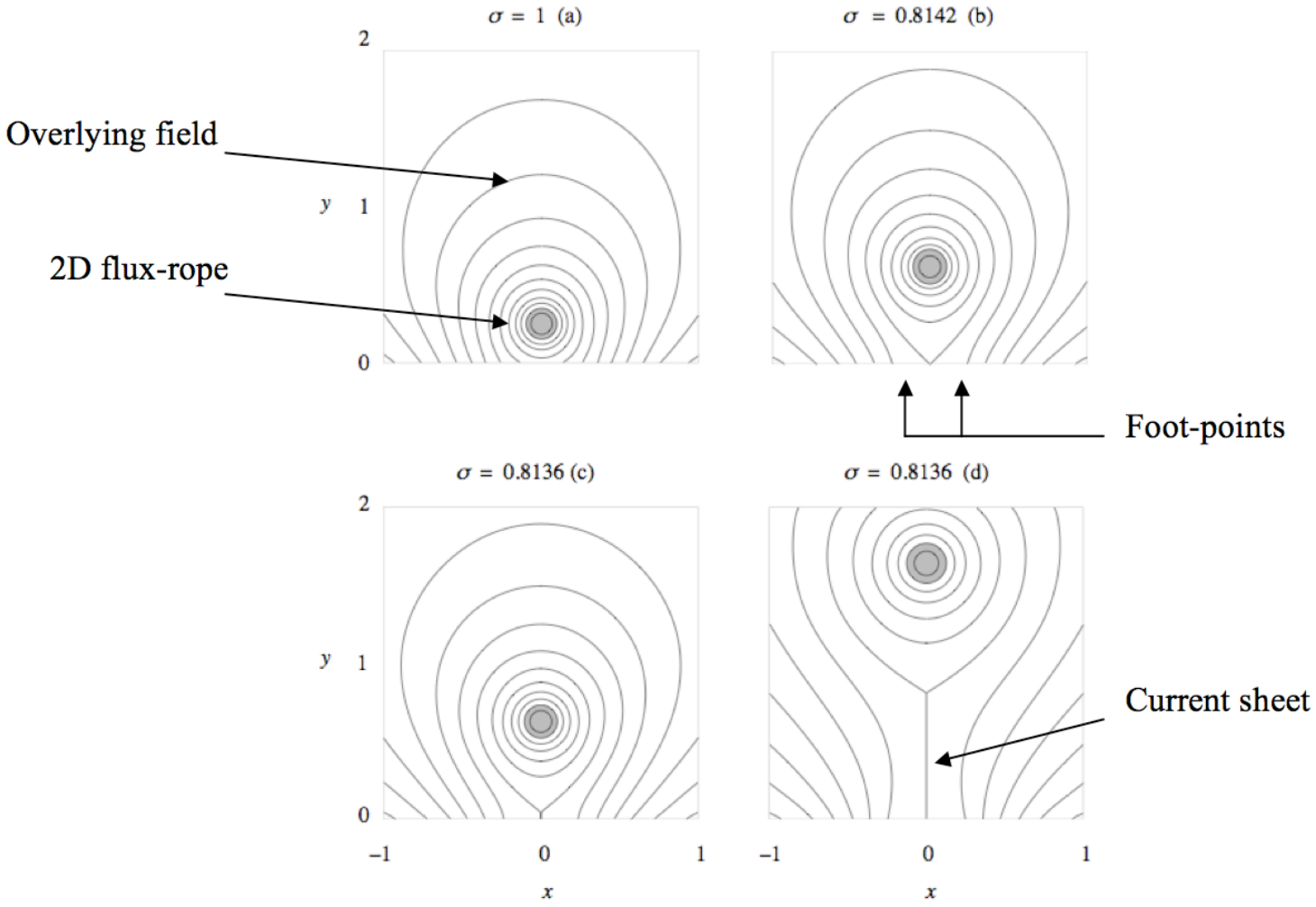




LASCO/C3 27-Feb-00

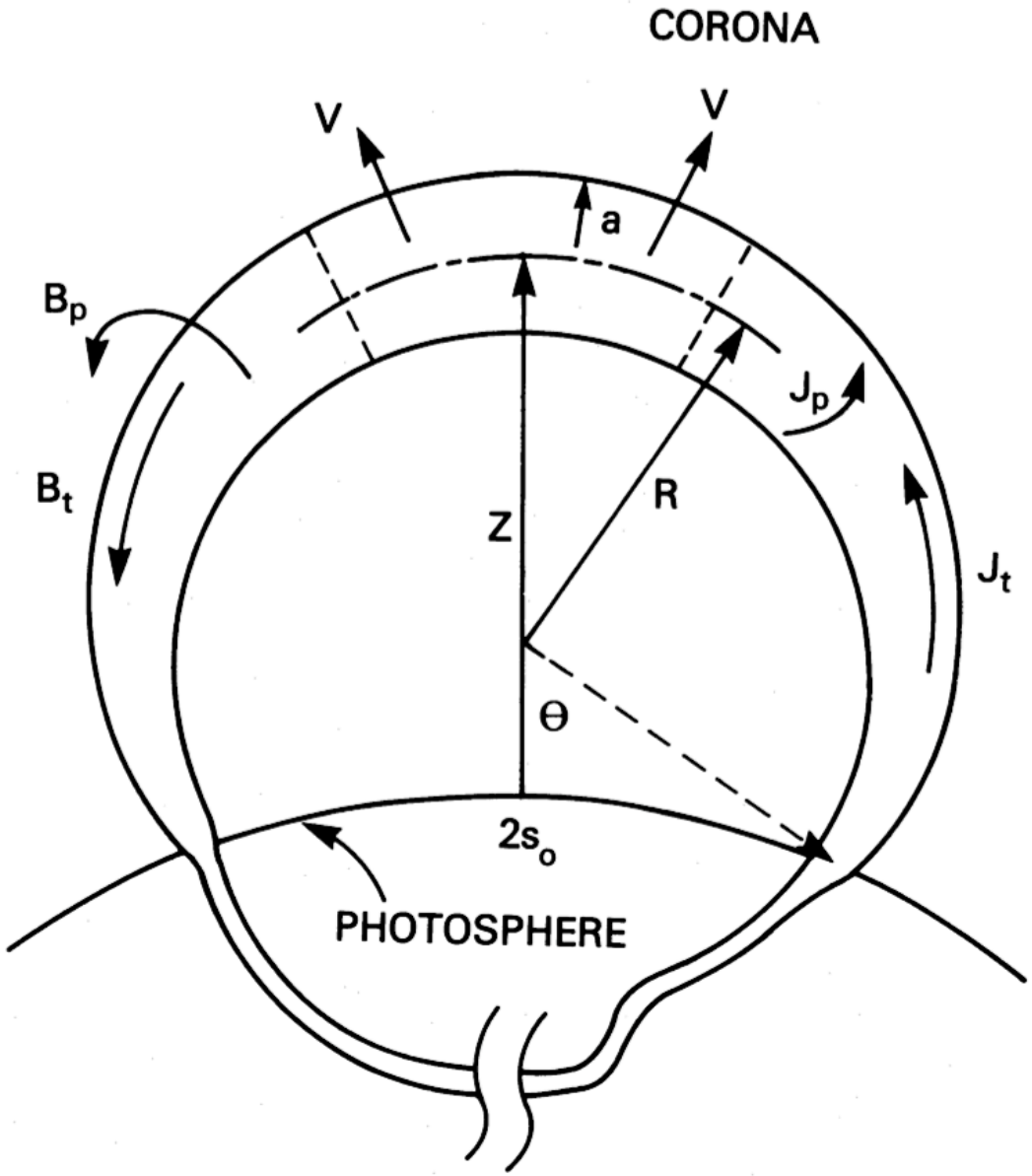
CME Models

- 2D flux-rope



CME Models

- 3D flux-rope



CME Models

- 2.5D breakout

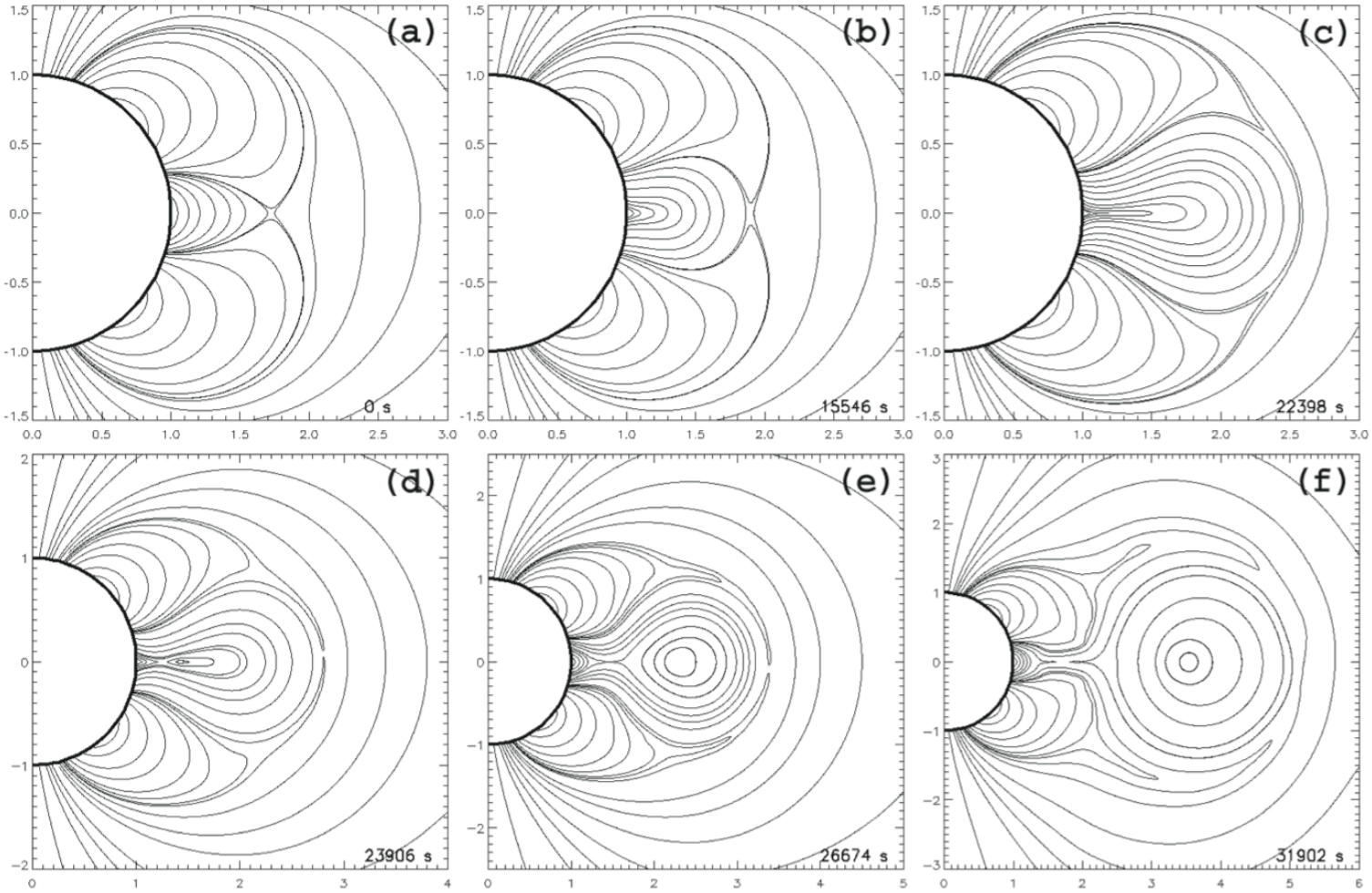
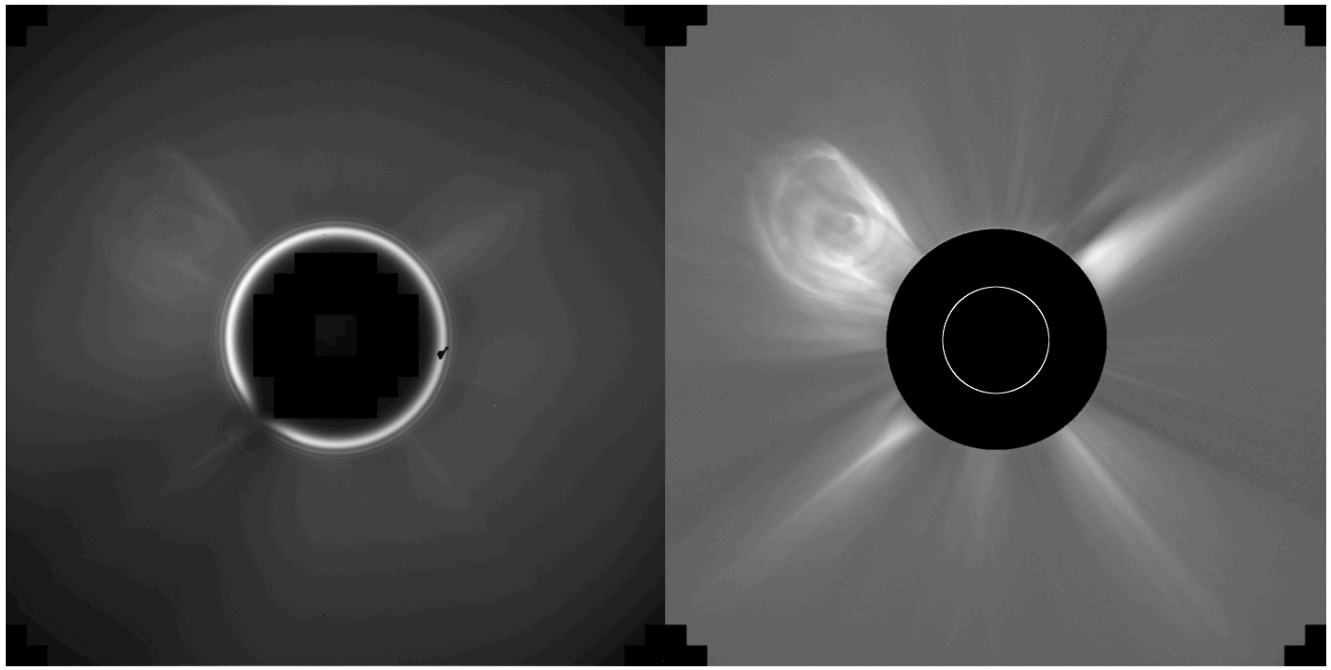


Image Pre-Processing

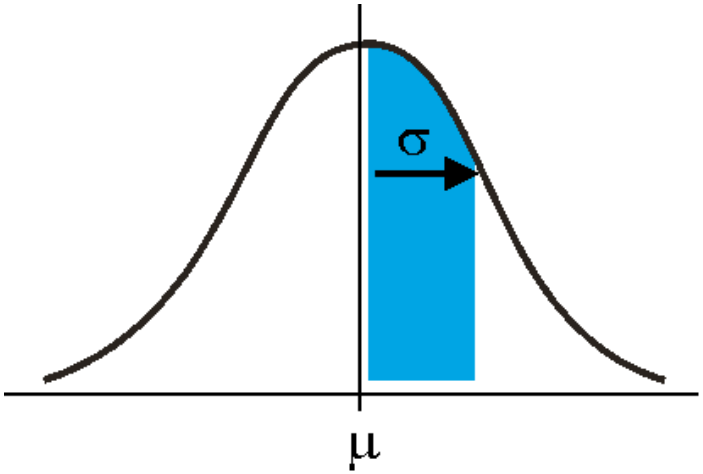
- Normalisation
  - exposure time
  - CCD bias
  - data dropouts
- Background subtraction
- Median filtering (de-noising)

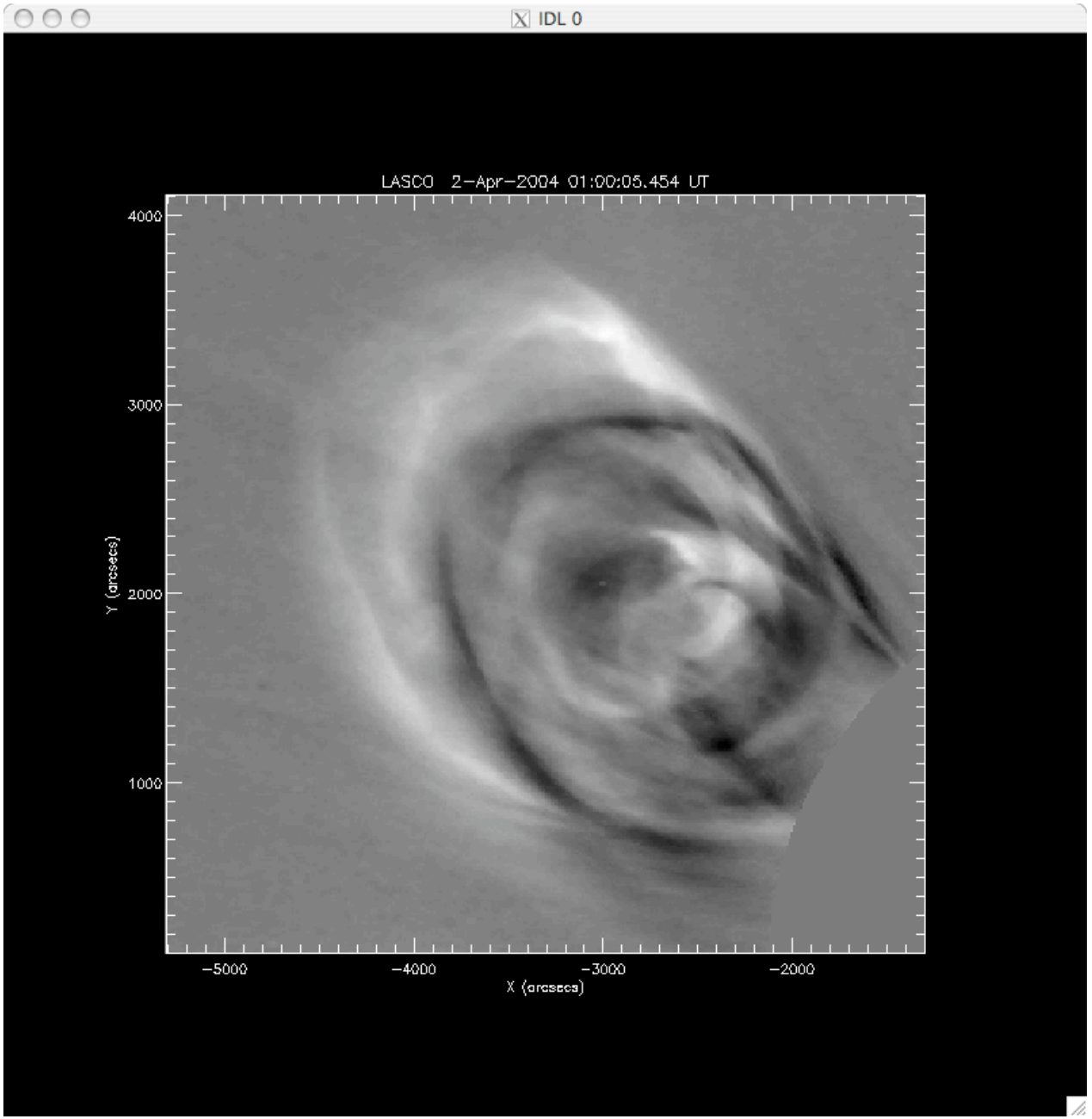


LASCO/C2 18-Apr-00

Multiscale Motivation

Running difference:





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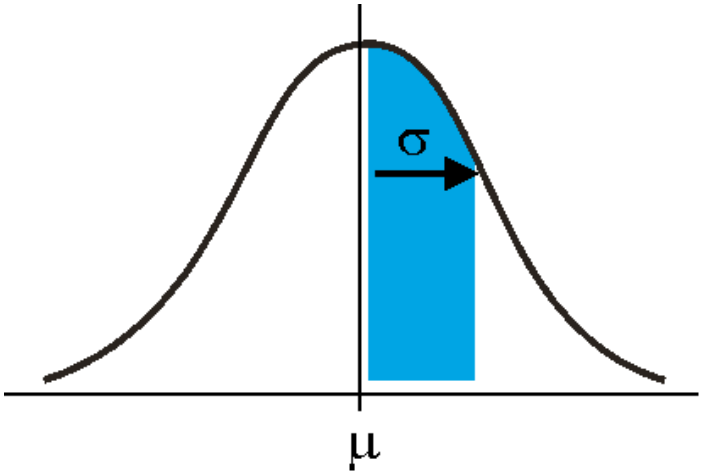
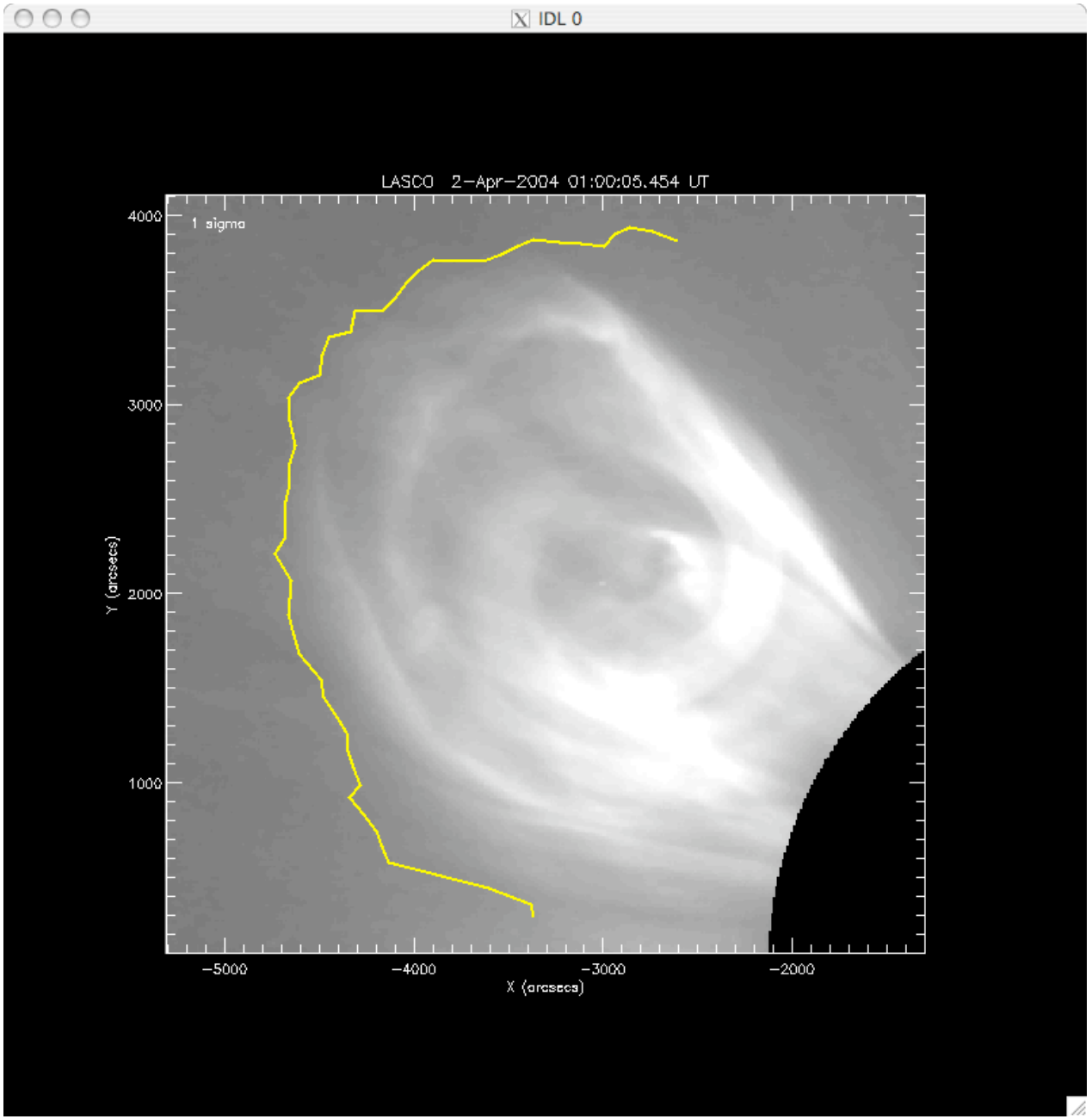


- 1 sigma



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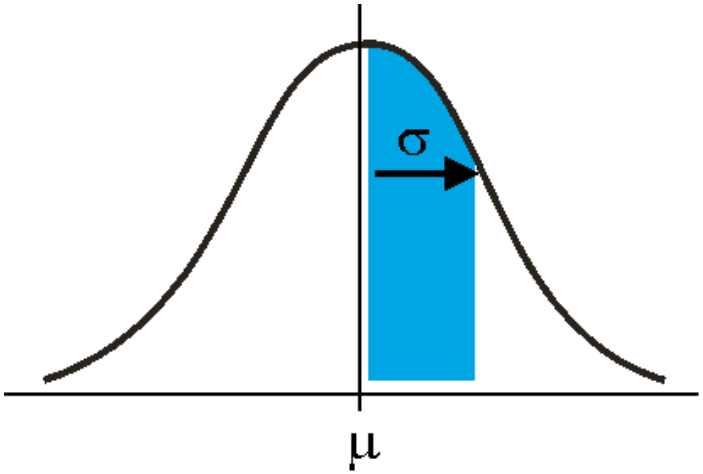
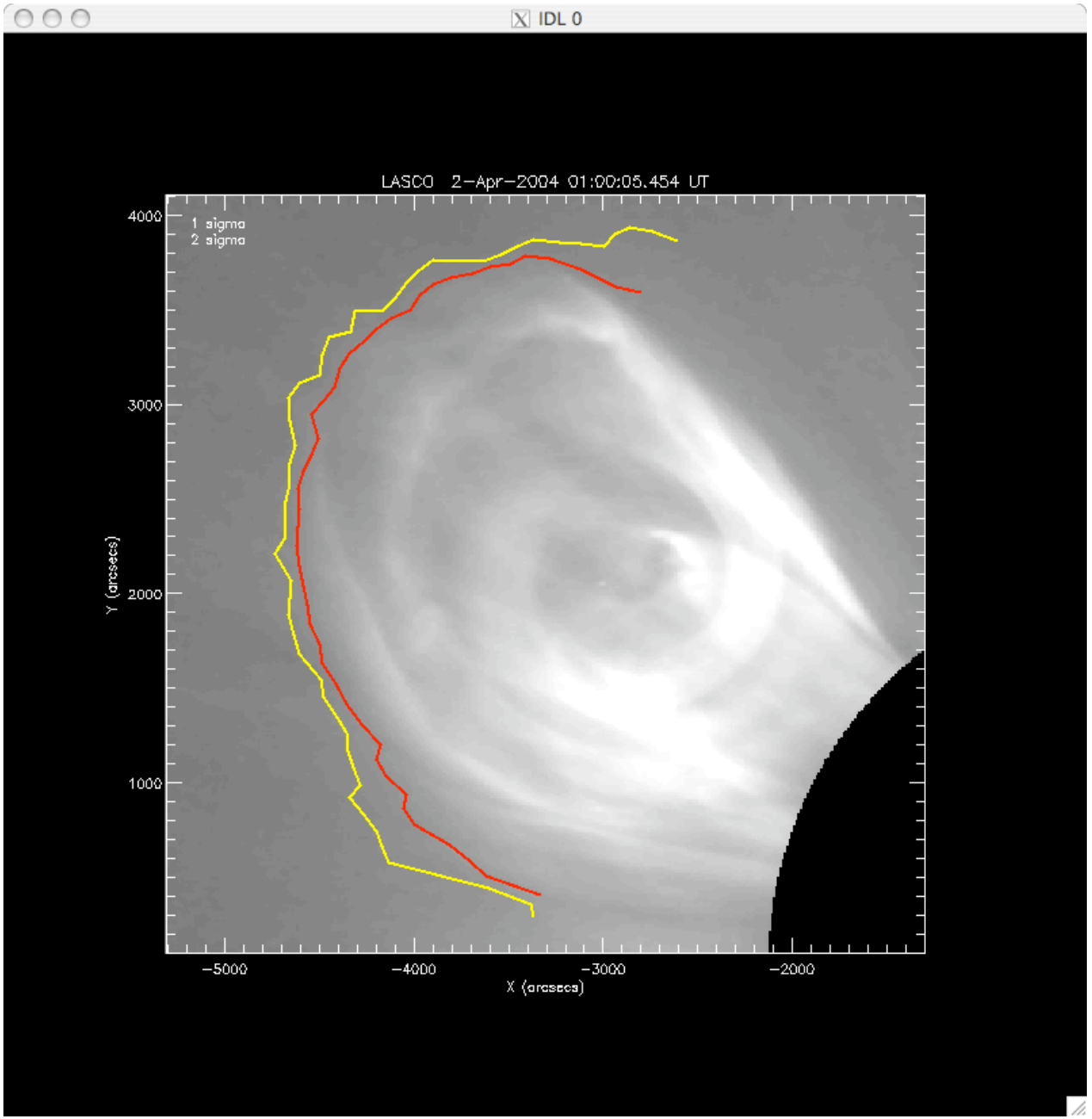
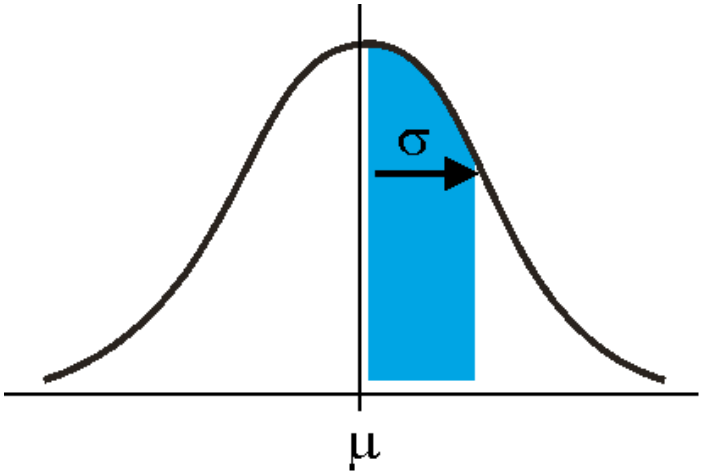


- 1 sigma
- 2 sigma

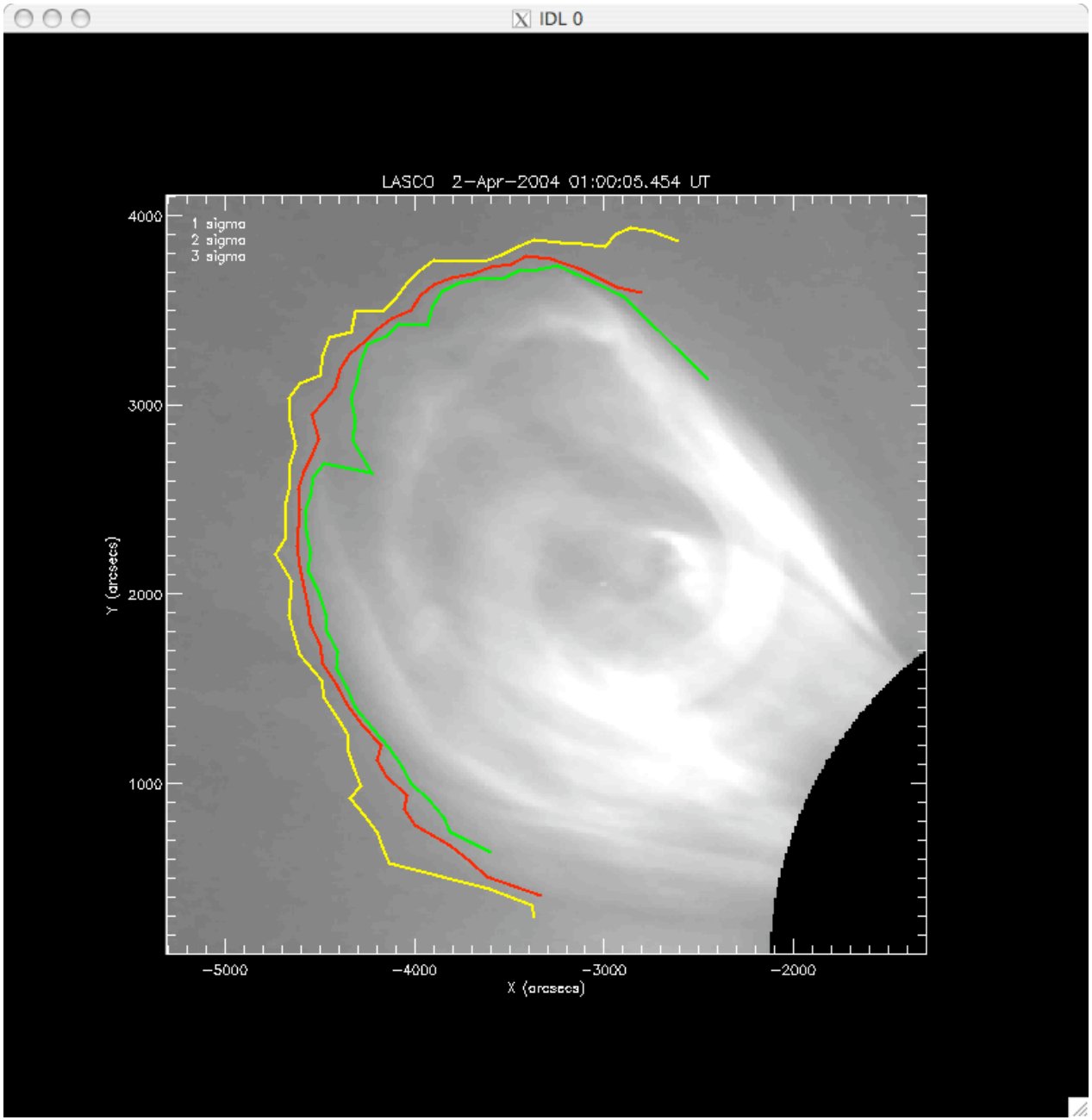


Multiscale Motivation

Running difference:

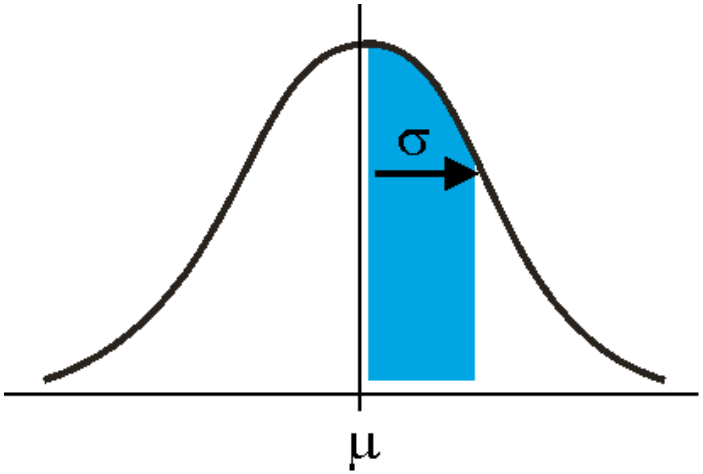


- 1 sigma
- 2 sigma
- 3 sigma



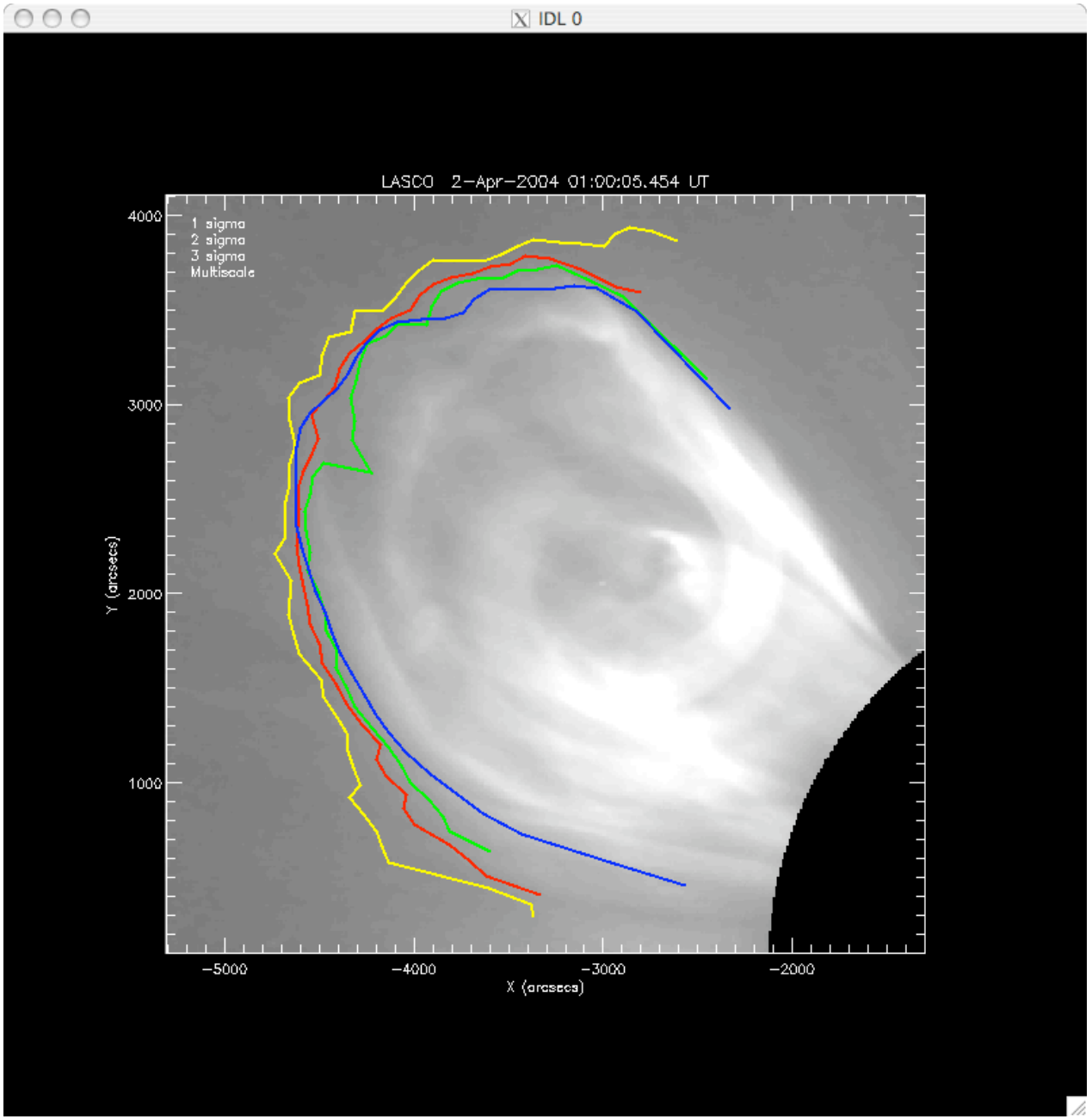
Multiscale Motivation

Running difference:



- 1 sigma
- 2 sigma
- 3 sigma
- Multiscale

Errors are small
--exposure time



Finding the CME Front

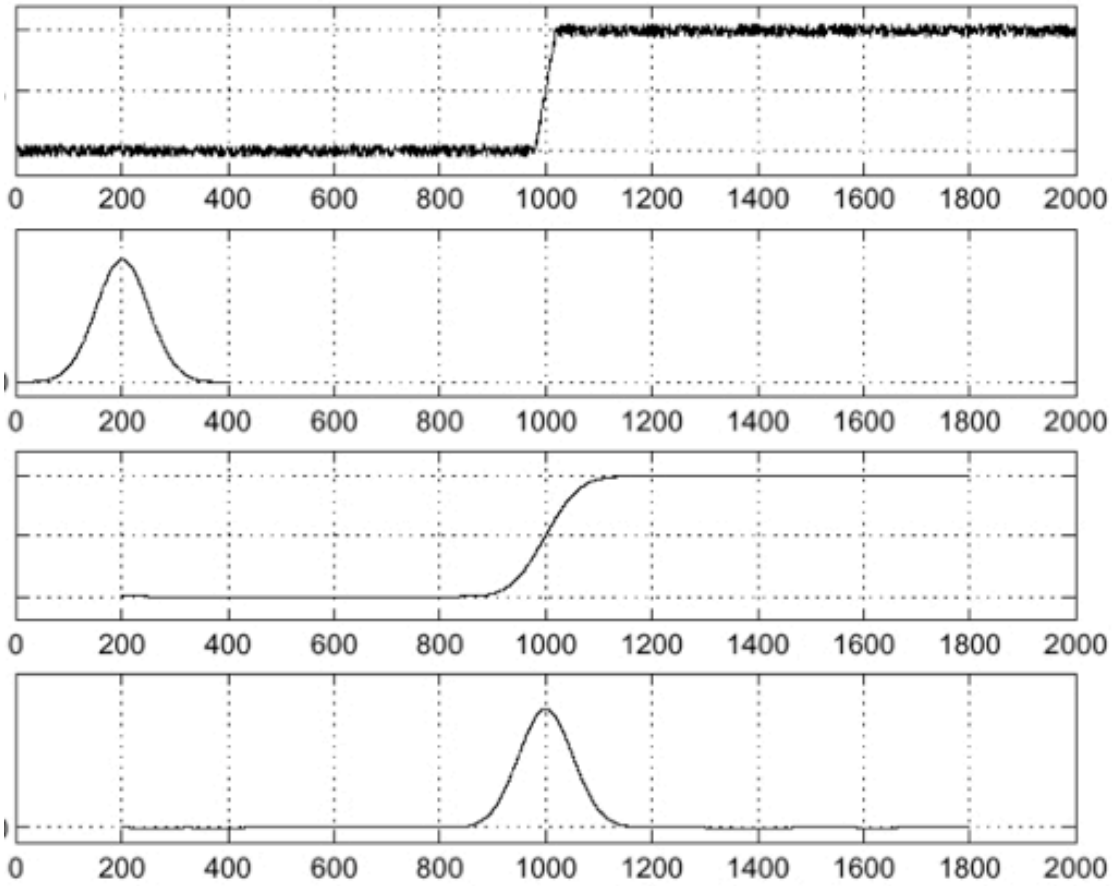
Edge Detection:

s

h

$s * h$

$\frac{\partial}{\partial x}(s * h)$



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

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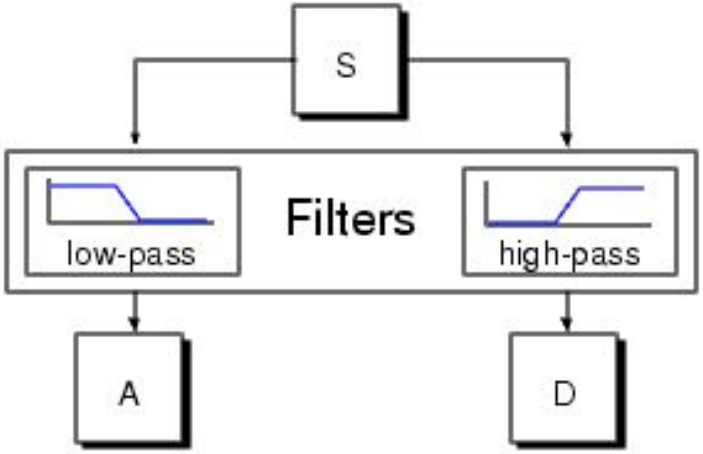
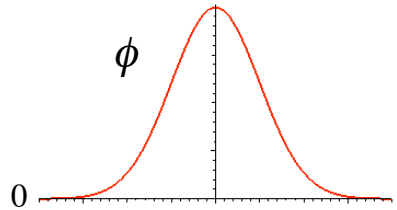
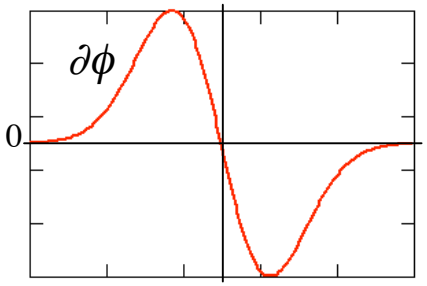
Input: s

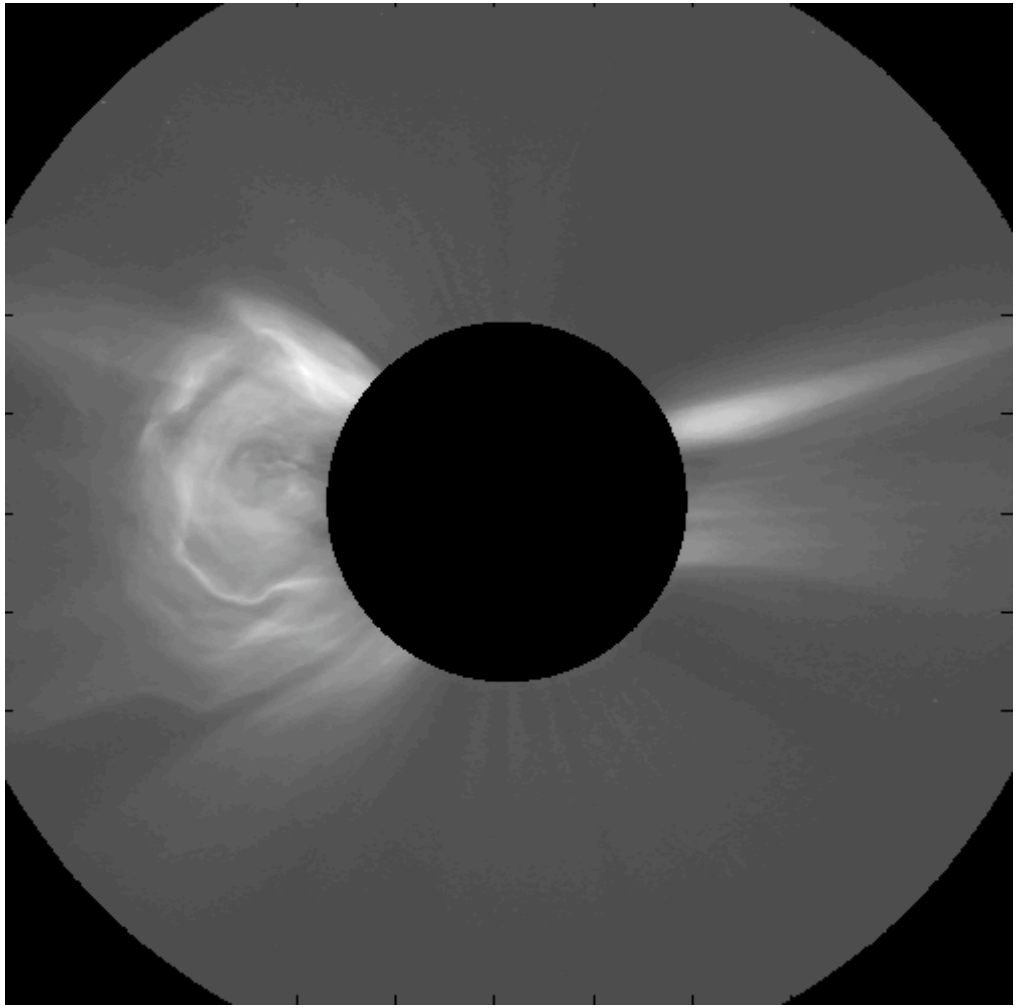


Low pass: Approximation



High pass: Detail

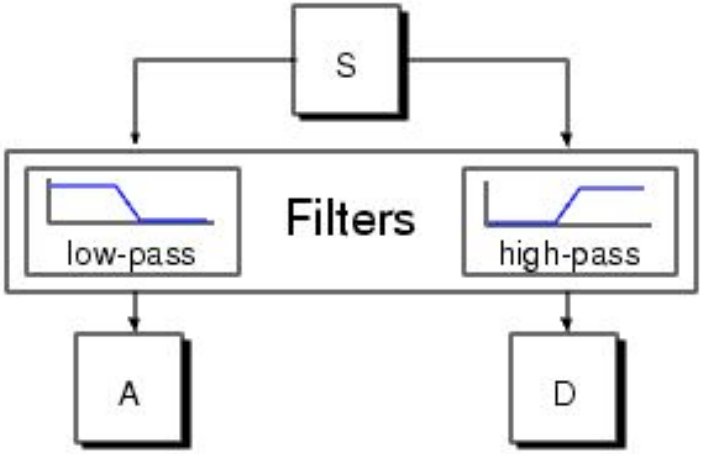




LASCO/C2 24-Jan-07

1) Multiscale Decomposition

Input: s



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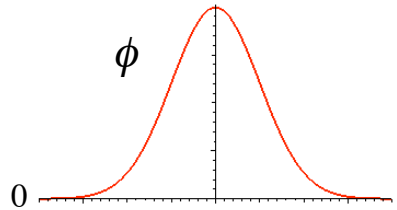

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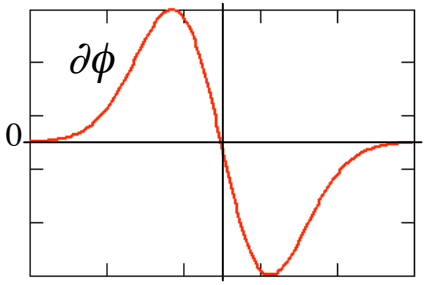

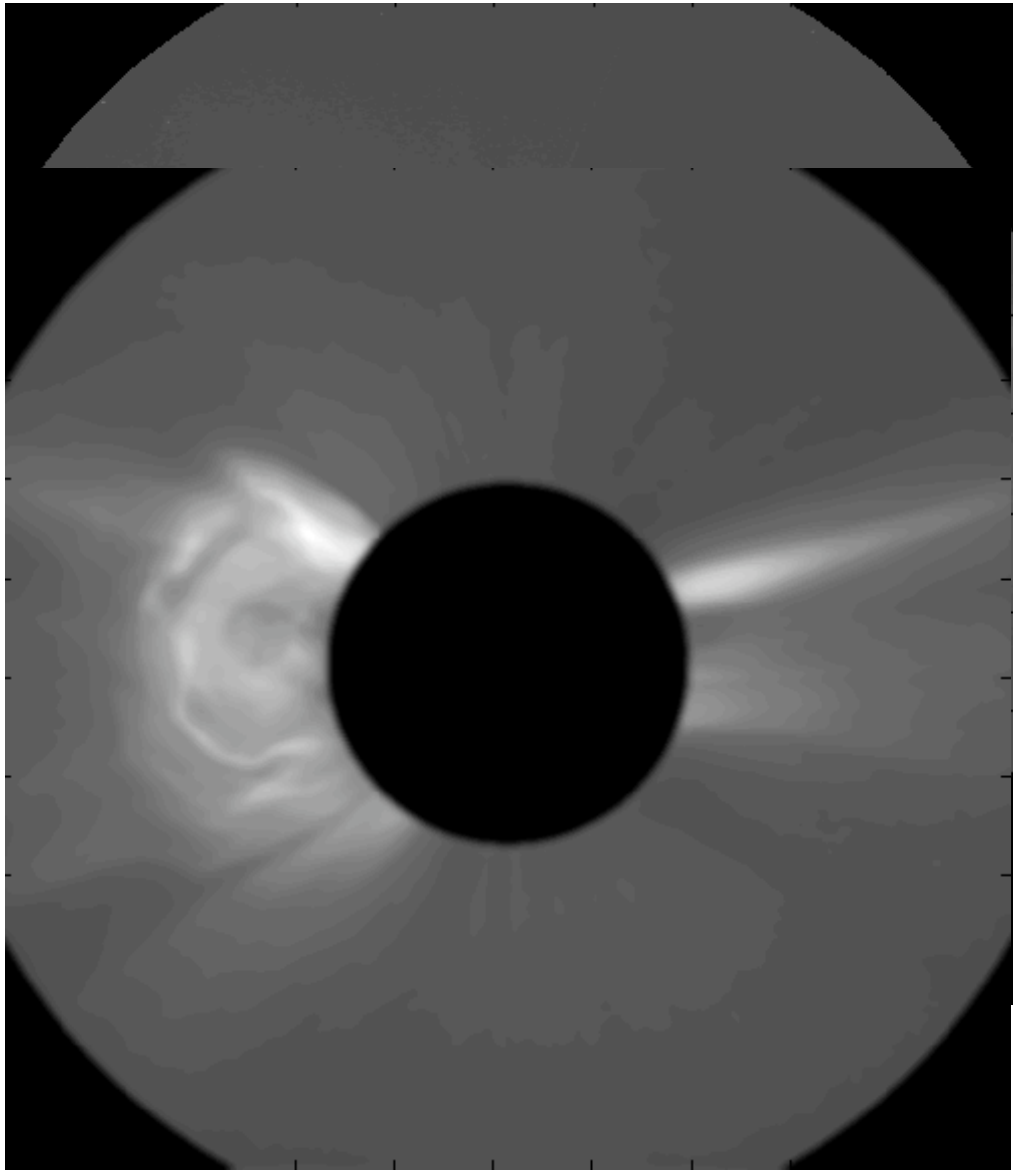

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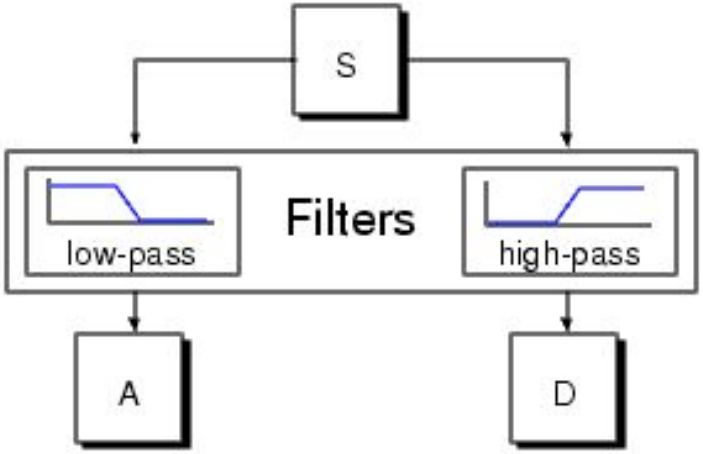

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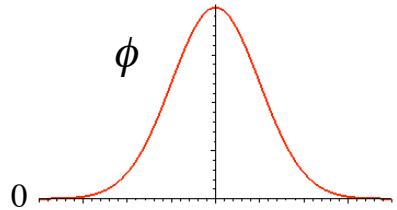

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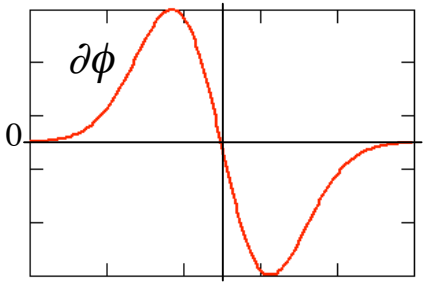

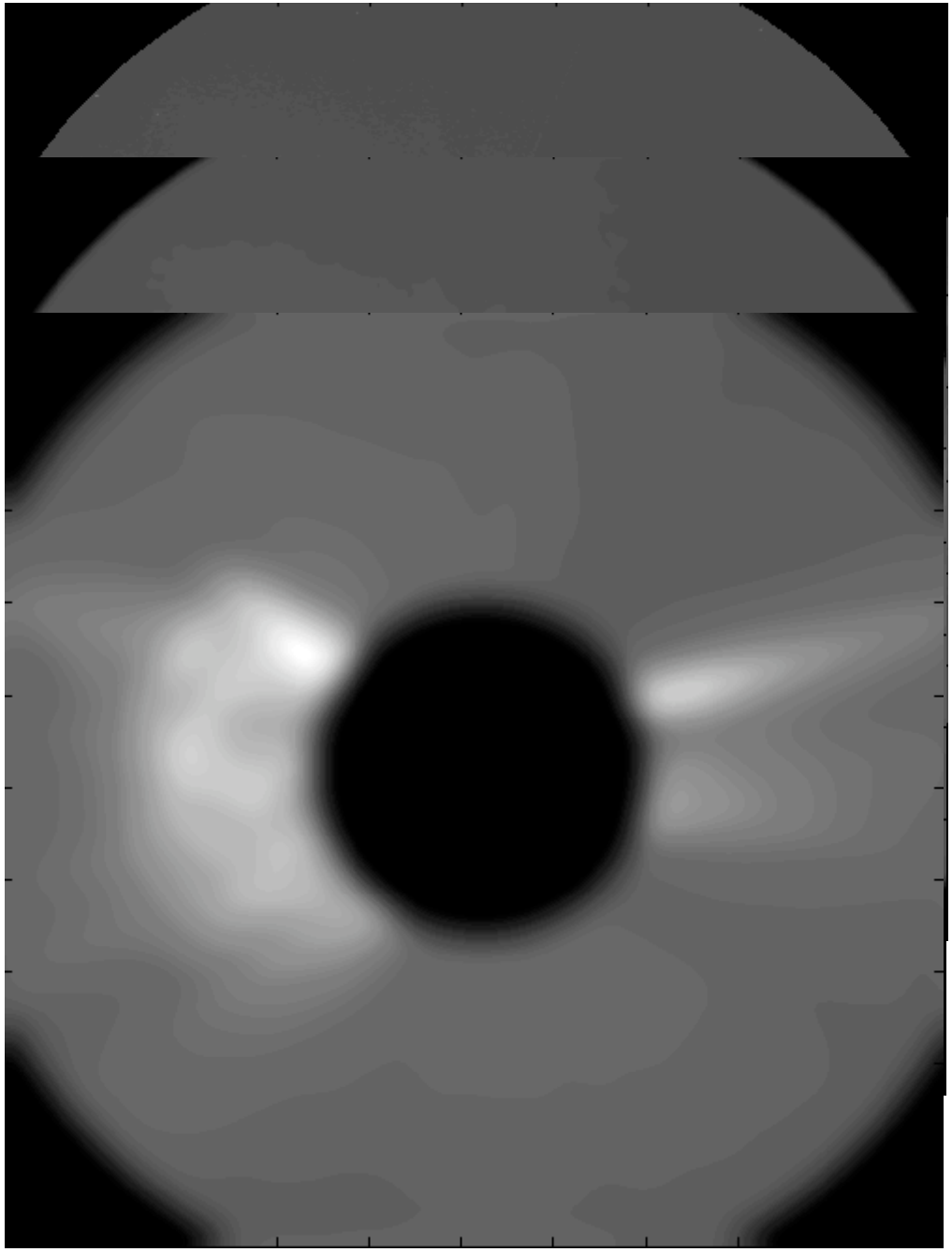

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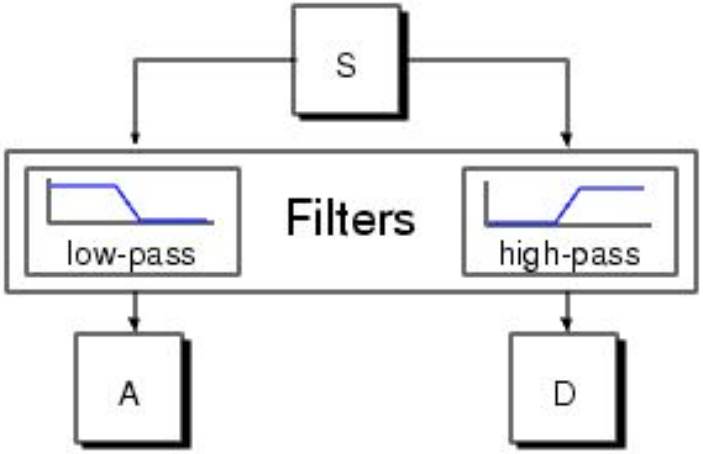

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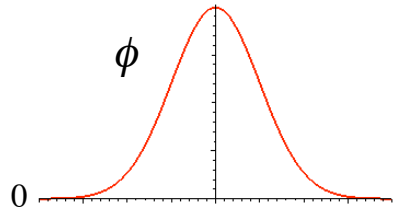

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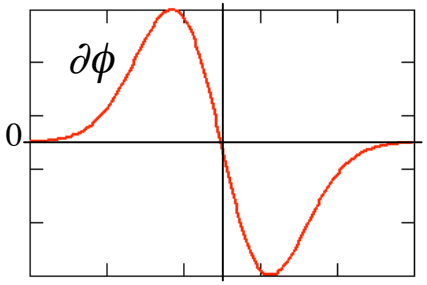
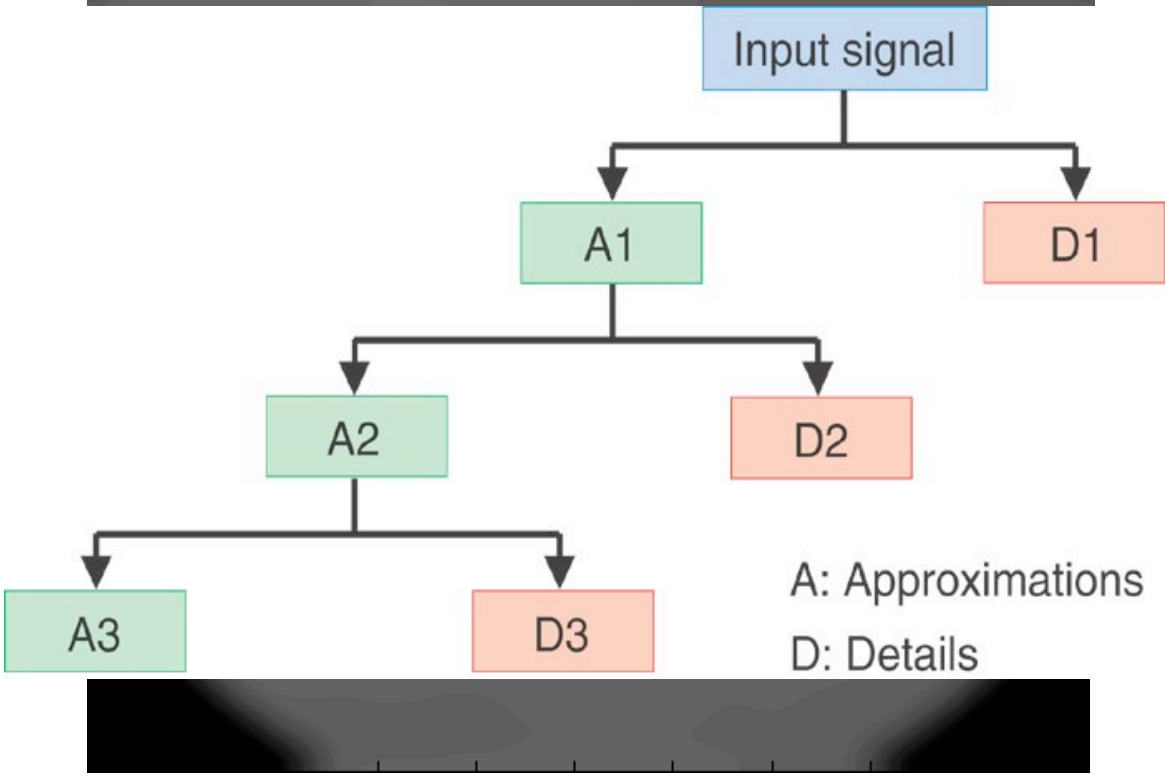
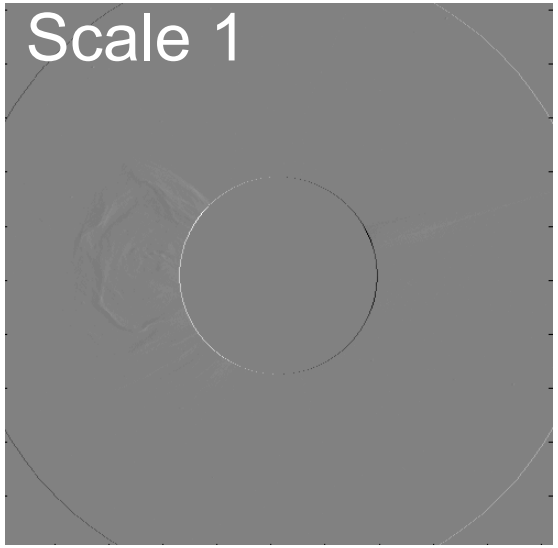
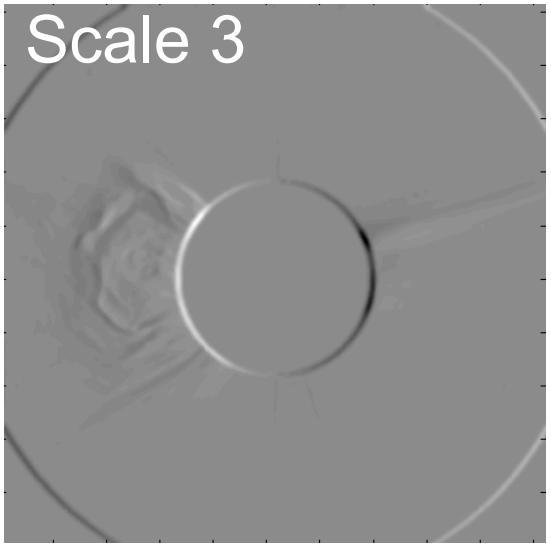


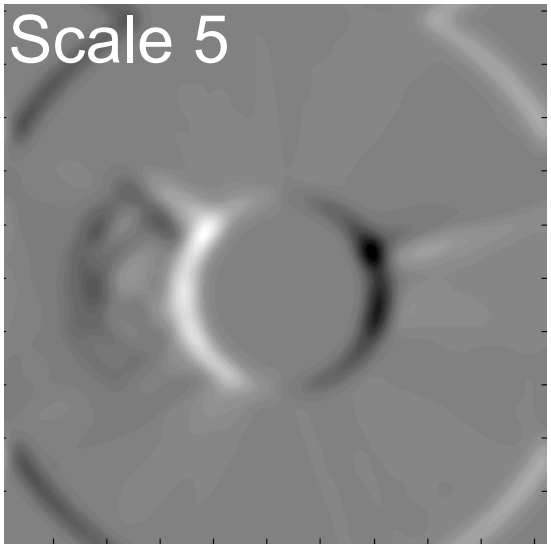


1) Multiscale Decomposition

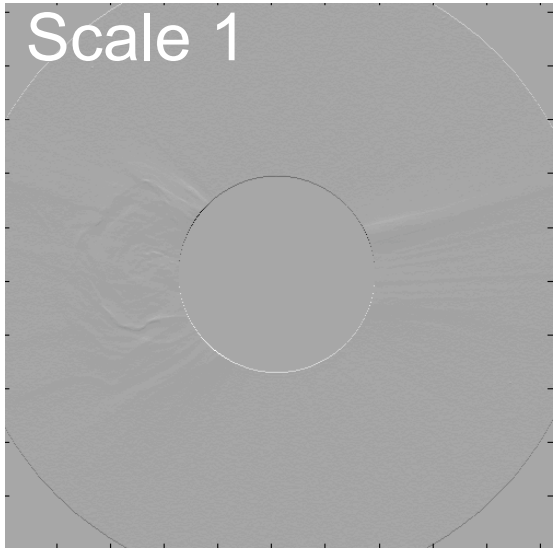
Horizontal Direction:

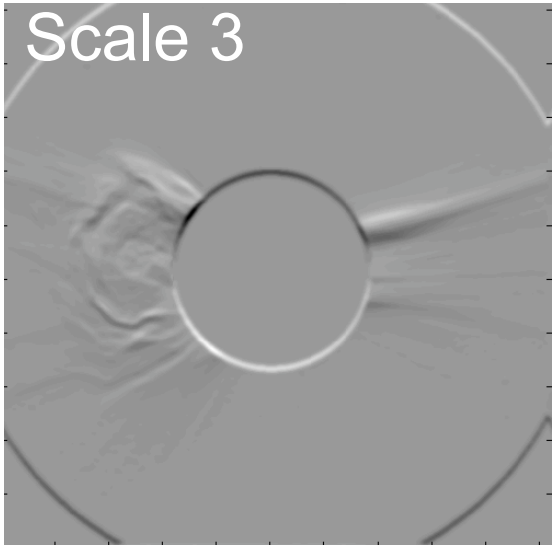


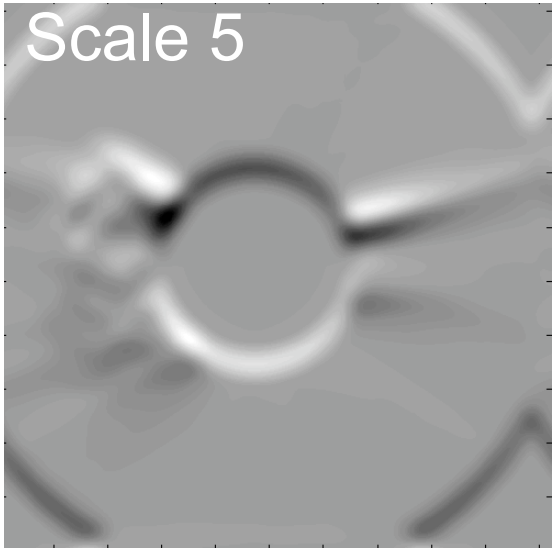




Vertical Direction:







Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter

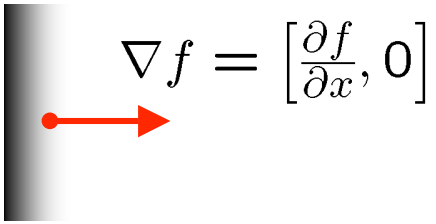
4) Non-Maxima Suppression

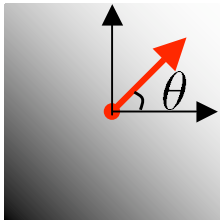
5) CME Front Characterisation

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





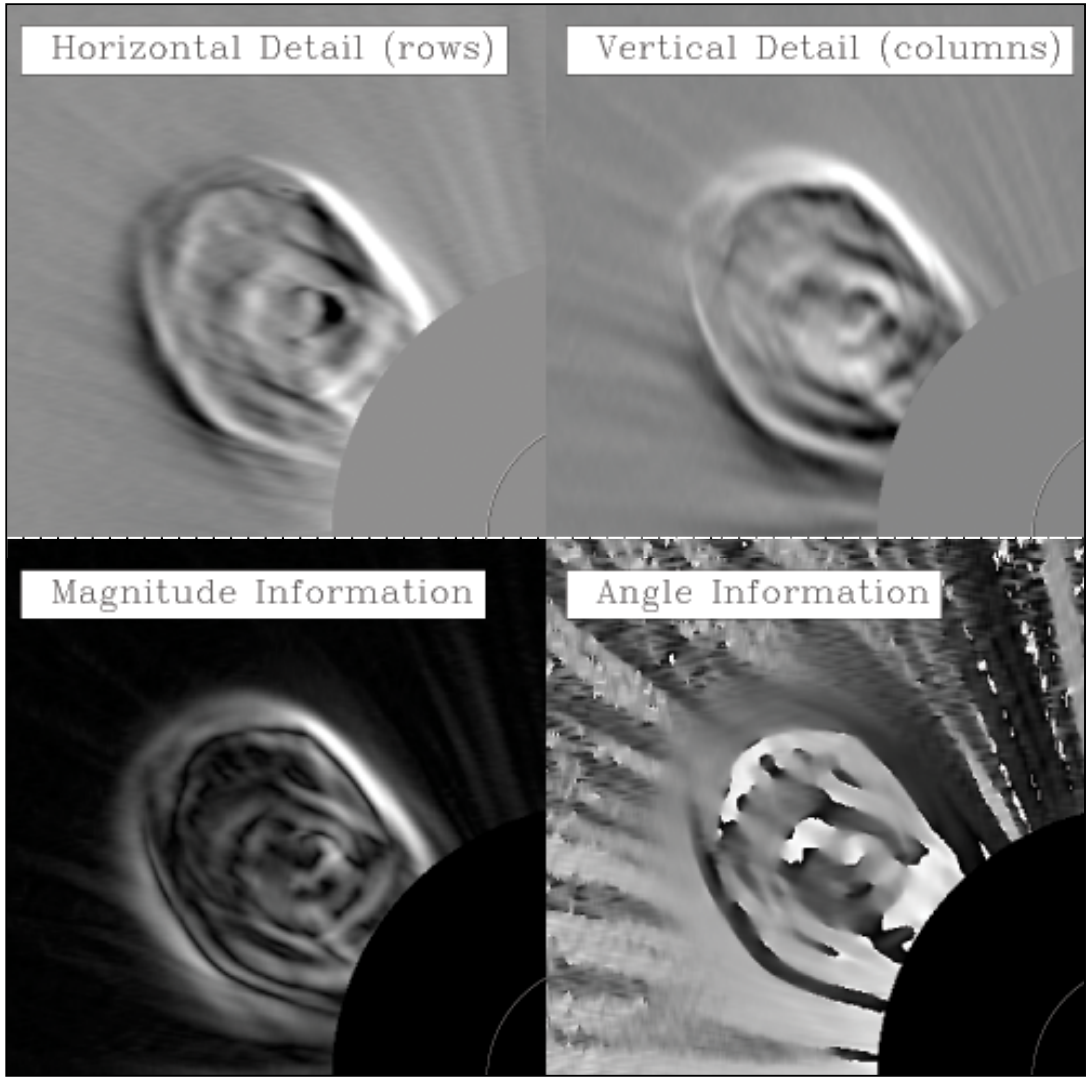
- The gradient direction is given by:

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

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

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

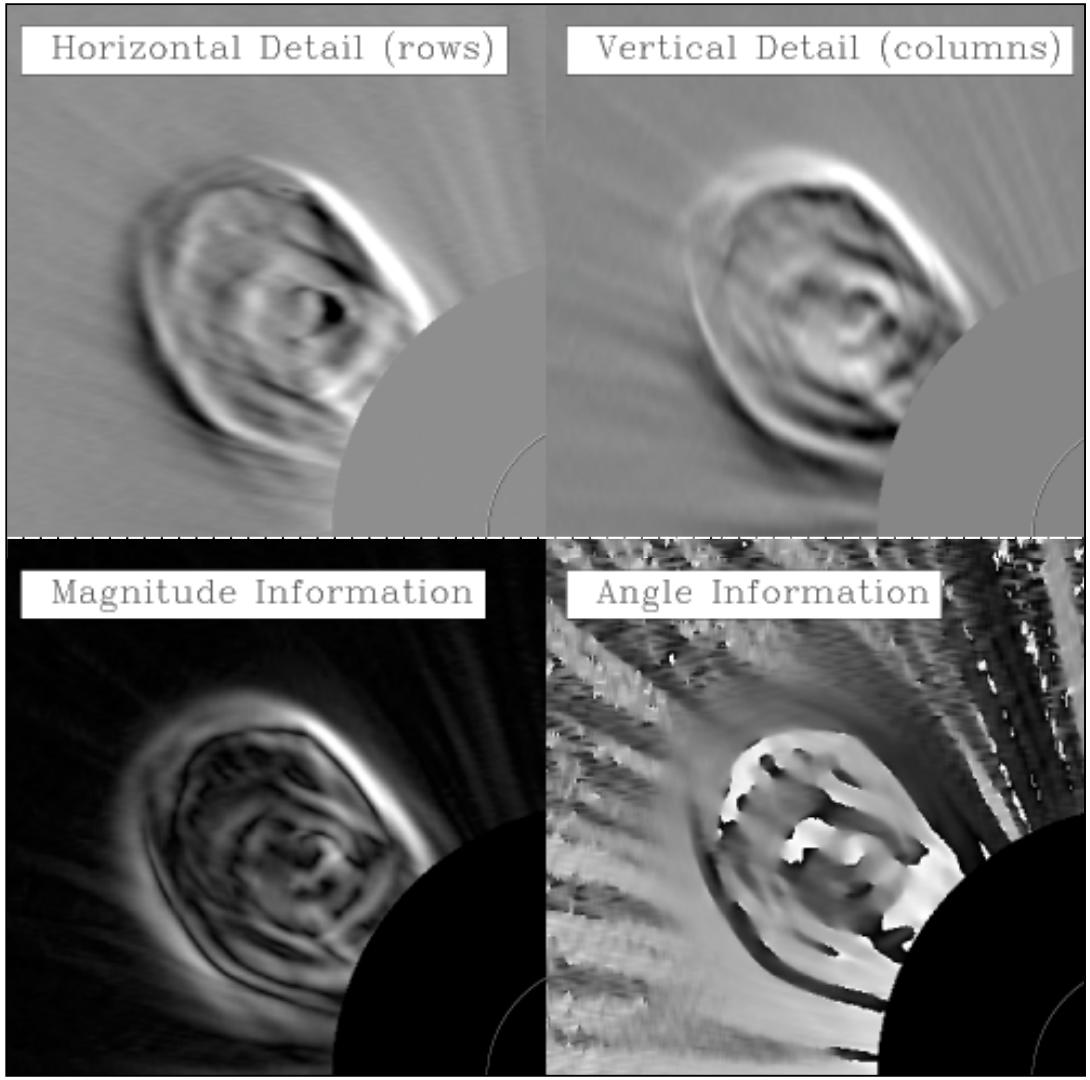
2) Gradient Space Information



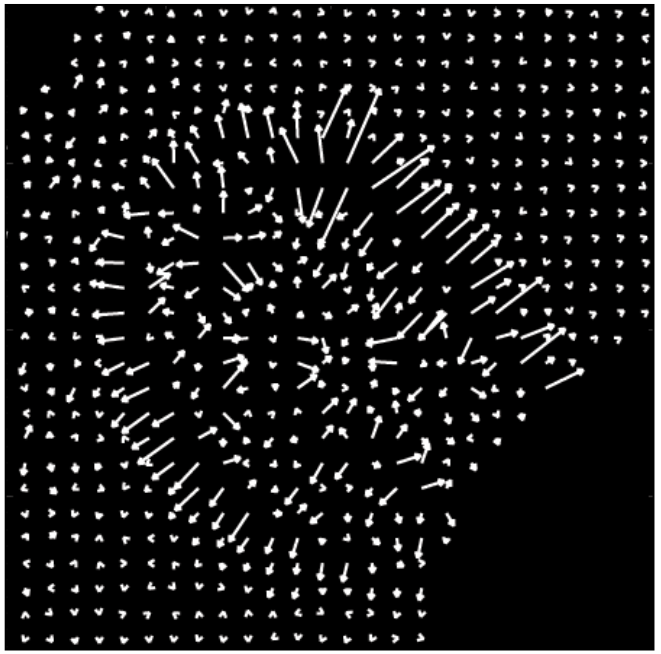
C2 01-Apr-04

2) Gradient Space Information

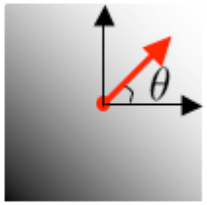
Vector-Arrow Field



C2 01-Apr-04



Vectors with magnitude: $\|\nabla f\|$
and inclination angle: θ



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

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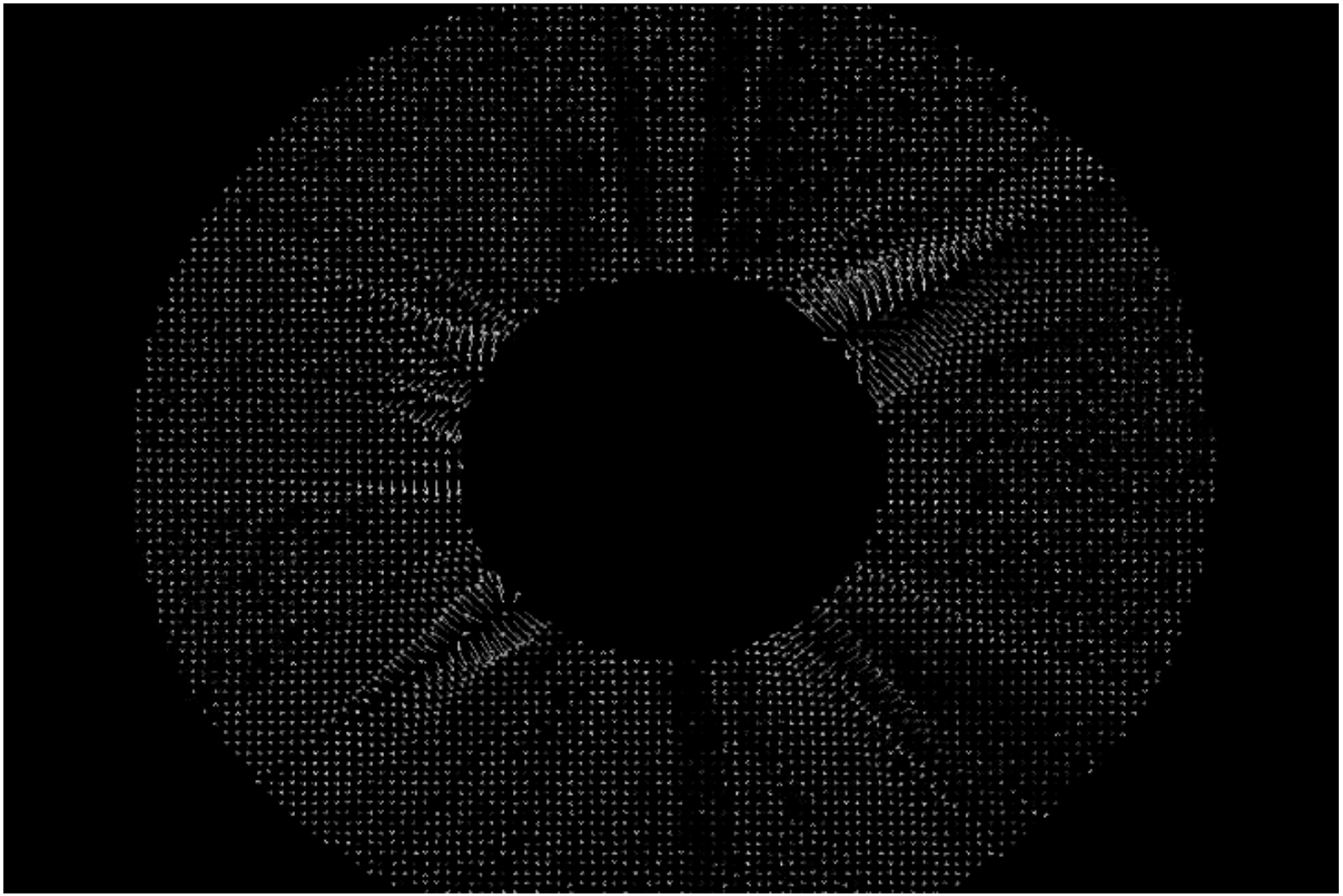
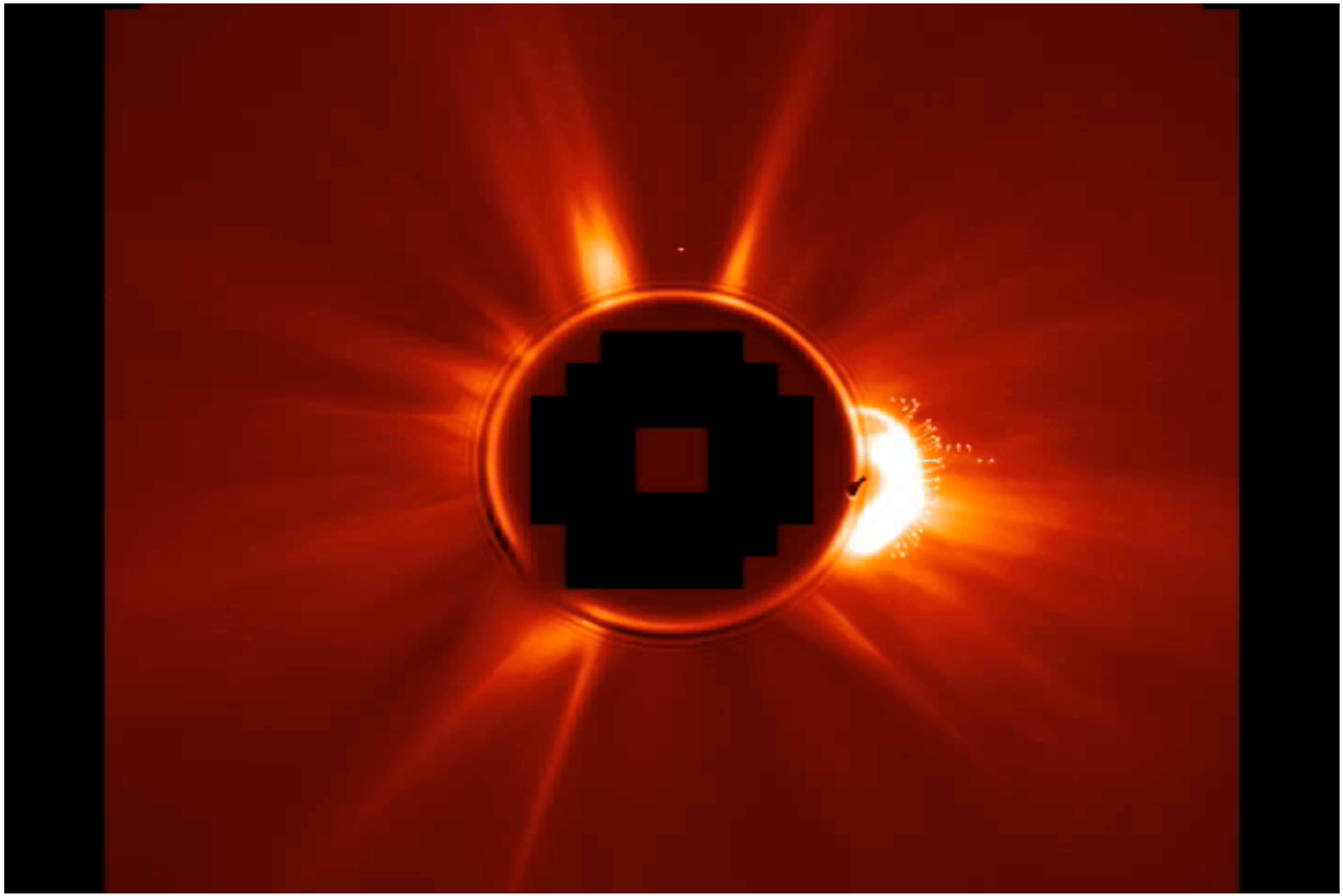


Vector-arrows corresponding to the magnitude and inclination angle of the Scale 5 decomposition of a LASCO/C2 CME on 01-Apr-04.

3) Spatio-Temporal Filter

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



LASCO/C2 18-Jan-00

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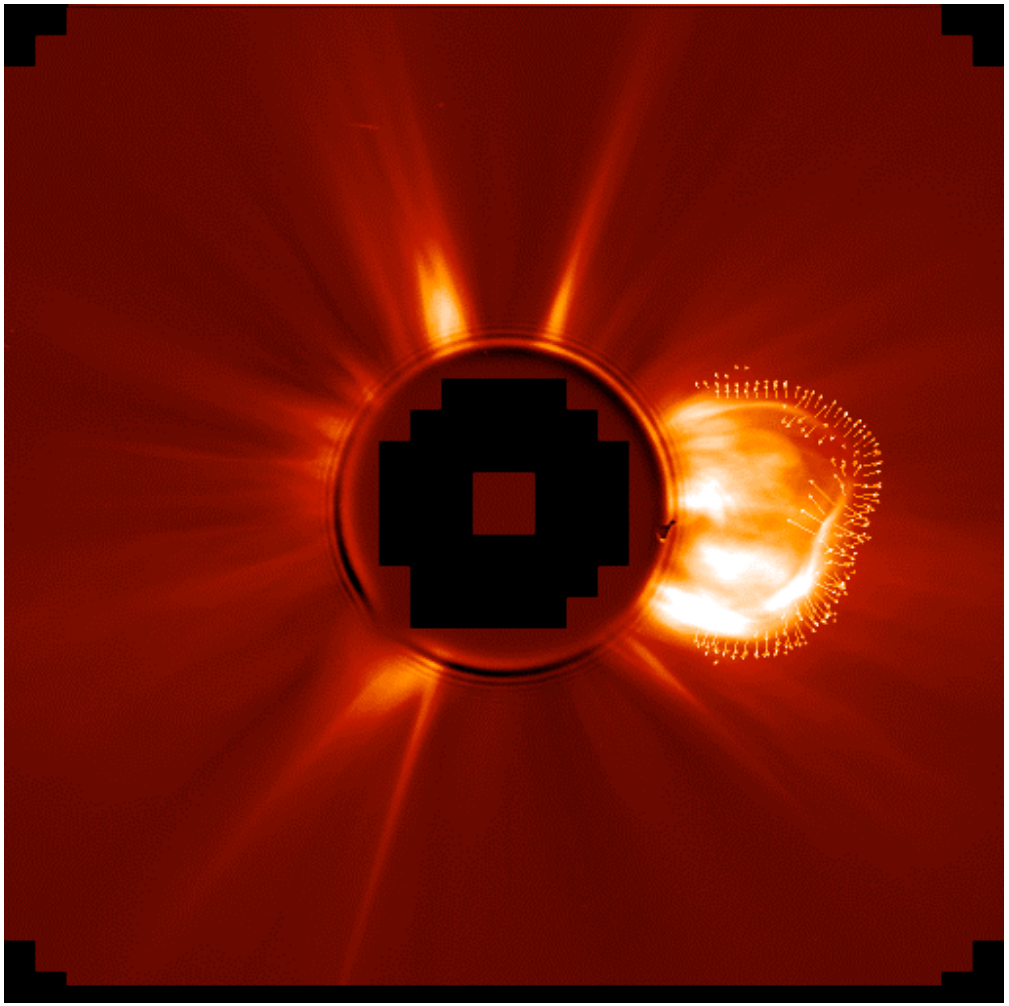

LASCO/C2 18-Jan-00

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1) Multiscale Decomposition

2) Gradient Space Information

Vector-Arrow Field

3) Spatio-Temporal Filter

4) Non-Maxima Suppression

5) CME Front Characterisation

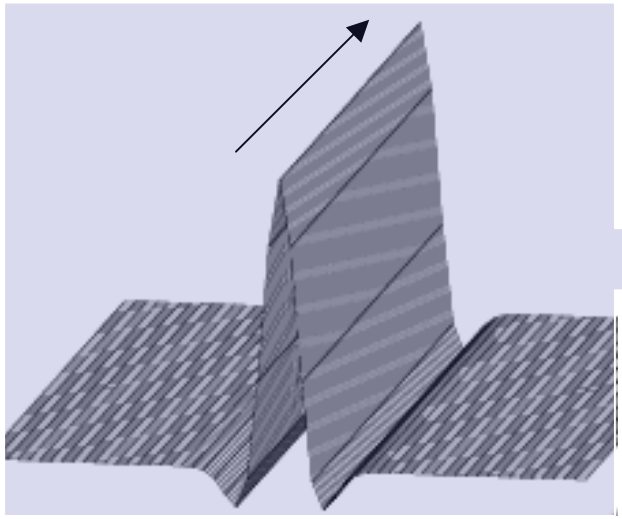
Kinematics & Morphology

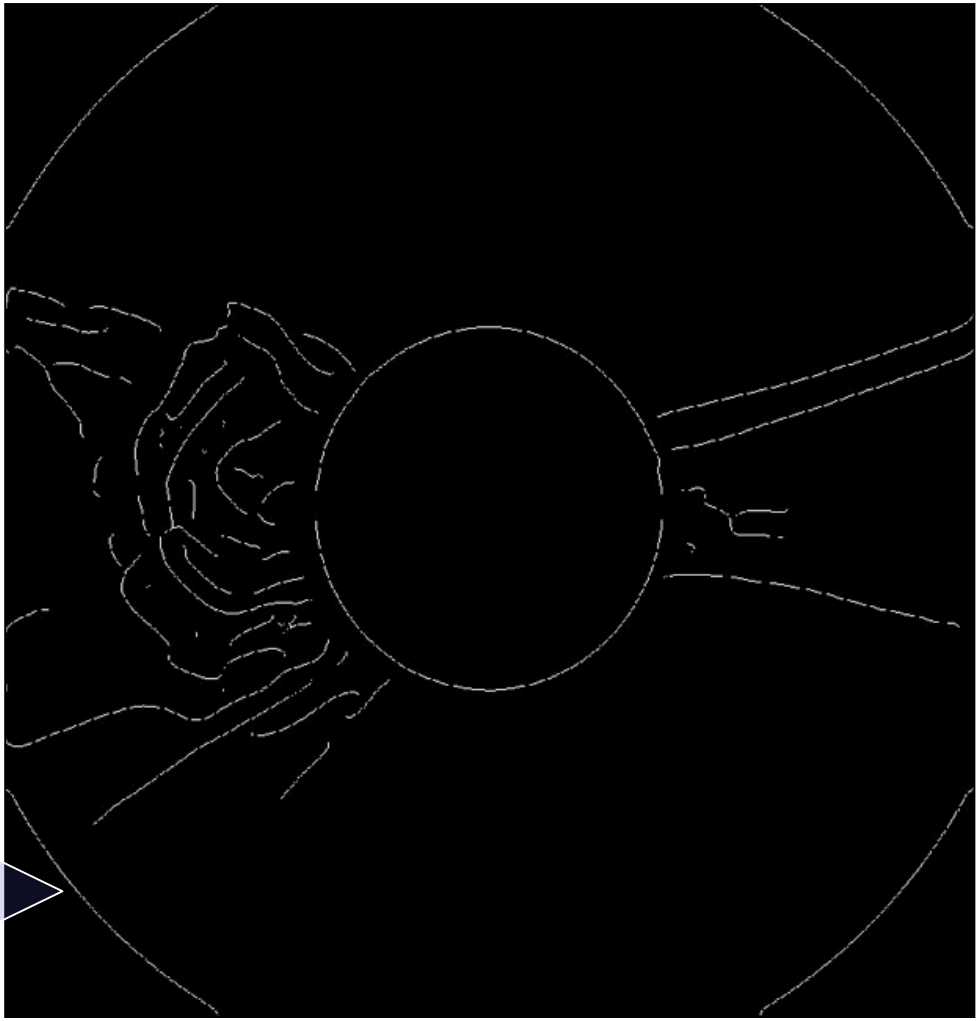
4) Non-Maxima Suppression

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

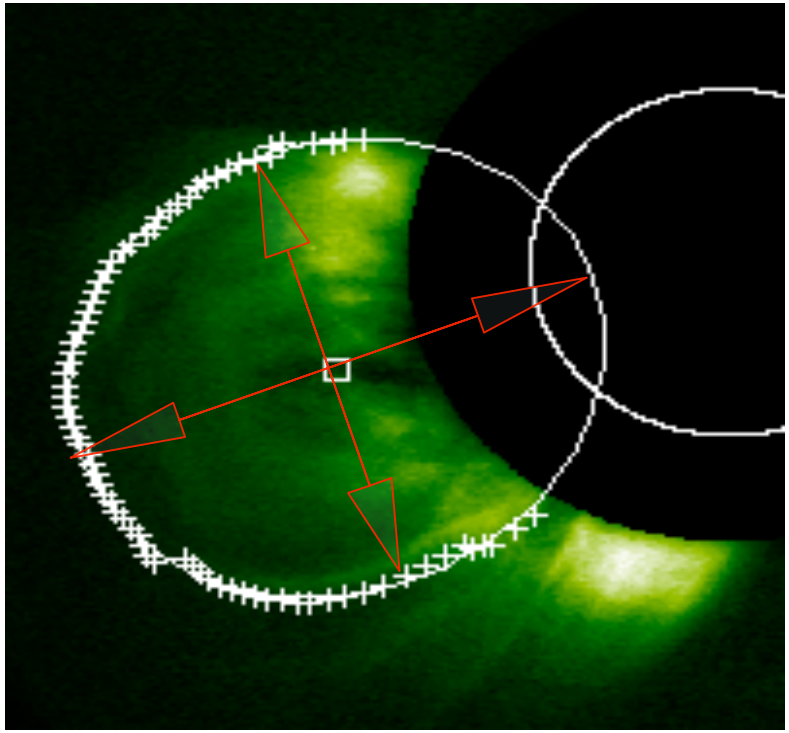
Kinematics & Morphology

5) CME Front Characterisation

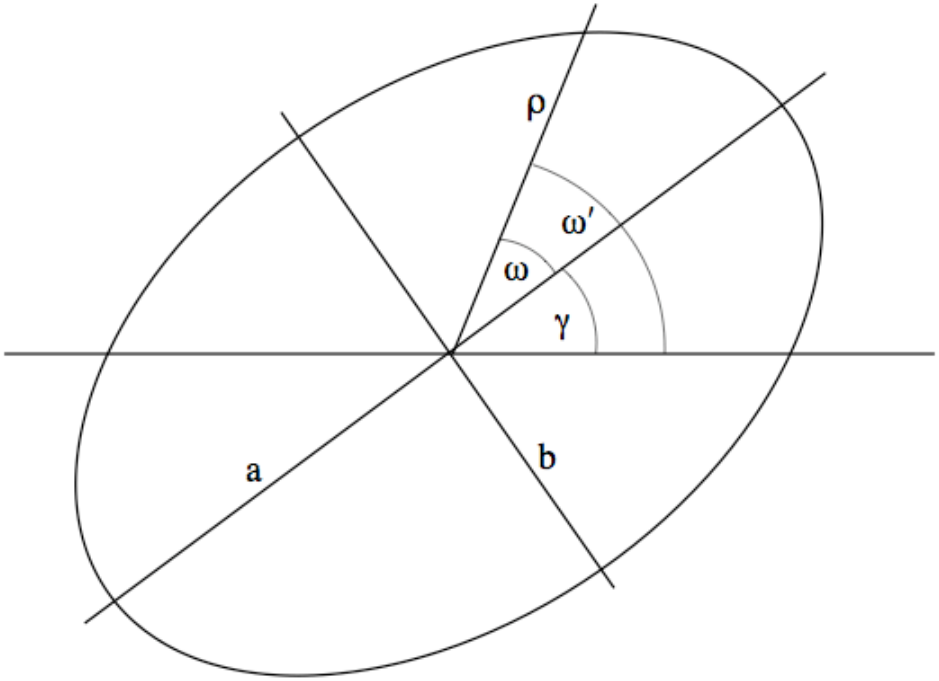
- Ellipse fit
- Height, Width, Curvature, Orientation

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

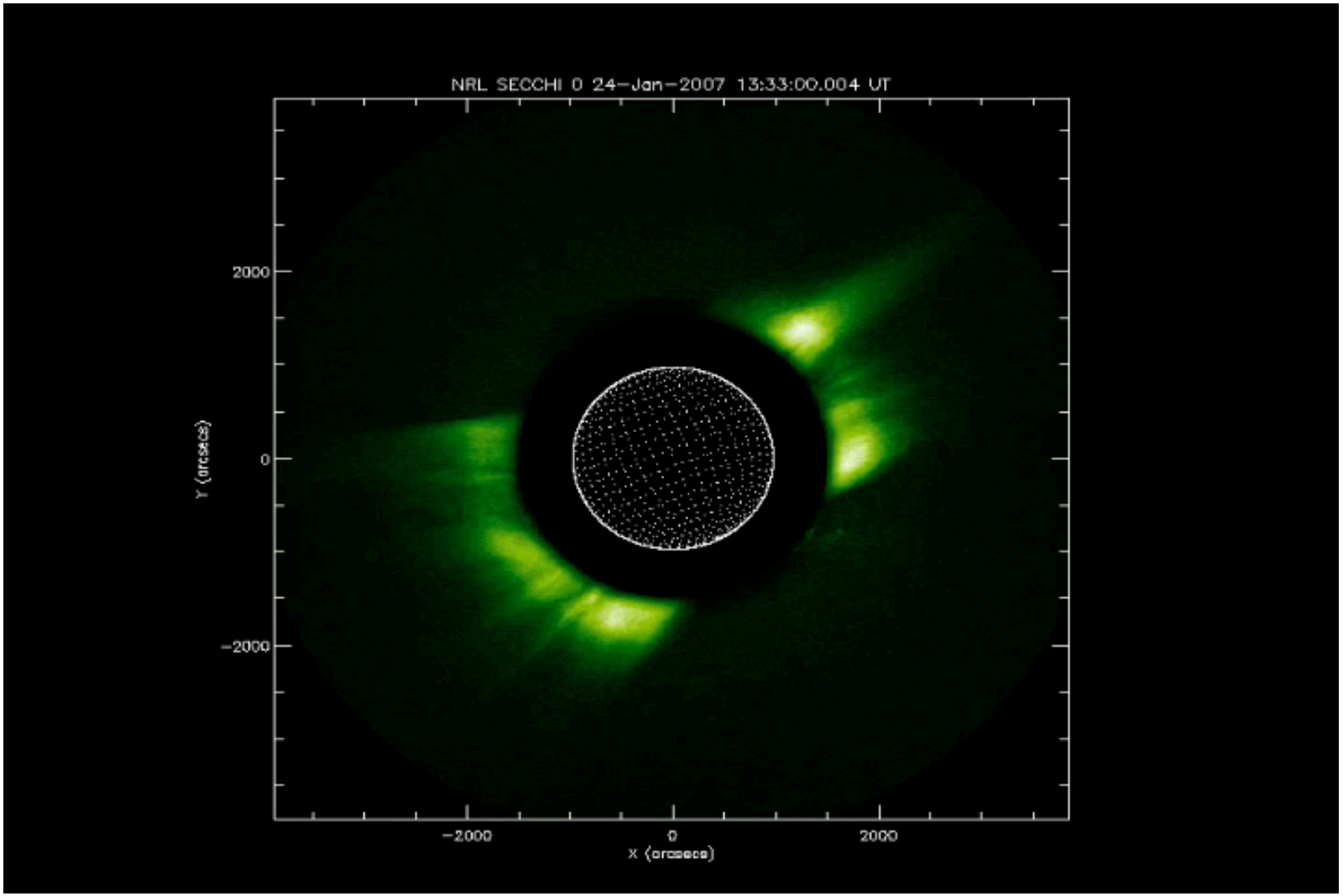
$$\rho^2 = \frac{a^2 b^2}{\left(\frac{a^2 + b^2}{2}\right) - \left(\frac{a^2 - b^2}{2}\right)\cos(2\omega' - 2\gamma)}$$



SECCHI/COR1 24-Jan-07

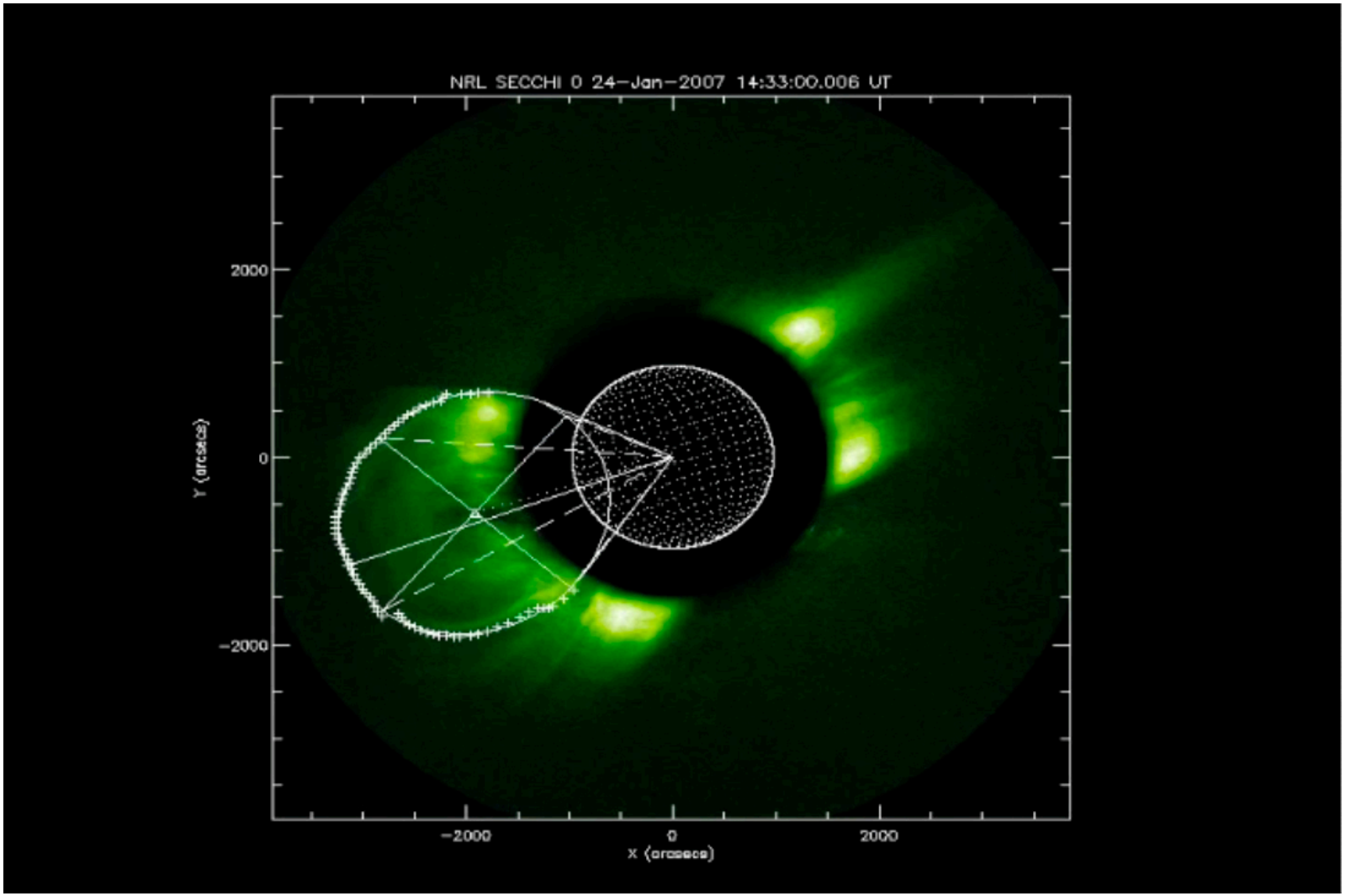


5) CME Front Characterisation



SECCHI/COR1-A 24-Jan-07

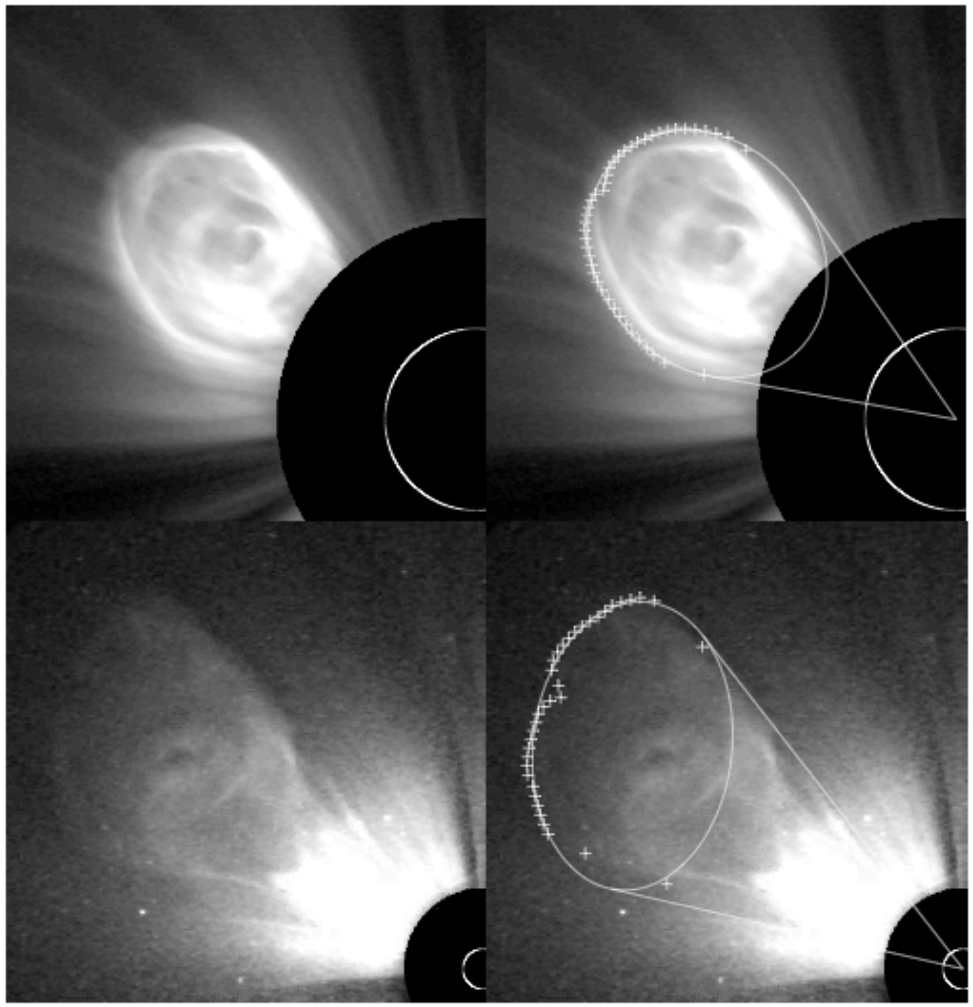
5) CME Front Characterisation



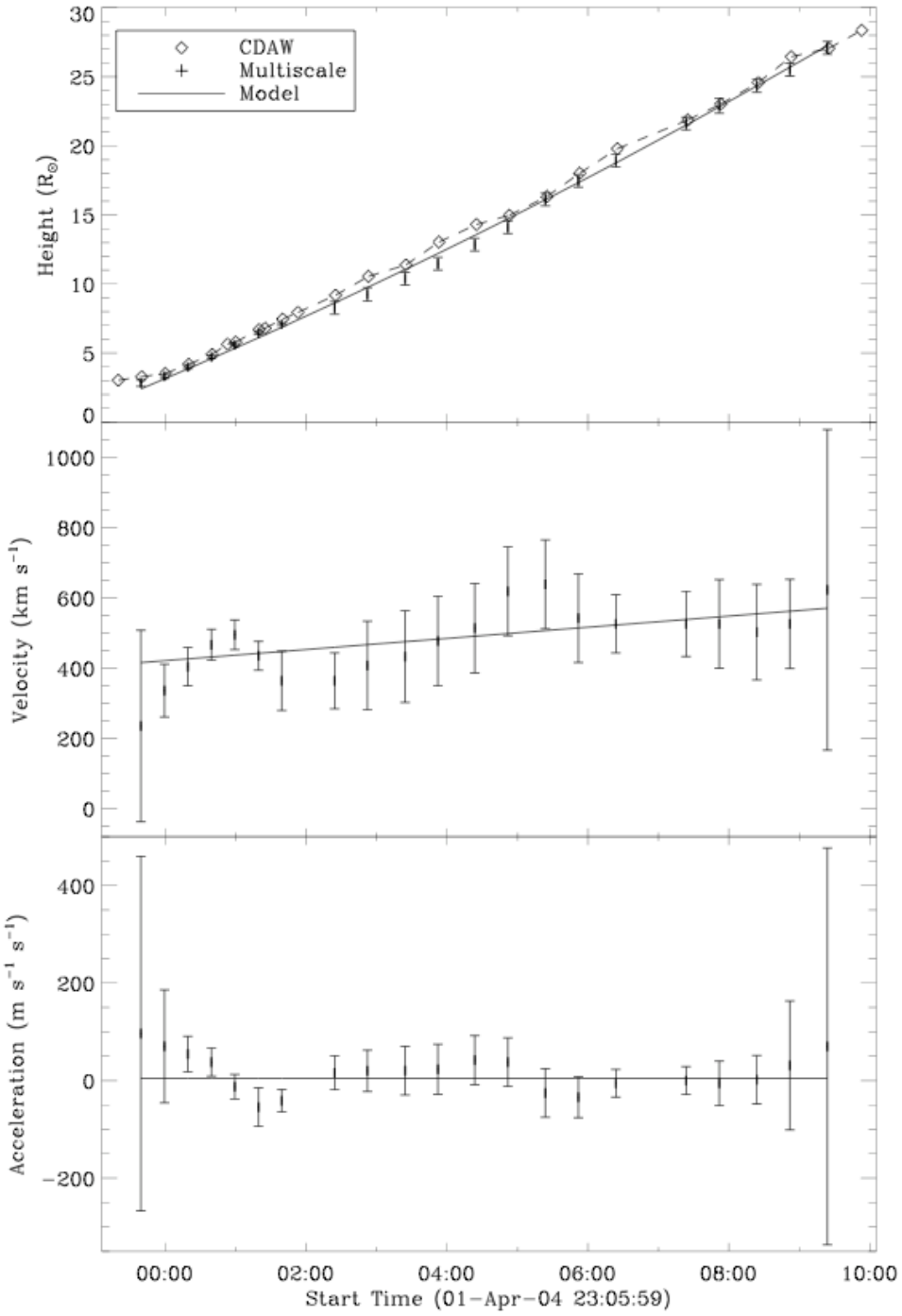
SECCHI/COR1-A 24-Jan-07

5) CME Front Characterisation

Kinematics & Morphology

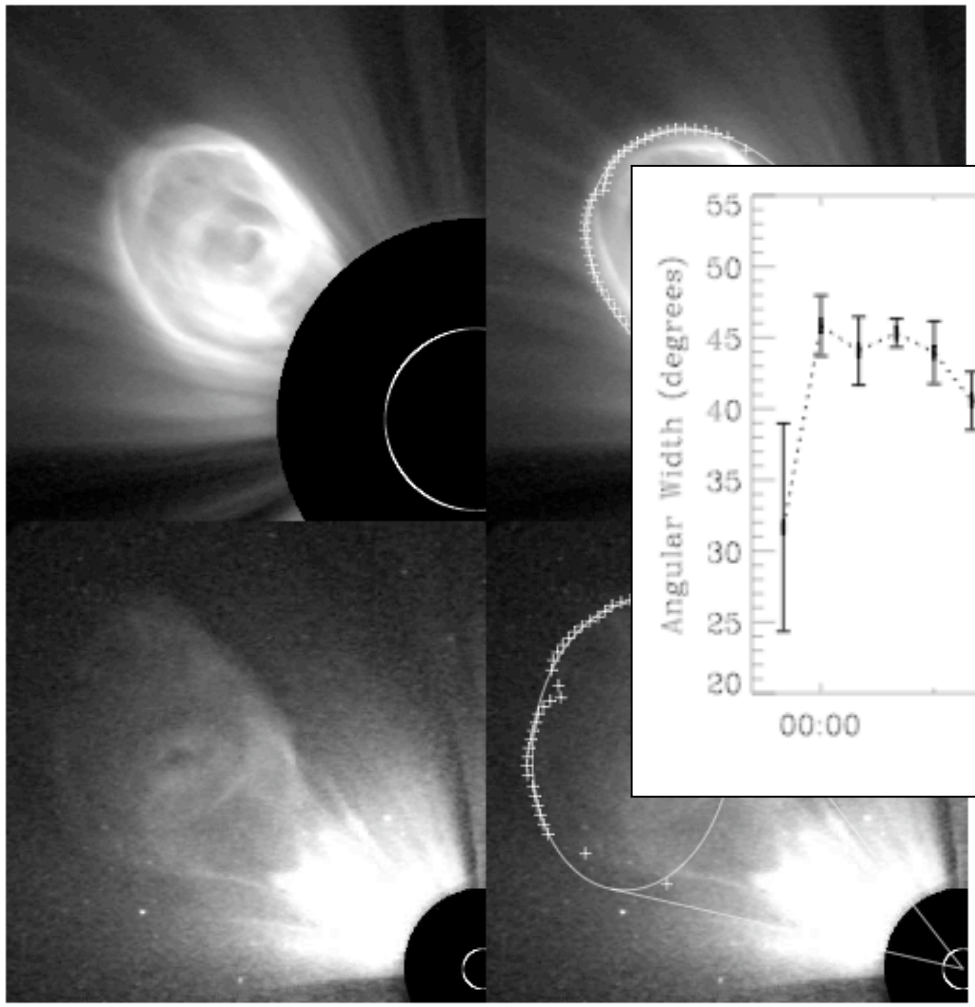


LASCO 01-Apr-04

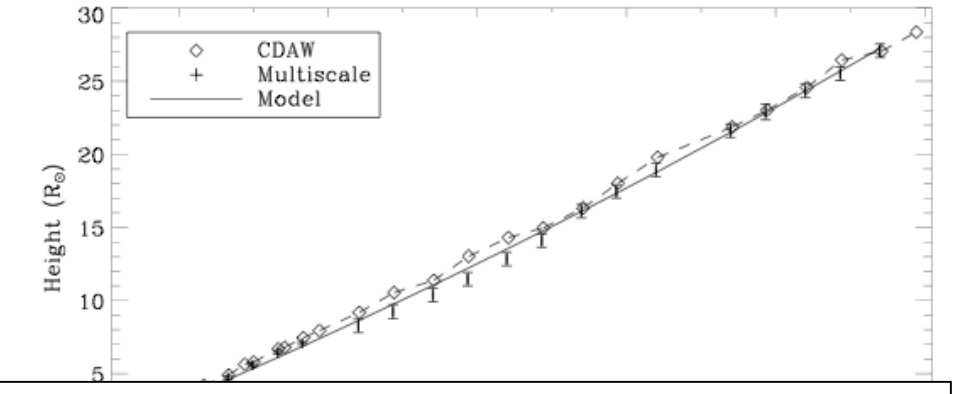


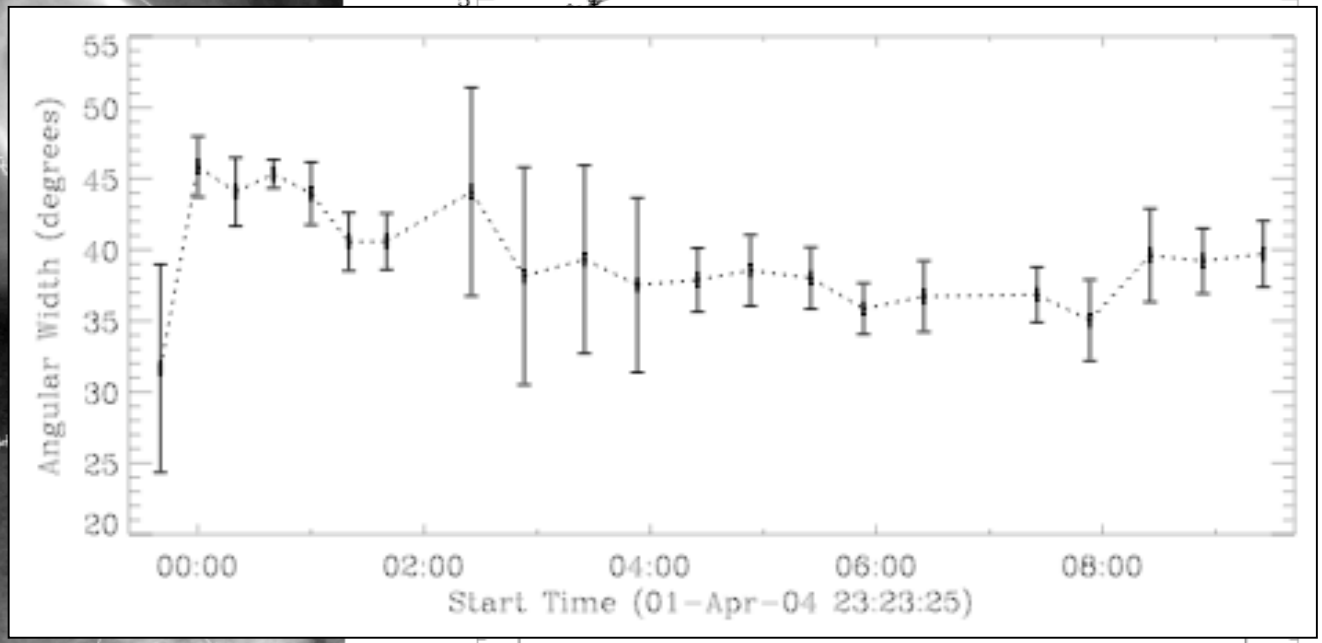
5) CME Front Characterisation

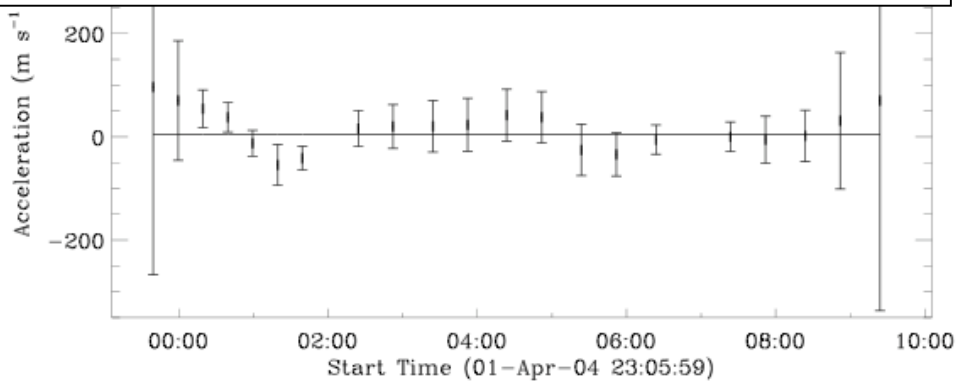
Kinematics & Morphology



LASCO 01-Apr-04

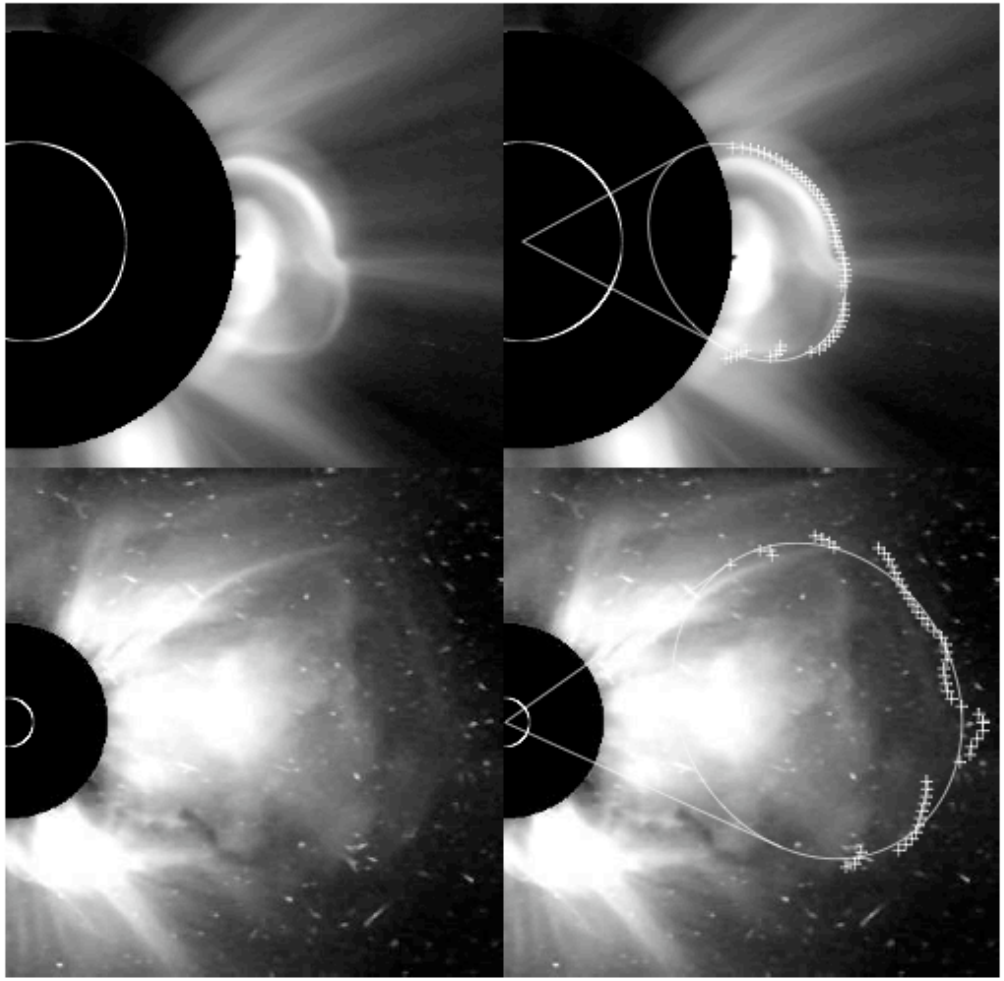




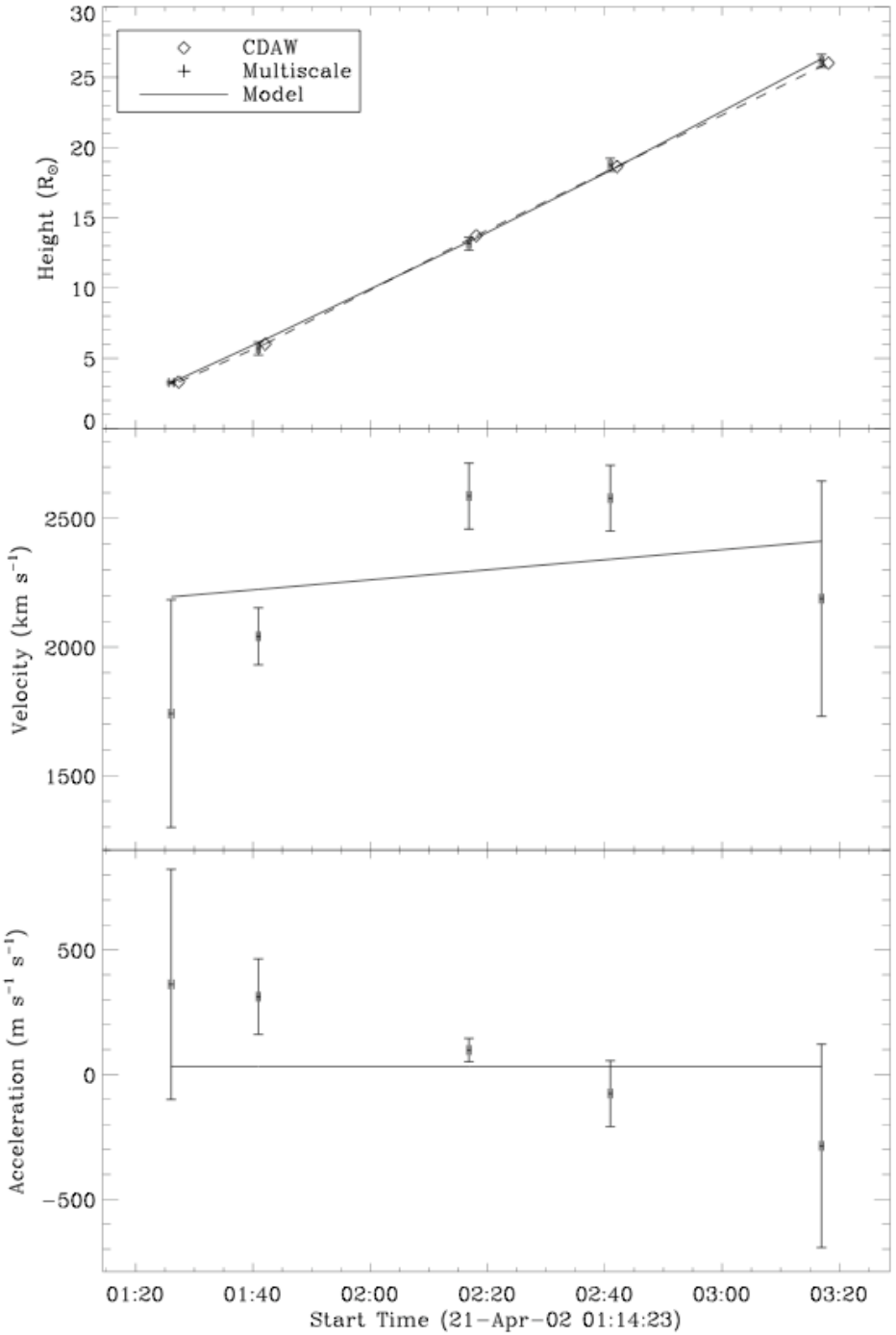


5) CME Front Characterisation

Kinematics & Morphology

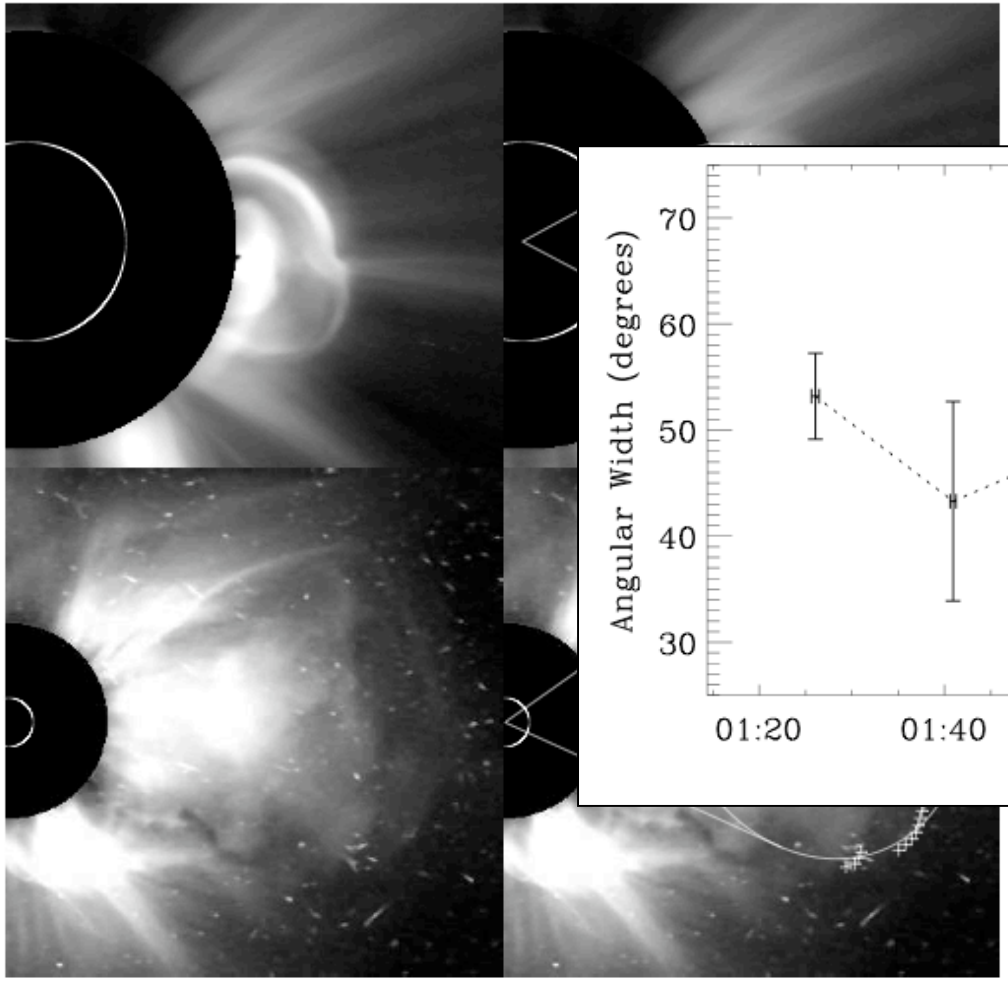


LASCO 21-Apr-02



5) CME Front Characterisation

Kinematics & Morphology



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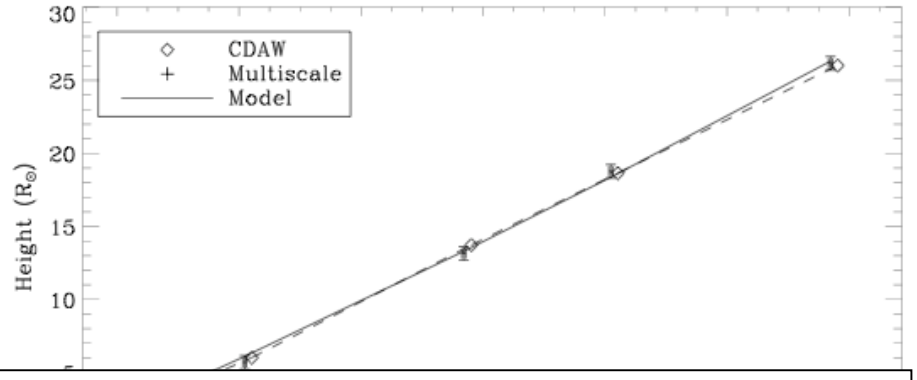
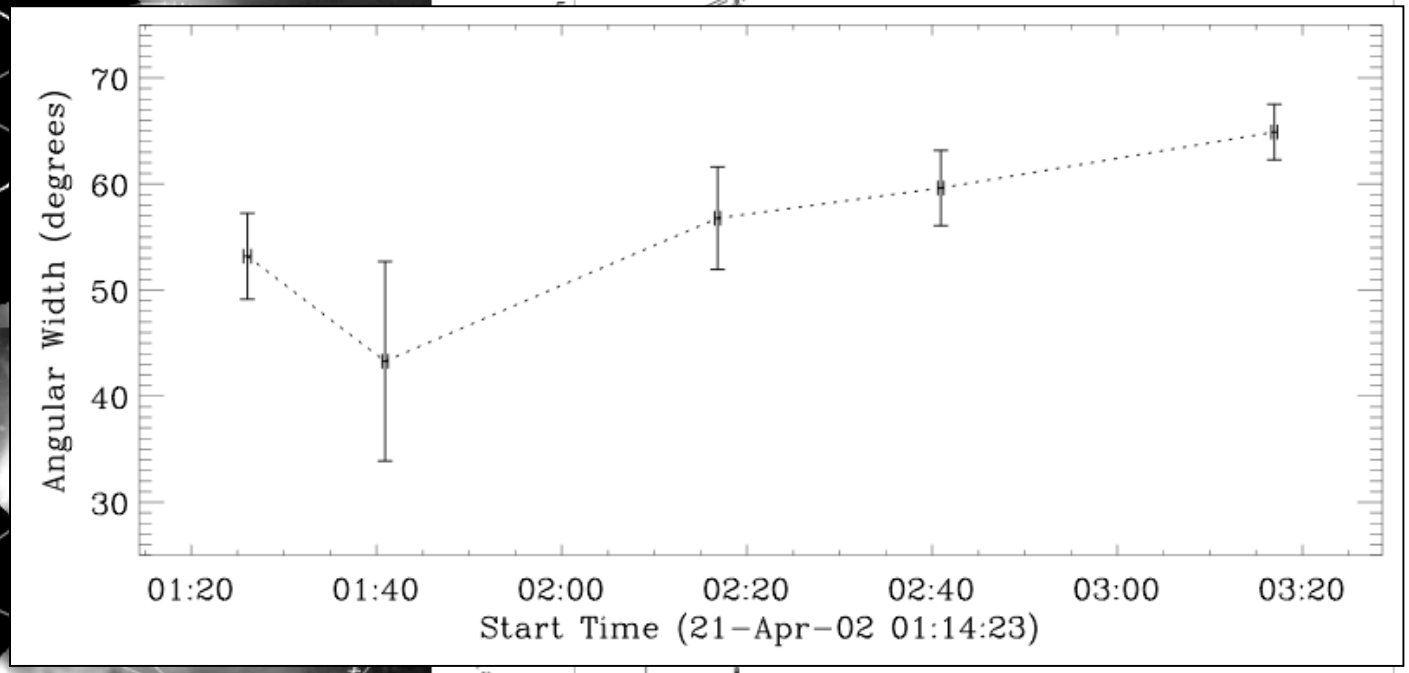
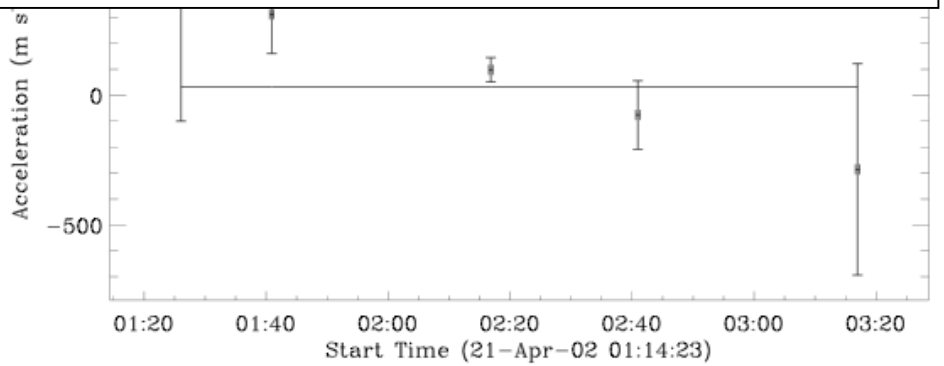
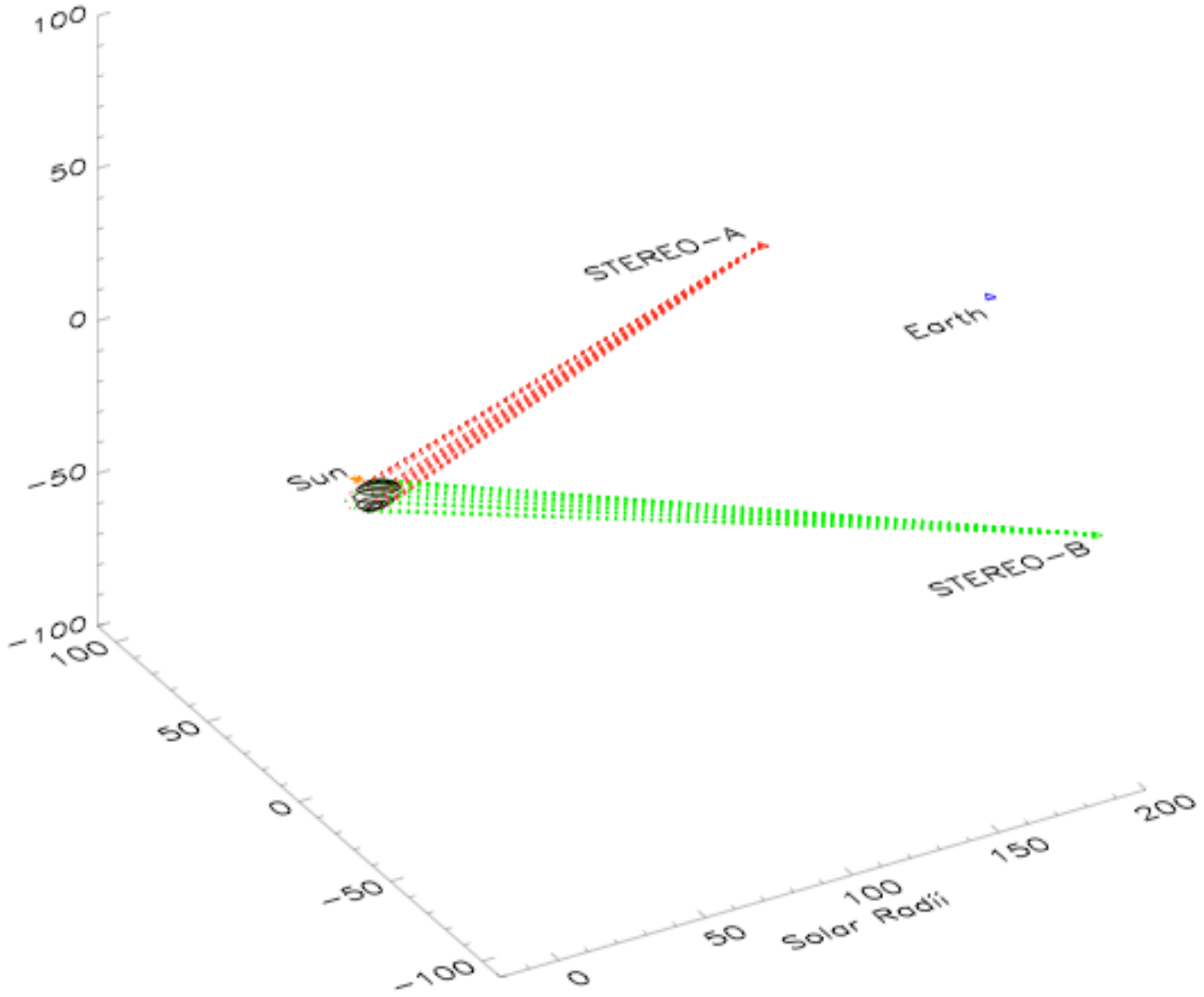
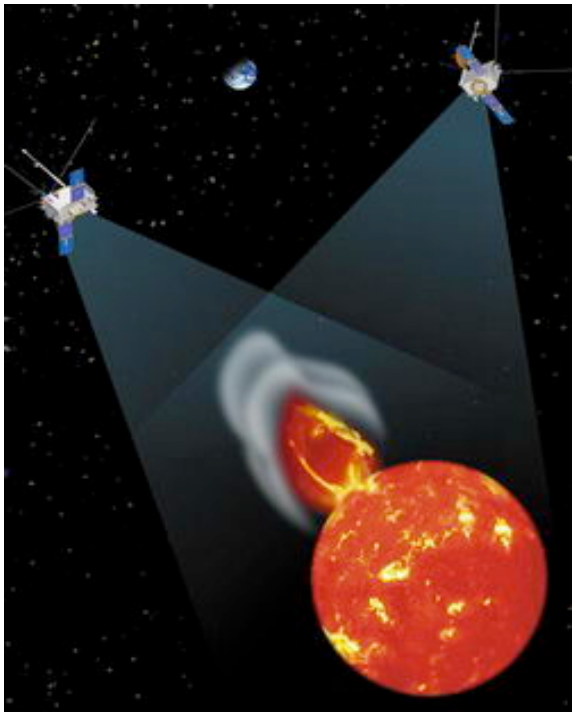




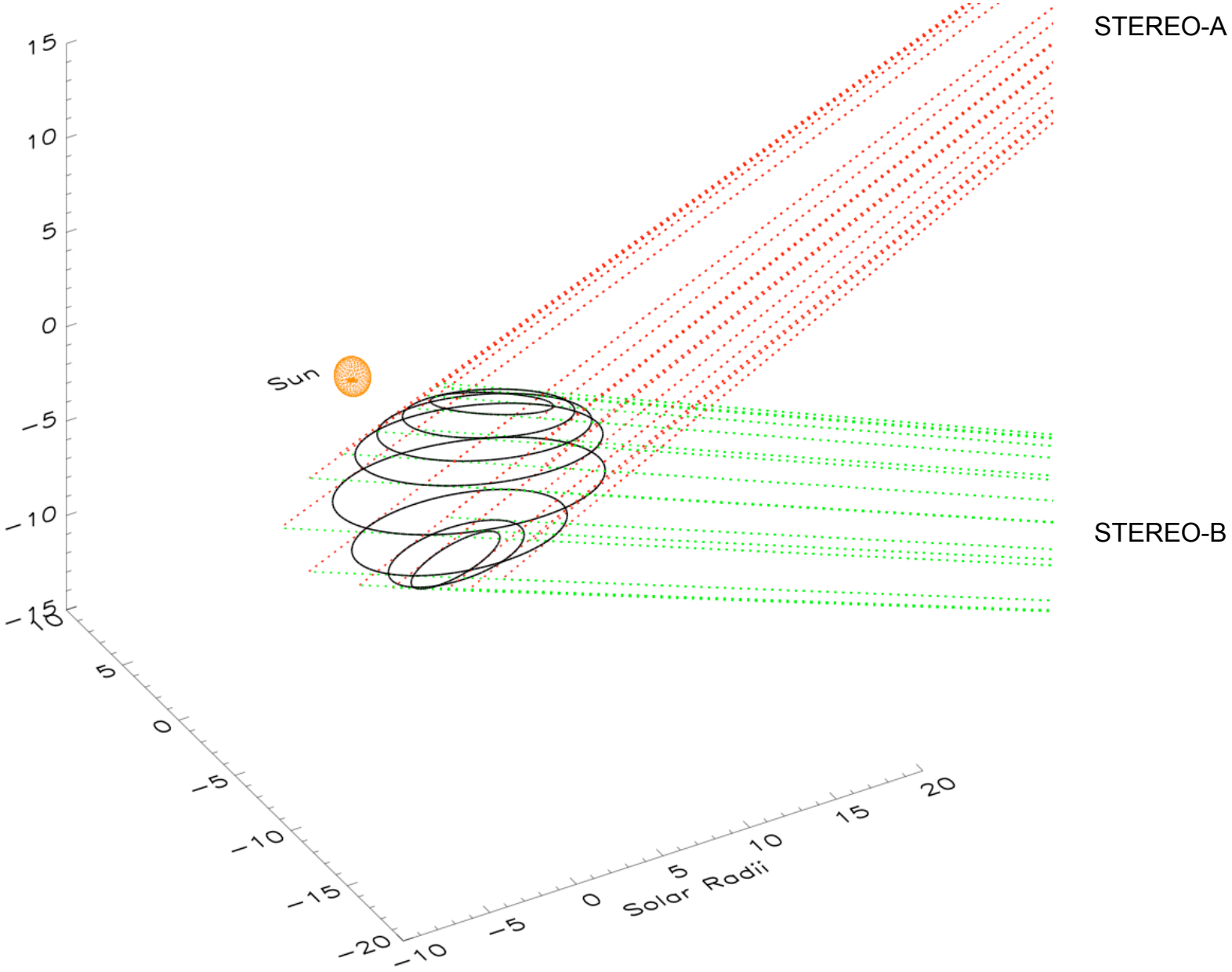


Forward Plan





Forward Plan



Conclusions

- Multiscale methods provide high accuracy edge detections.
- Subsequent CME charaterisation and analysis shows cases of *possible non-constant acceleration*.
- Algorithm has great potential for automation,

  and the STEREO twin views may alleviate projection effects.