The Kinematics of CMEs using Multiscale Methods

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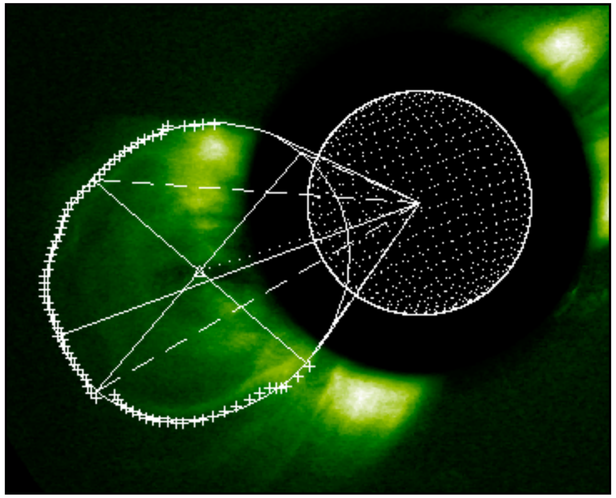


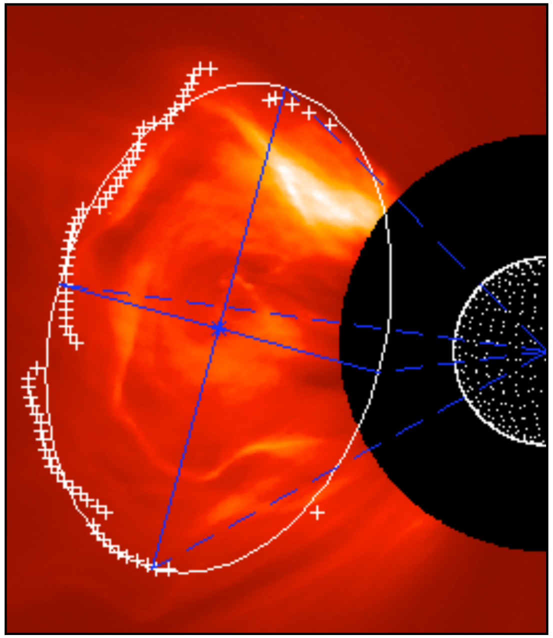
Today's Discussion

1) Submitted work

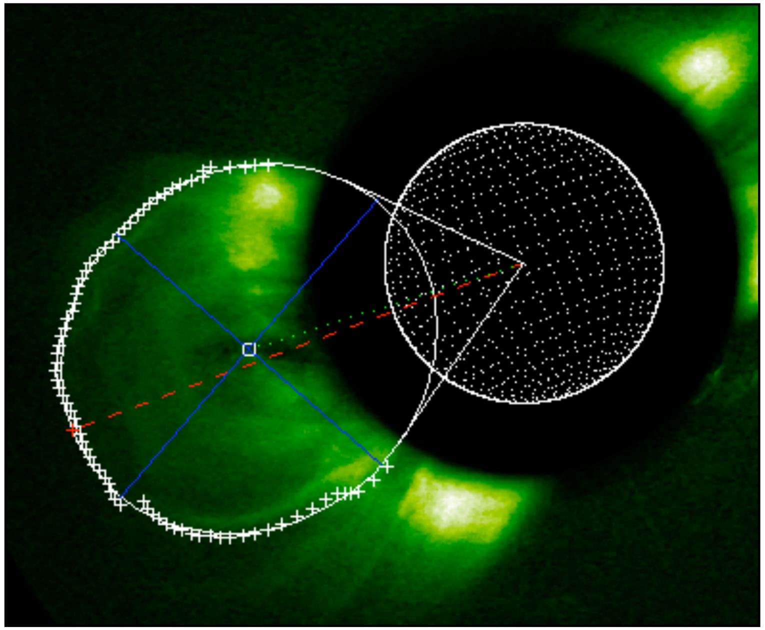
- Algorithm recap
- Results

2) Current work

- Automation

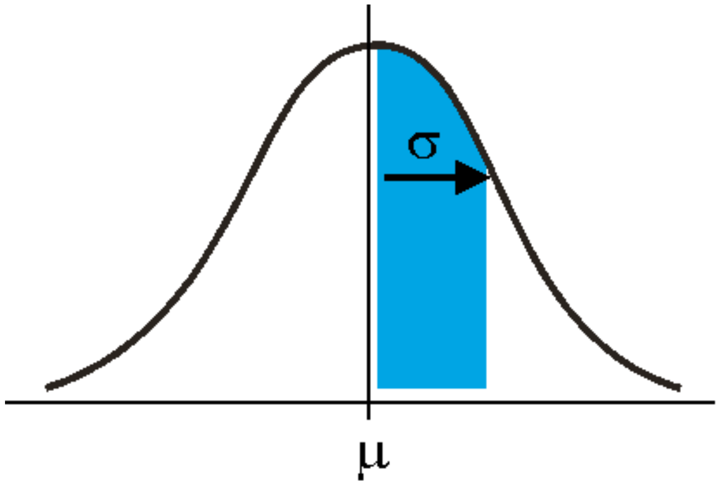


LASCO/C2 & SECCHI/COR1-A
24-Jan-07



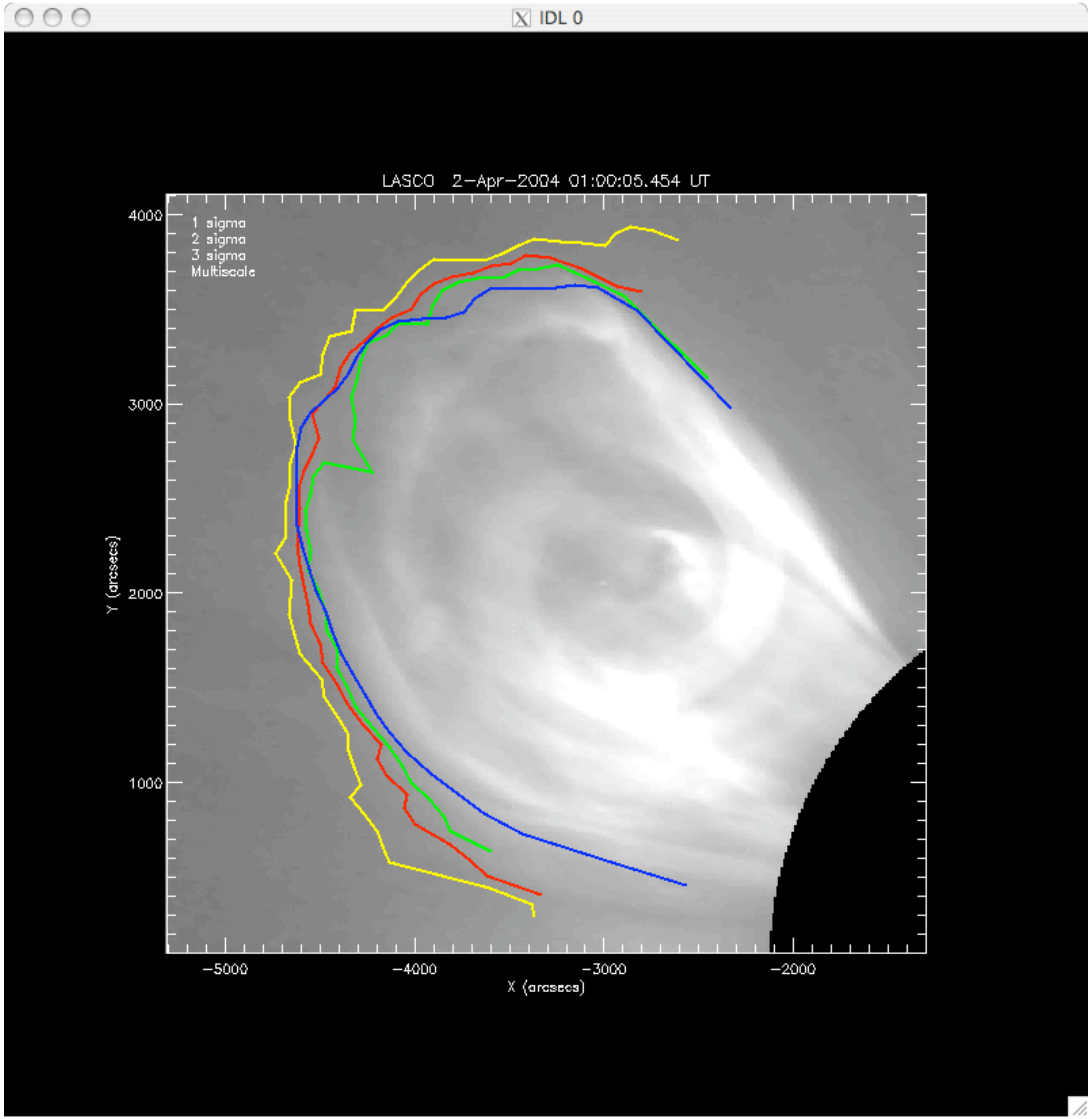
Multiscale Motivation

Running difference:



- 1 sigma
- 2 sigma
- 3 sigma
- Multiscale

Errors are small
--exposure time



Finding the CME Front

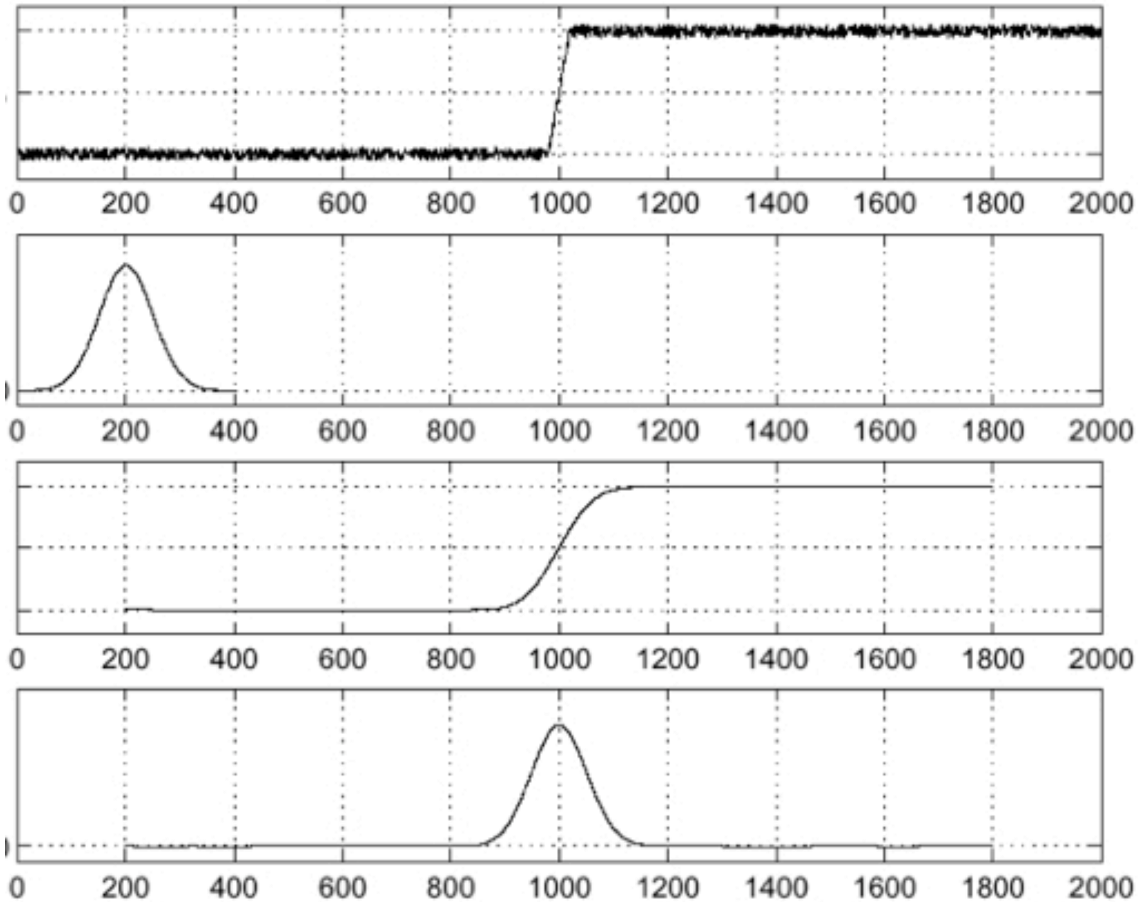
Edge Detection:

$$s$$

$$h$$

$$s * h$$

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



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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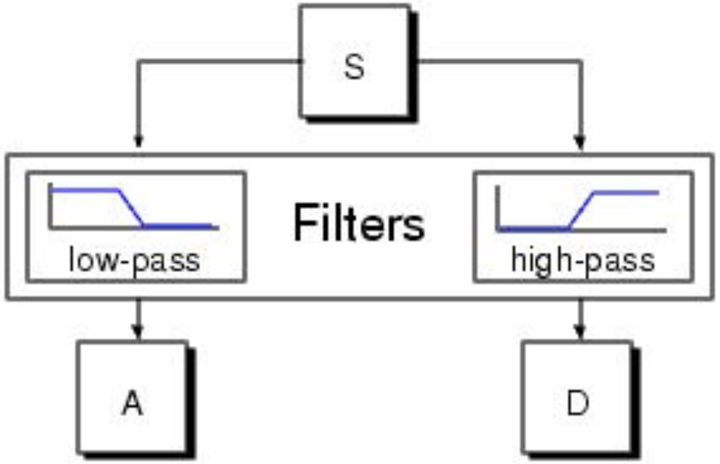
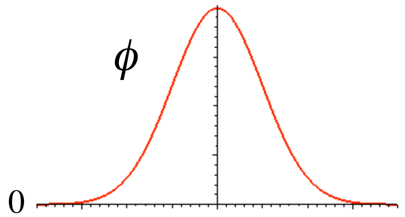
Kinematics & Morphology

1) Multiscale Decomposition

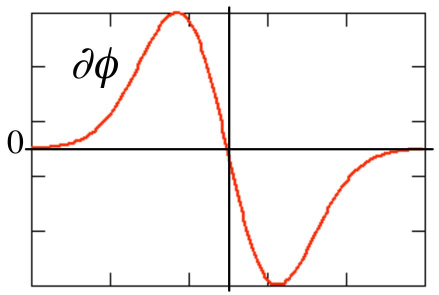
Input: s

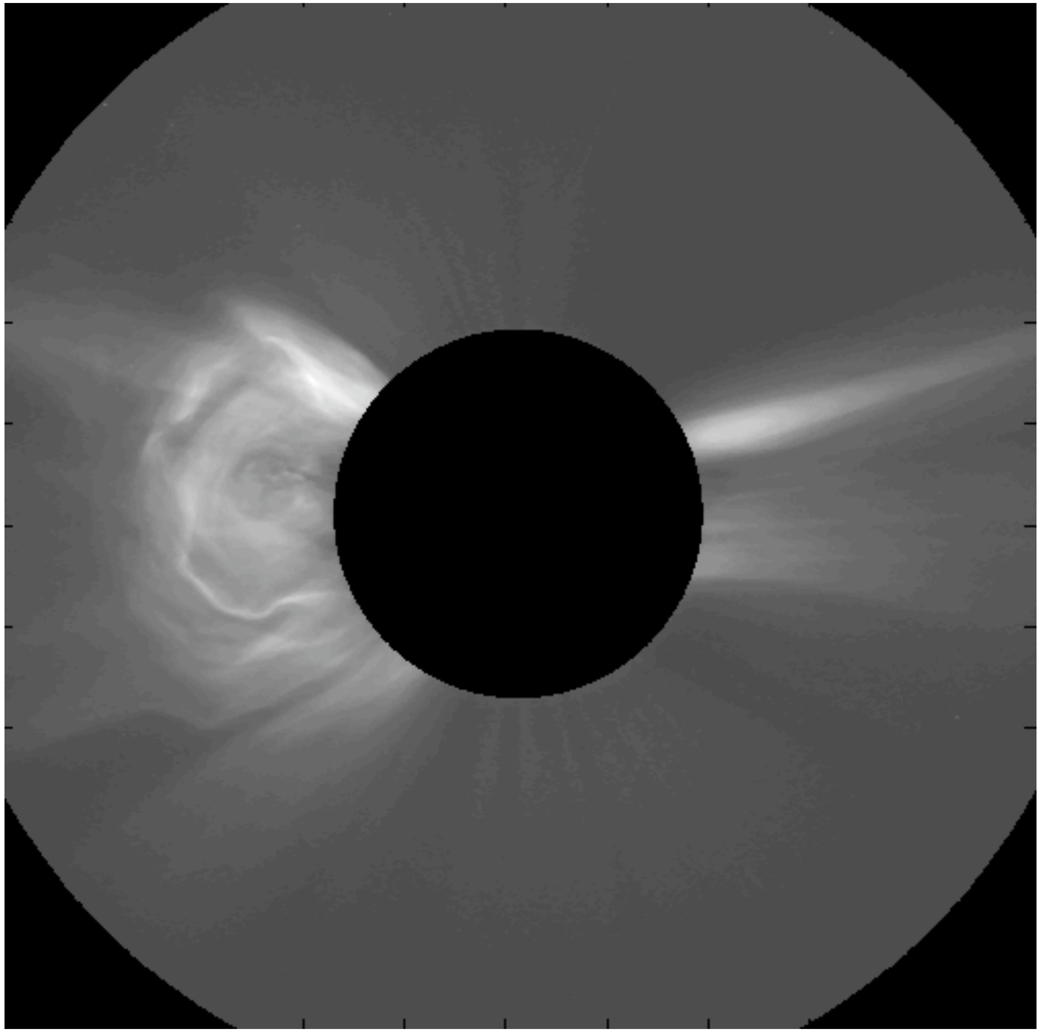


Low pass: Approximation



High pass: Detail

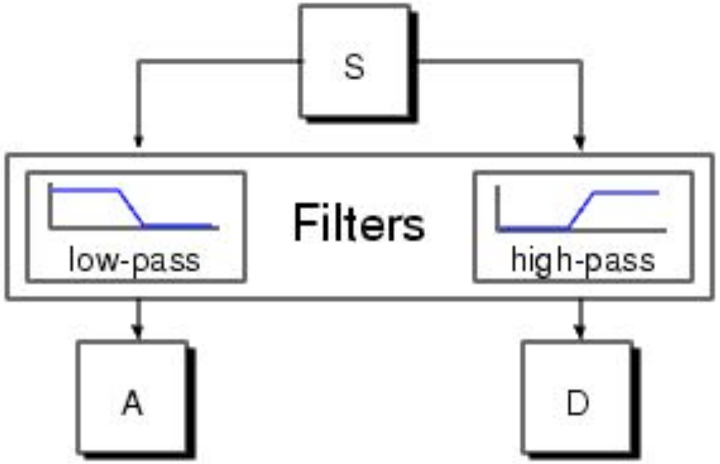




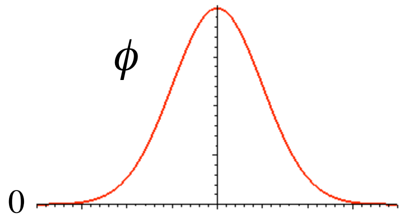
LASCO/C2 24-Jan-07

1) Multiscale Decomposition

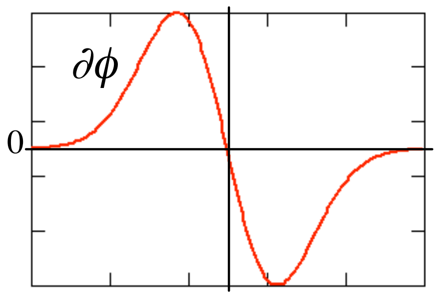
Input: s

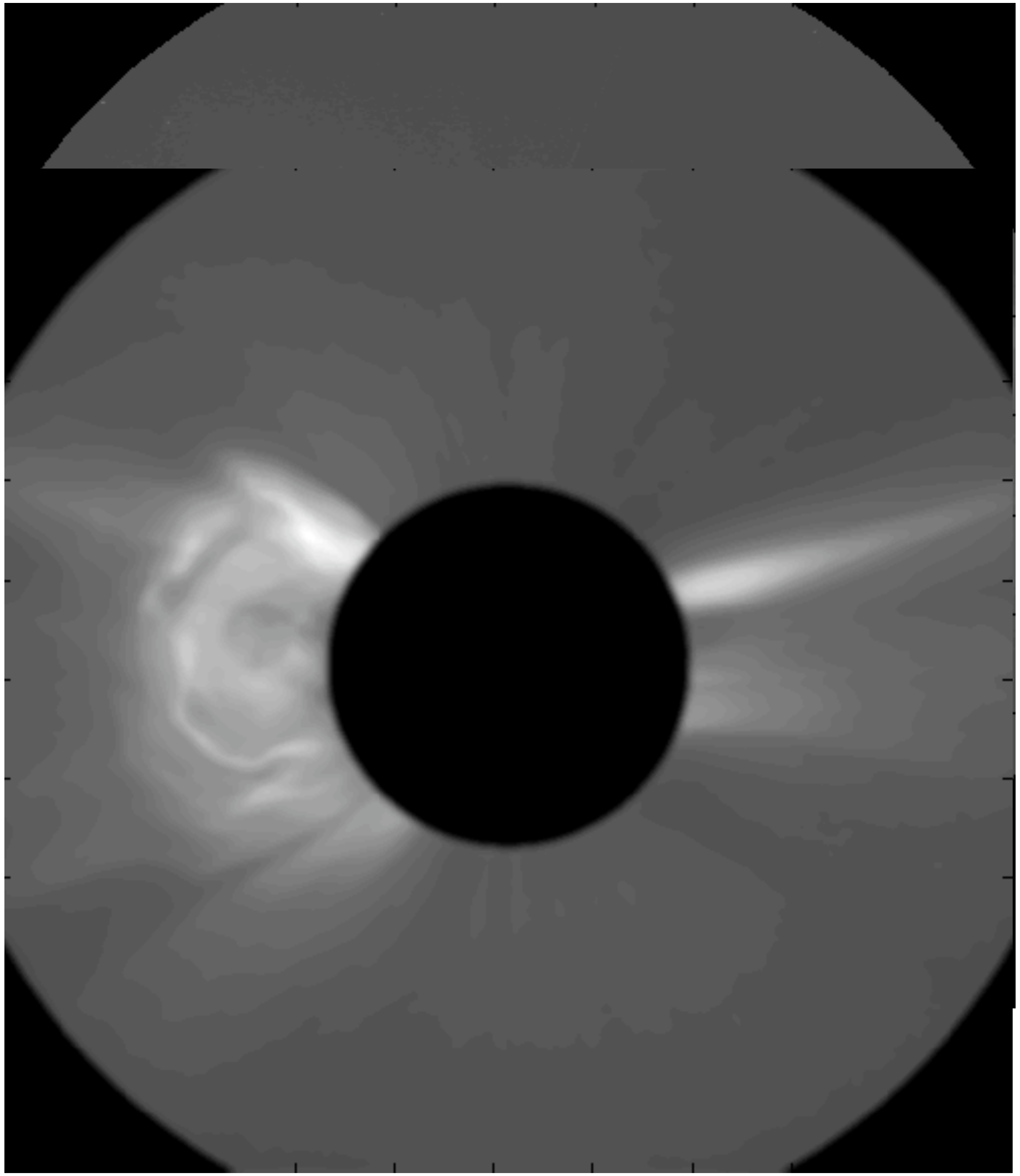


Low pass: Approximation



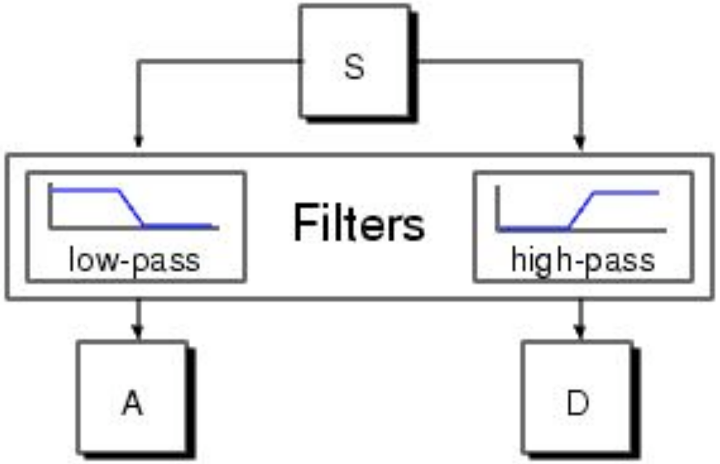
High pass: Detail



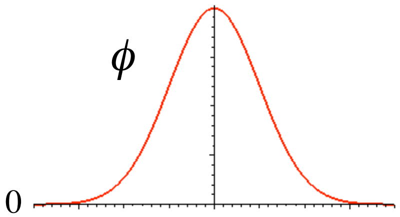


1) Multiscale Decomposition

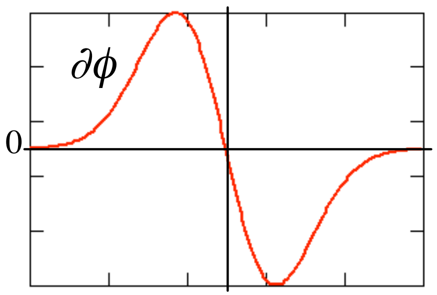
Input: s

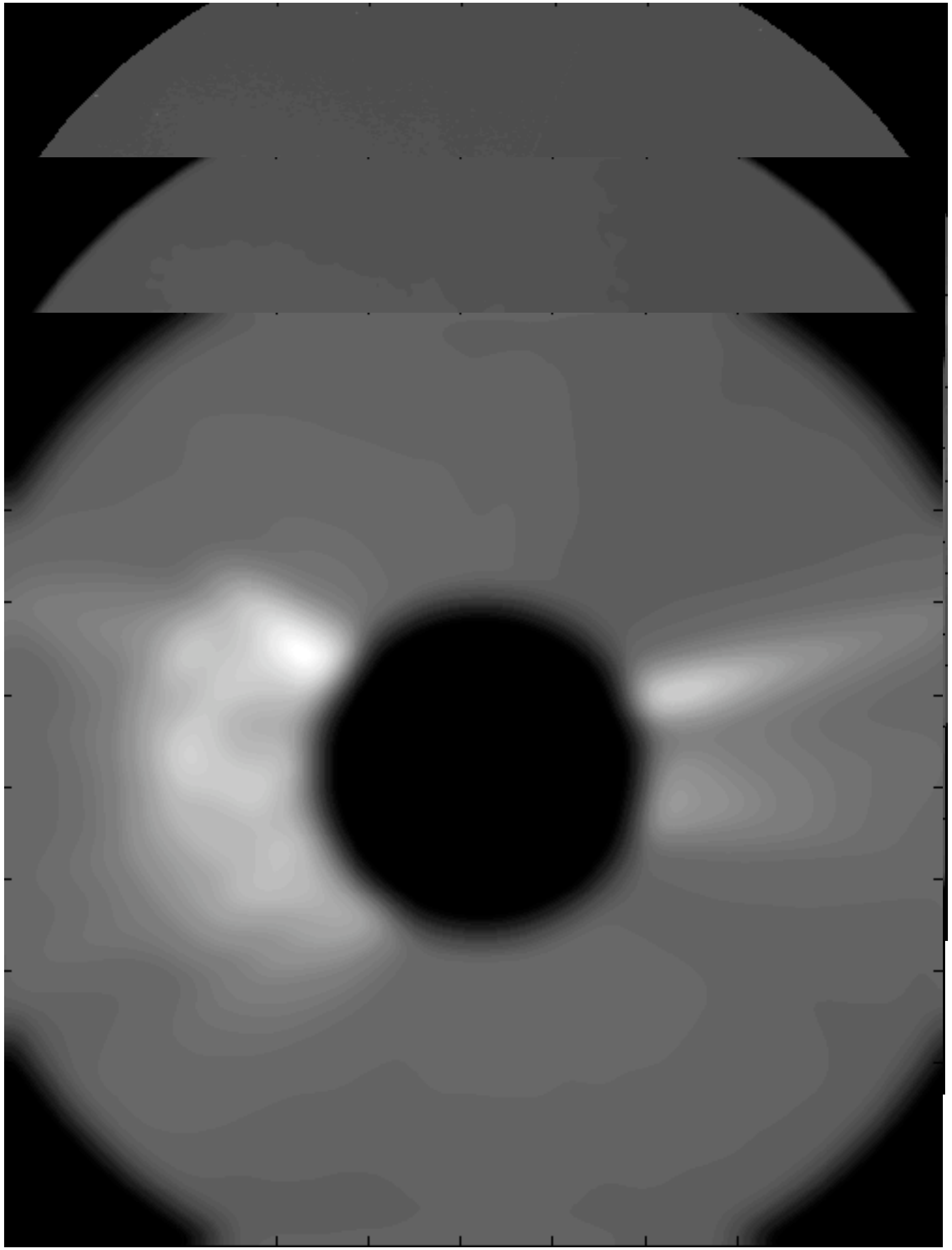


Low pass: Approximation



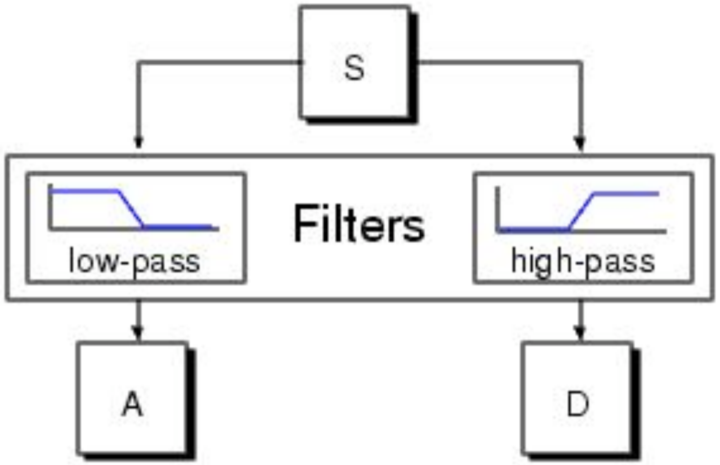
High pass: Detail



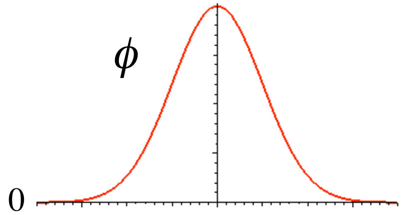


1) Multiscale Decomposition

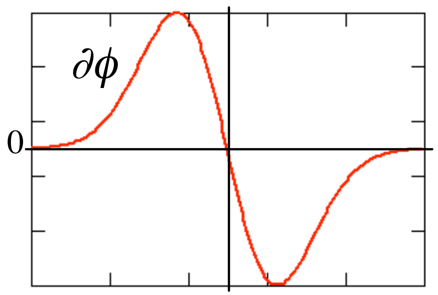
Input: s

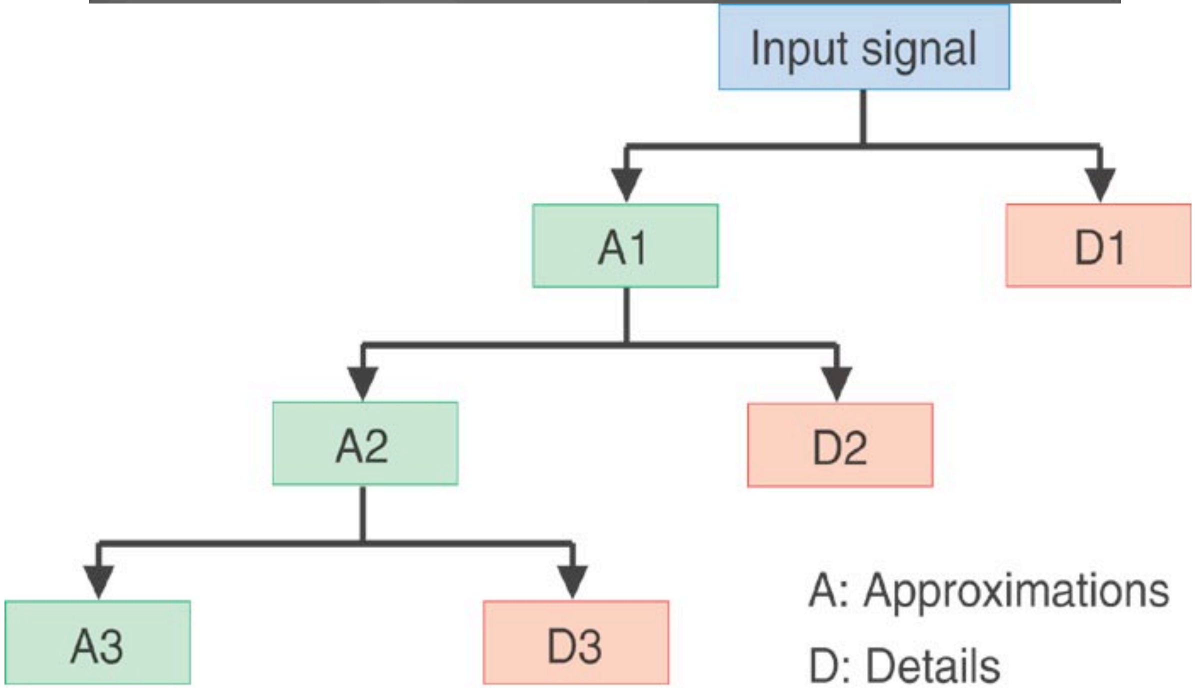


Low pass: Approximation



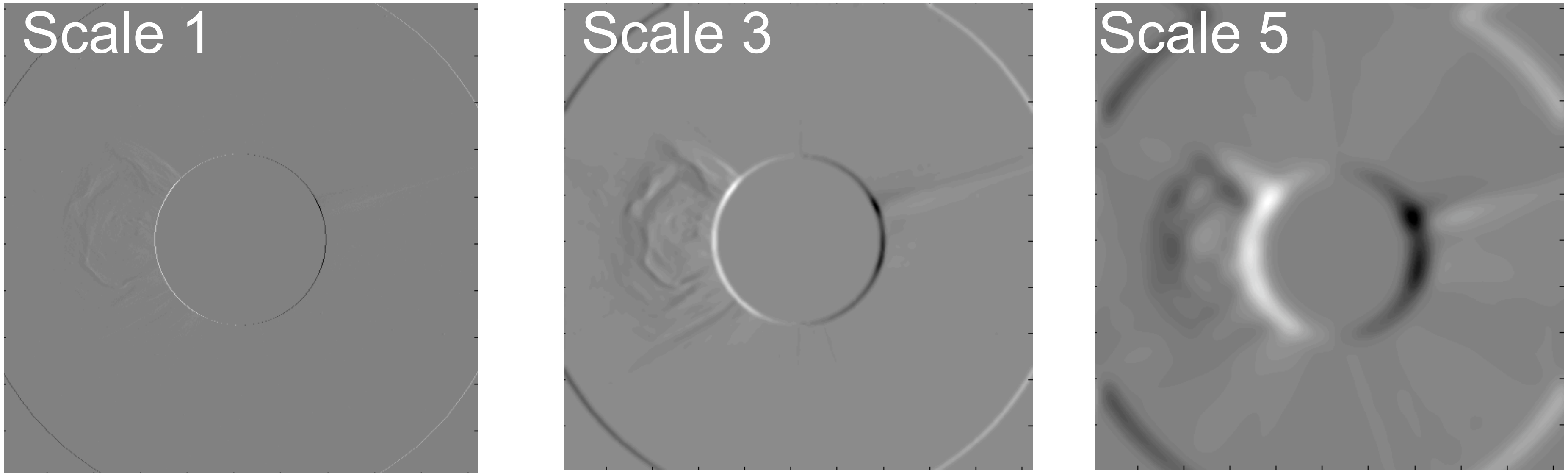
High pass: Detail



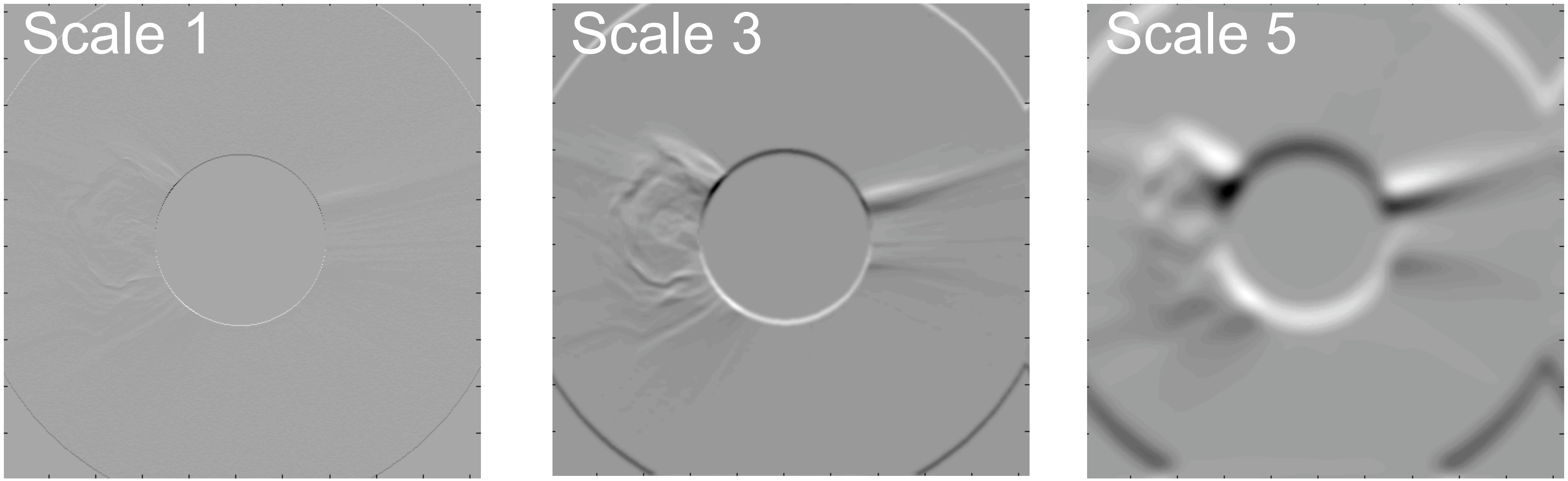


1) Multiscale Decomposition

Horizontal Direction:



Vertical Direction:



Our Algorithm

Image Pre-Processing

1) Multiscale Decomposition

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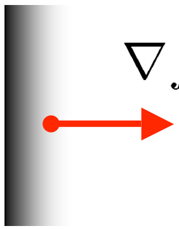
5) CME Front Characterisation

Kinematics & Morphology

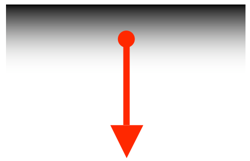
2) Gradient Space Information

- The gradient of an image: $$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

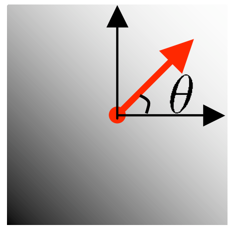
- The gradient points in the direction of most rapid change in intensity



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



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



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

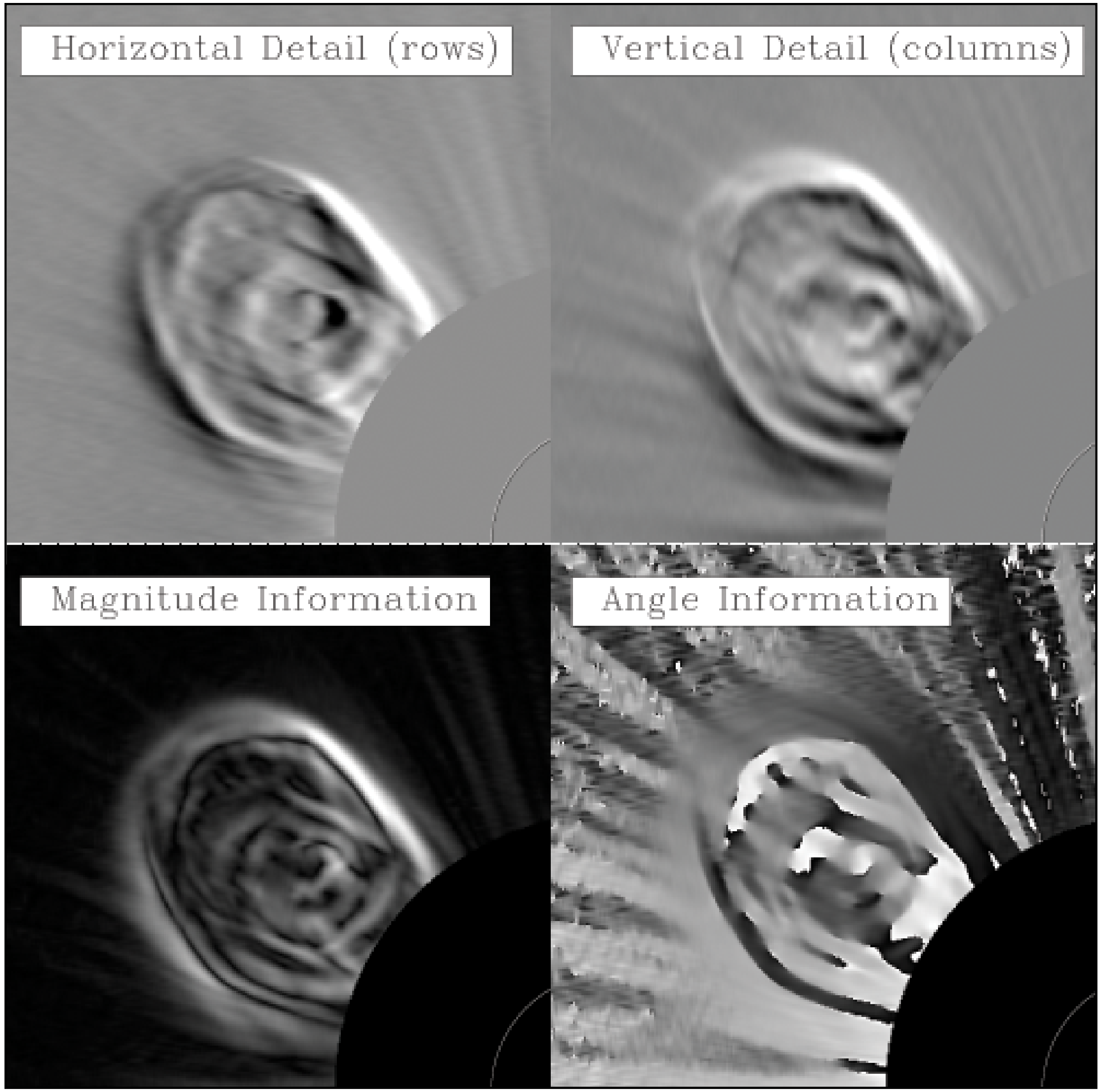
- The gradient direction is given by:

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

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

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

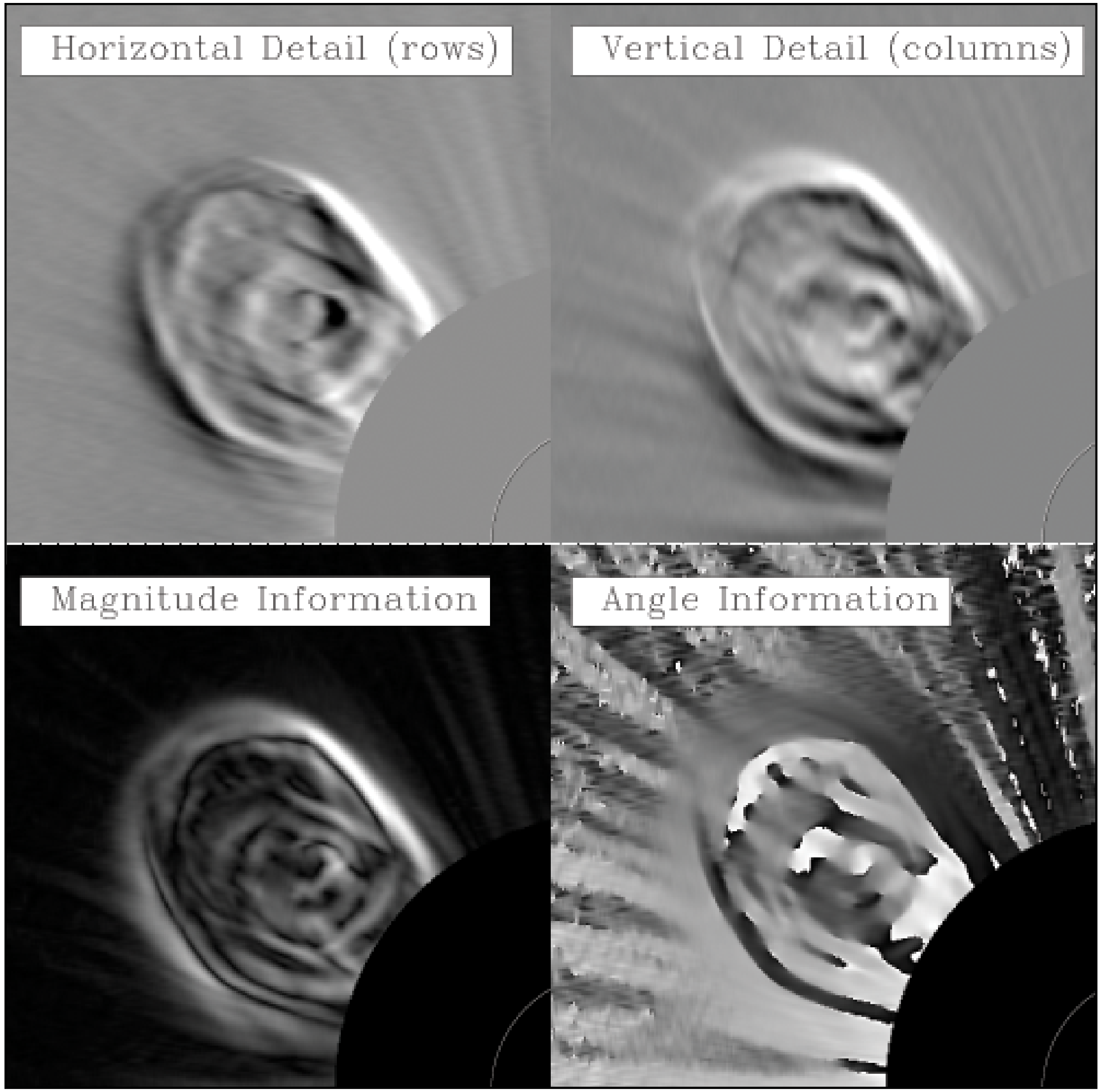
2) Gradient Space Information



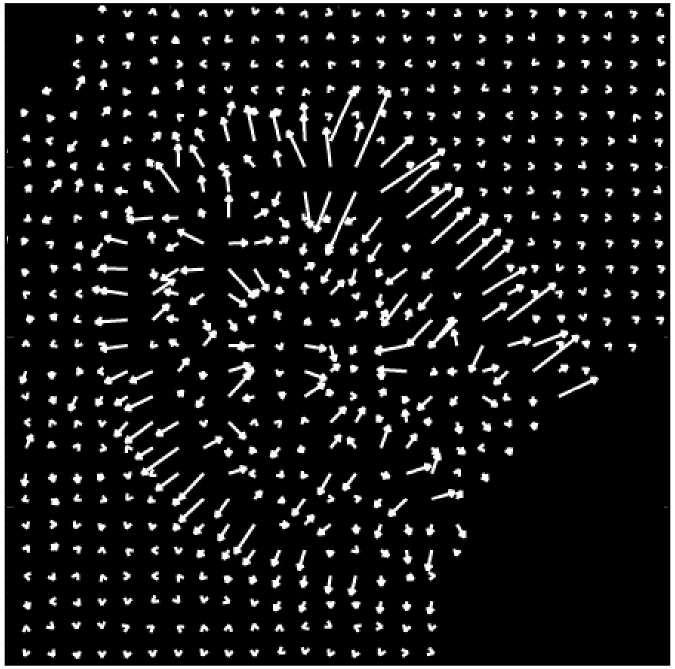
C2 01-Apr-04

2) Gradient Space Information

Vector-Arrow Field



C2 01-Apr-04



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

and inclination angle: θ

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

Our Algorithm

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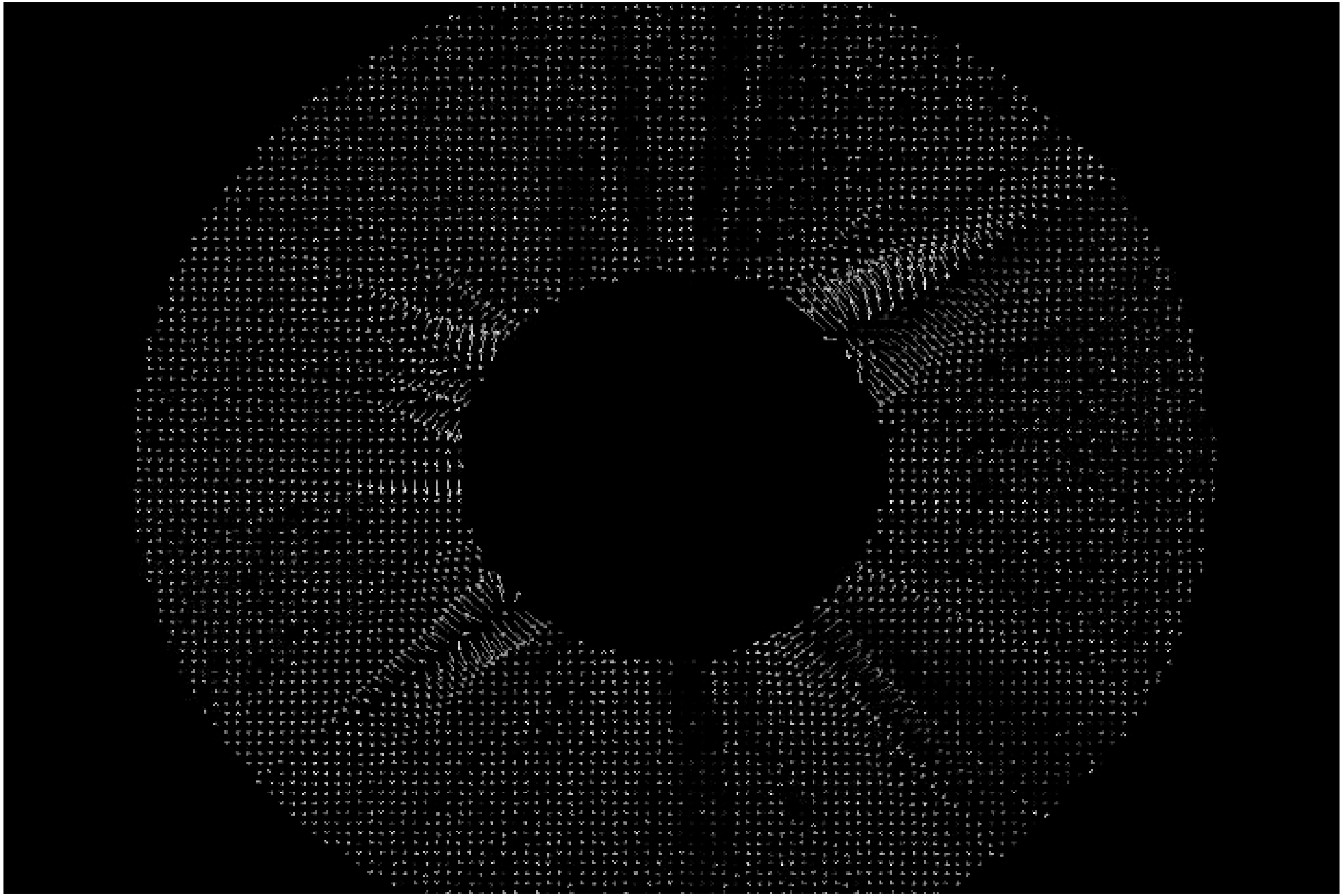
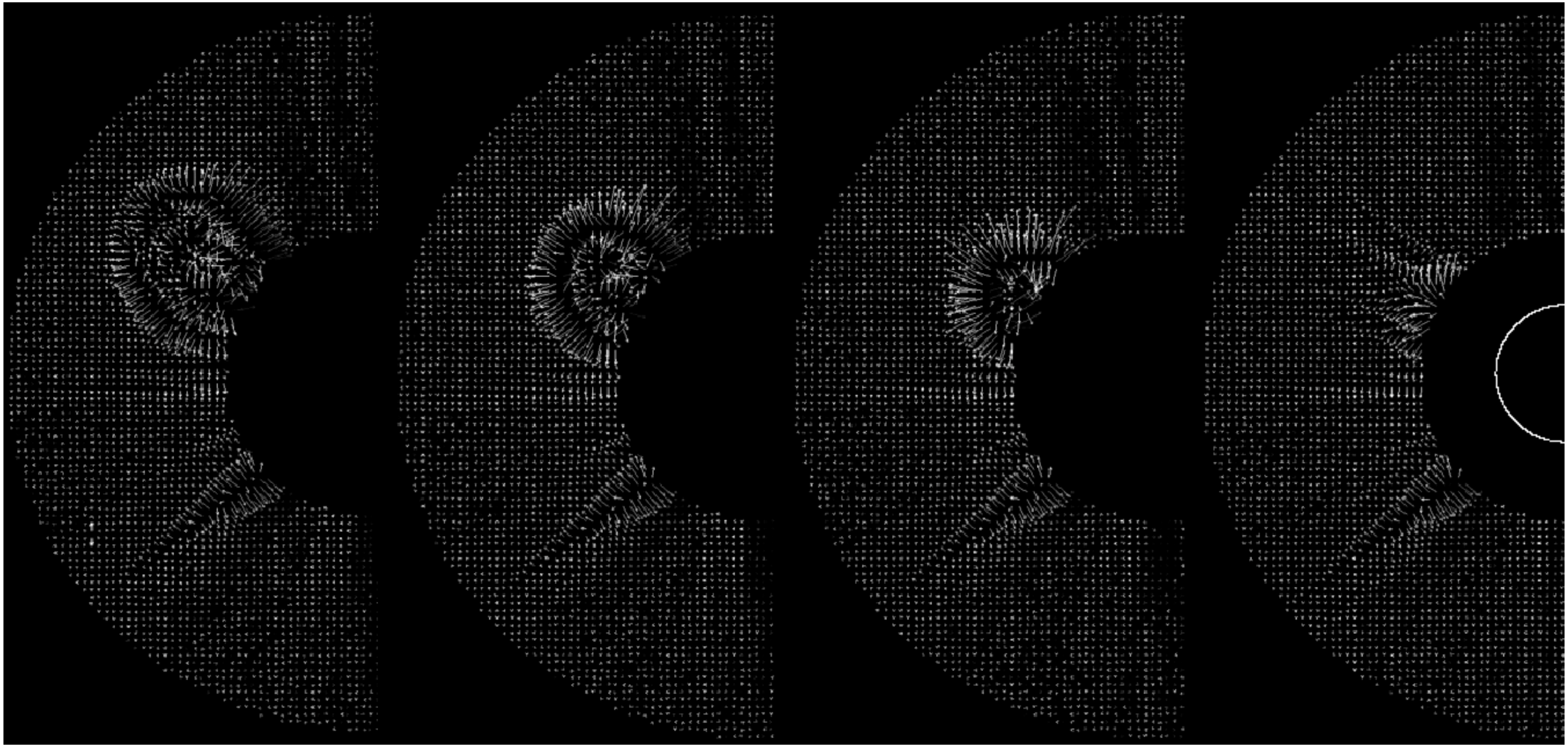
Kinematics & Morphology

3) Spatio-Temporal Filter



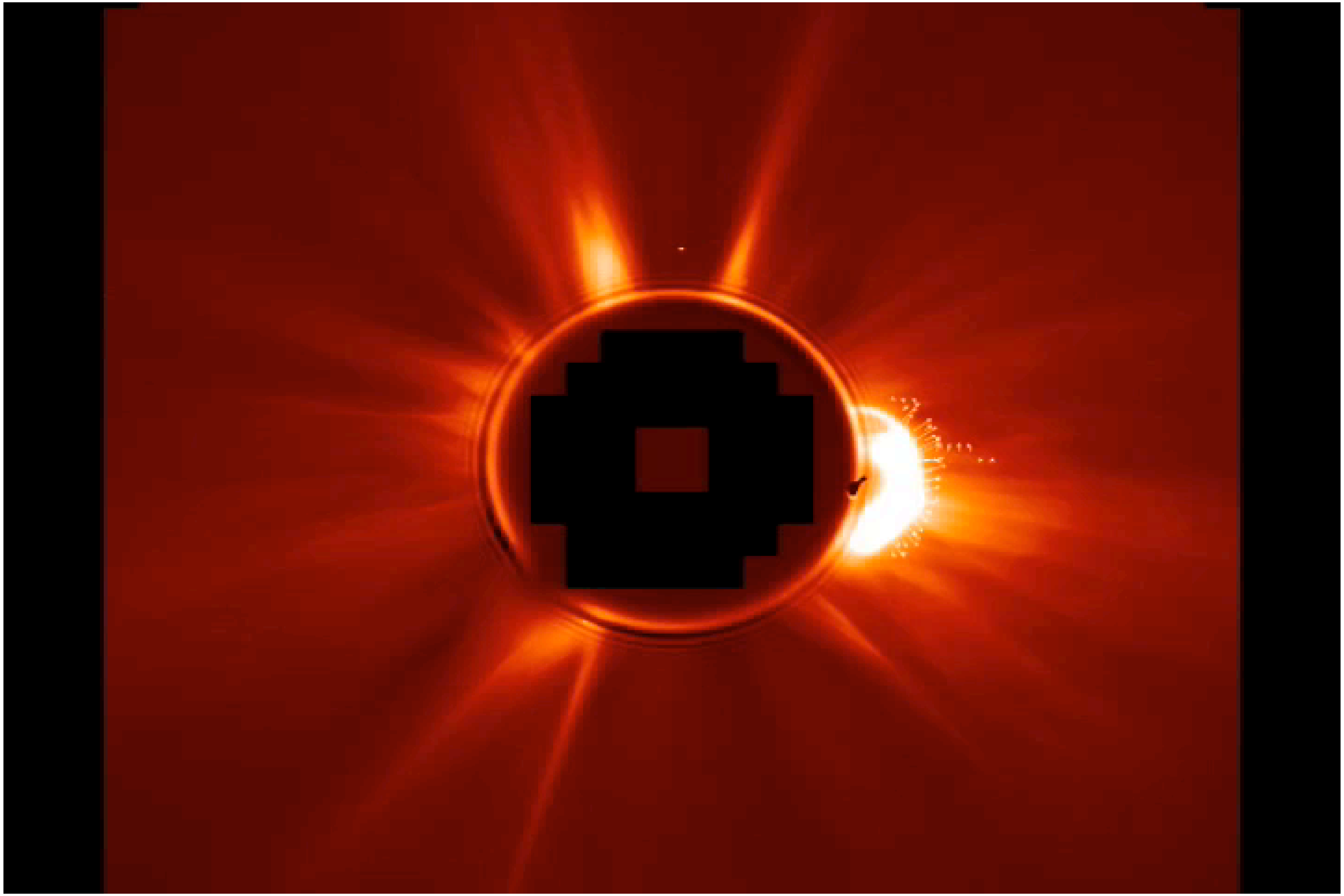
Arrows corresponding to the magnitude and inclination angle of the Scale 5 decomposition of a LASCO/C2 CME on 01-Apr-04.

3) Spatio-Temporal Filter



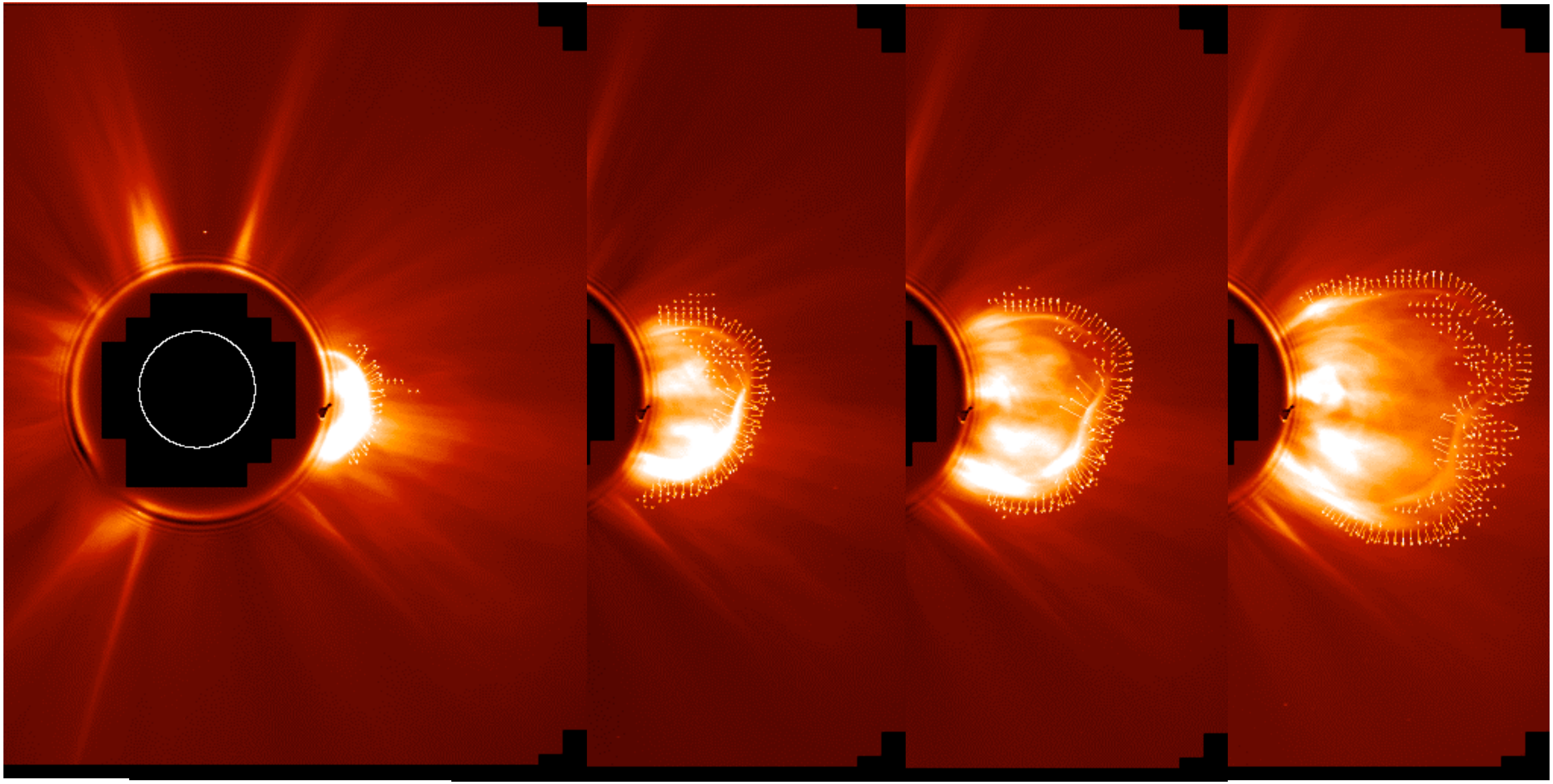
Vector-arrows corresponding to the magnitude and inclination angle of the Scale 5 decomposition of a LASCO/C2 CME on 01-Apr-04.

3) Spatio-Temporal Filter



LASCO/C2 18-Jan-00

3) Spatio-Temporal Filter



LASCO/C2 18-Jan-00

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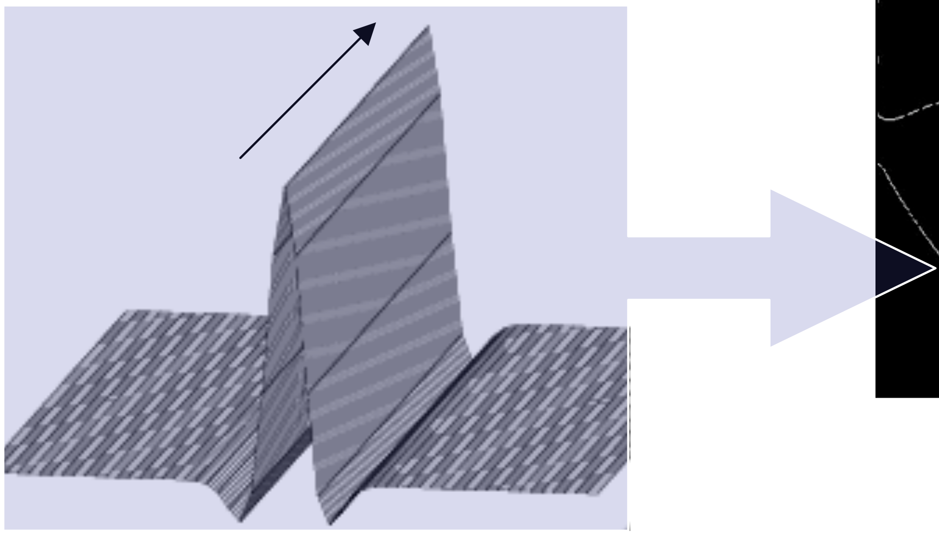
Kinematics & Morphology

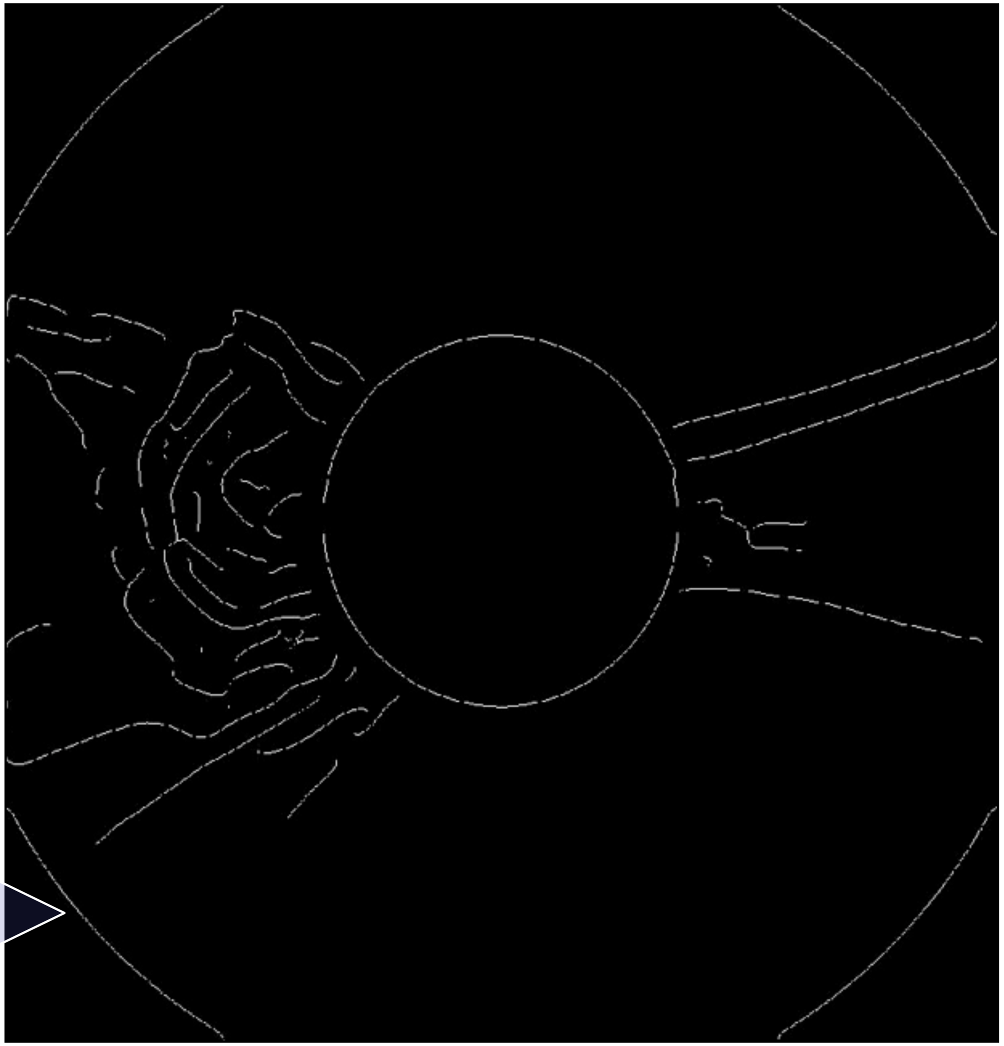
4) Non-Maxima Suppression

1) Nearest-neighbour info.

2) Criteria of angle and magnitude from gradients.

3) Pixels chained along edges.





LASCO/C2 24-Jan-07

Our Algorithm

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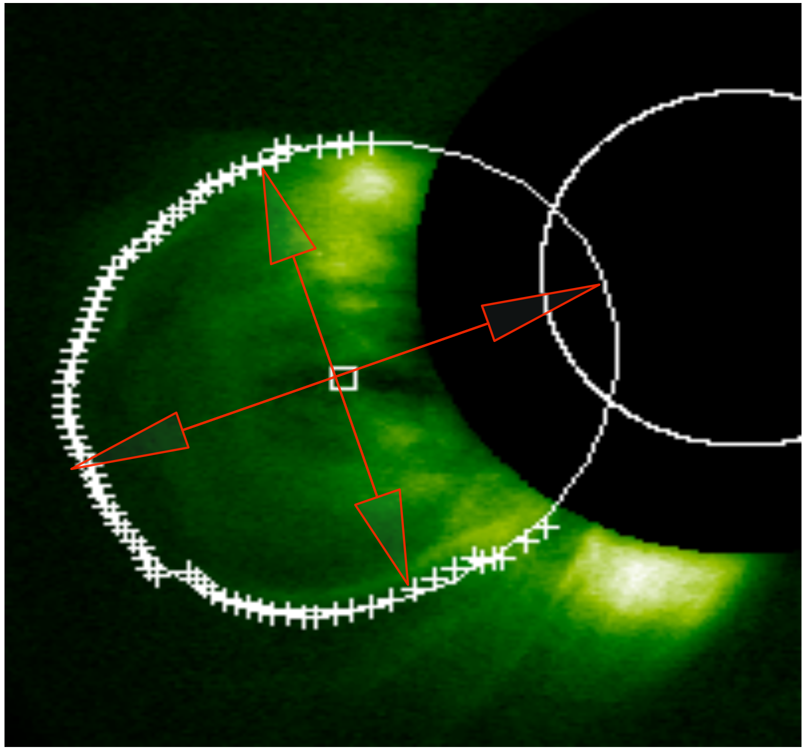
Kinematics & Morphology

5) CME Front Characterisation

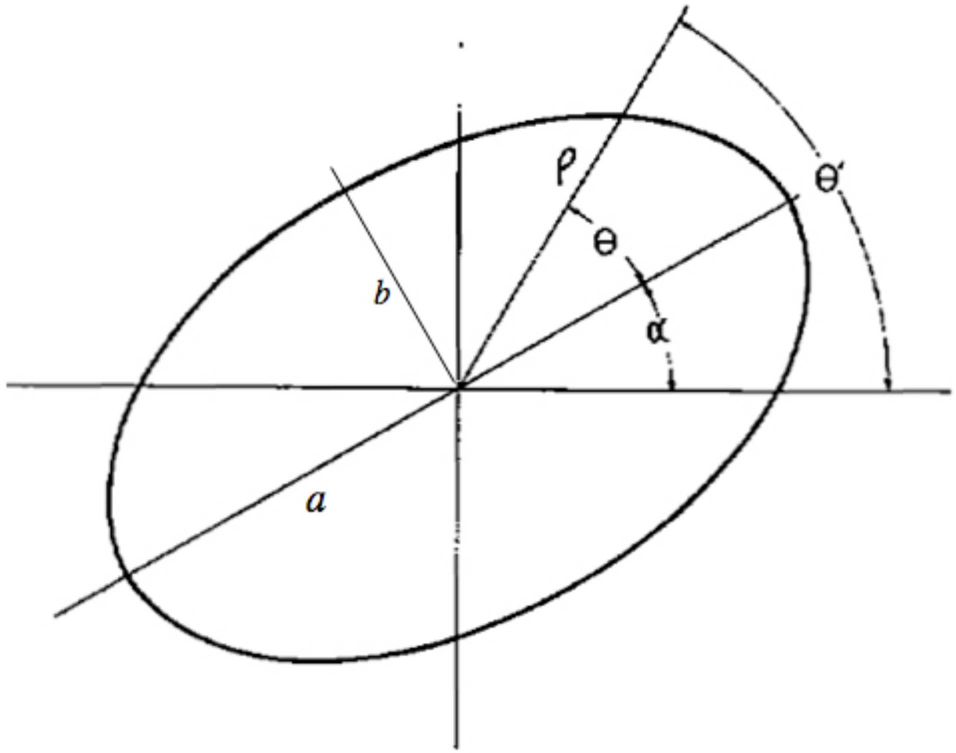
- Ellipse fit
- Height, Width, Curvature, Orientation

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

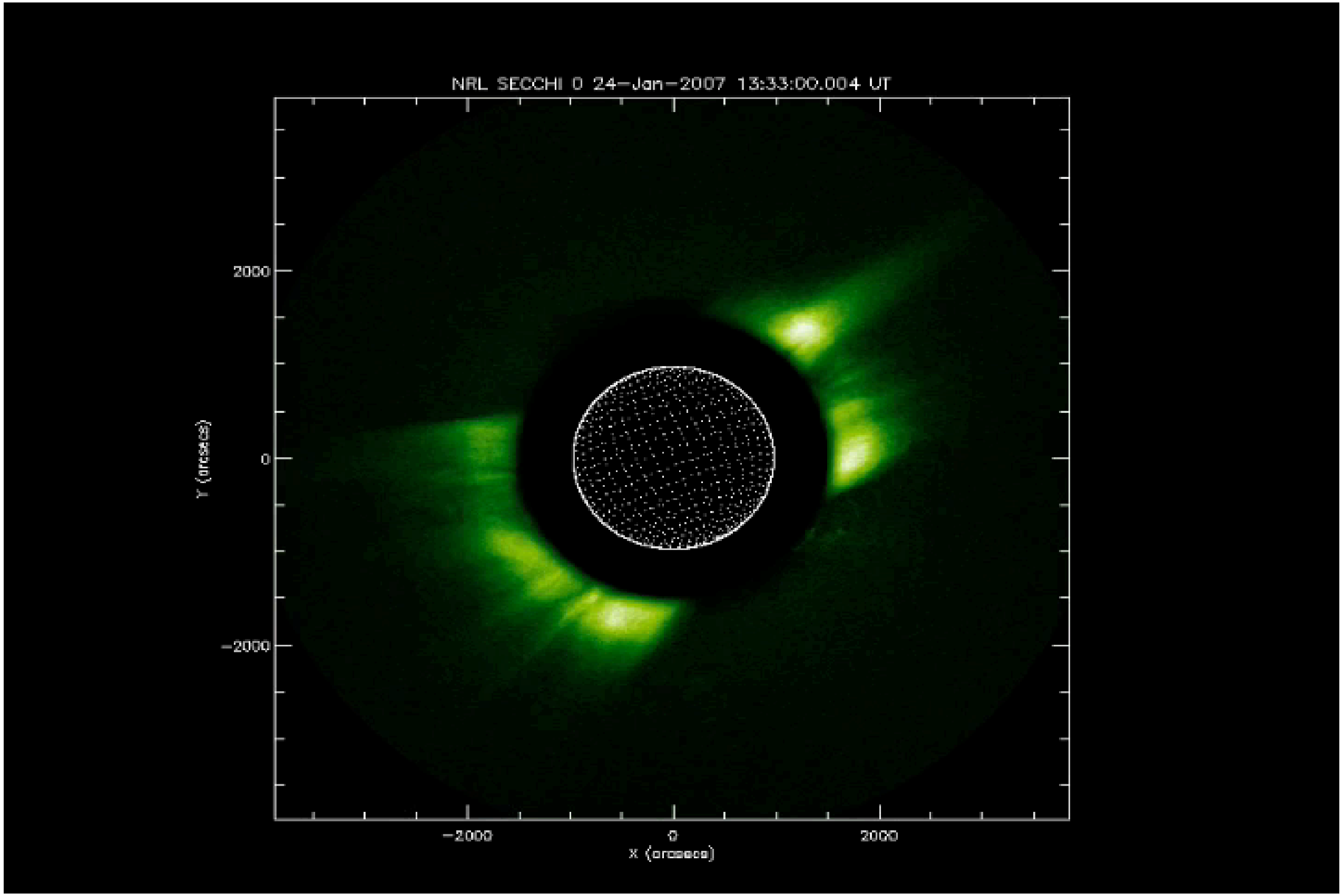
$$\rho^2 = \frac{a^2 b^2}{\left(\frac{a^2+b^2}{2}\right) - \left(\frac{a^2-b^2}{2}\right)\cos(2\theta' - 2\alpha)}$$



SECCHI/COR1 24-Jan-07

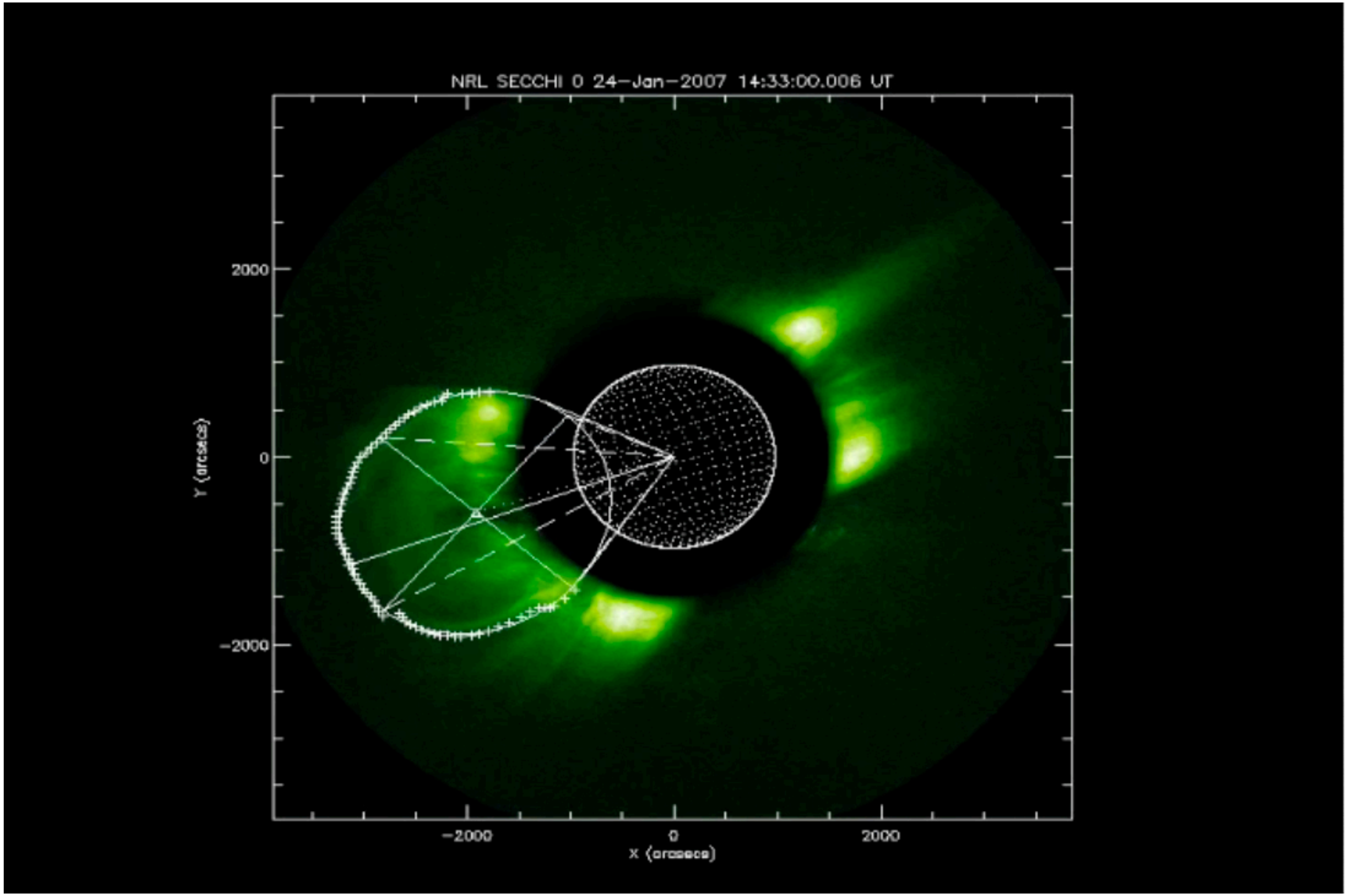


5) CME Front Characterisation



SECCHI/COR1-A 24-Jan-07

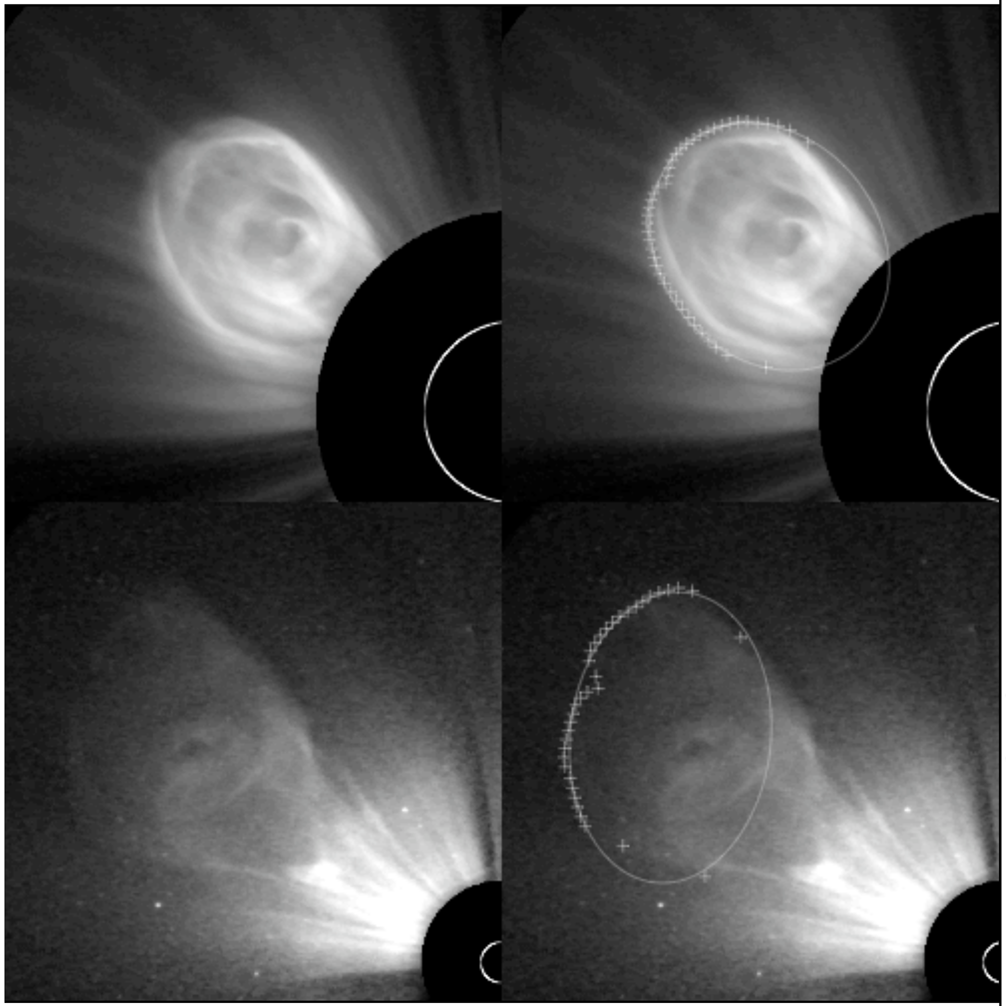
5) CME Front Characterisation



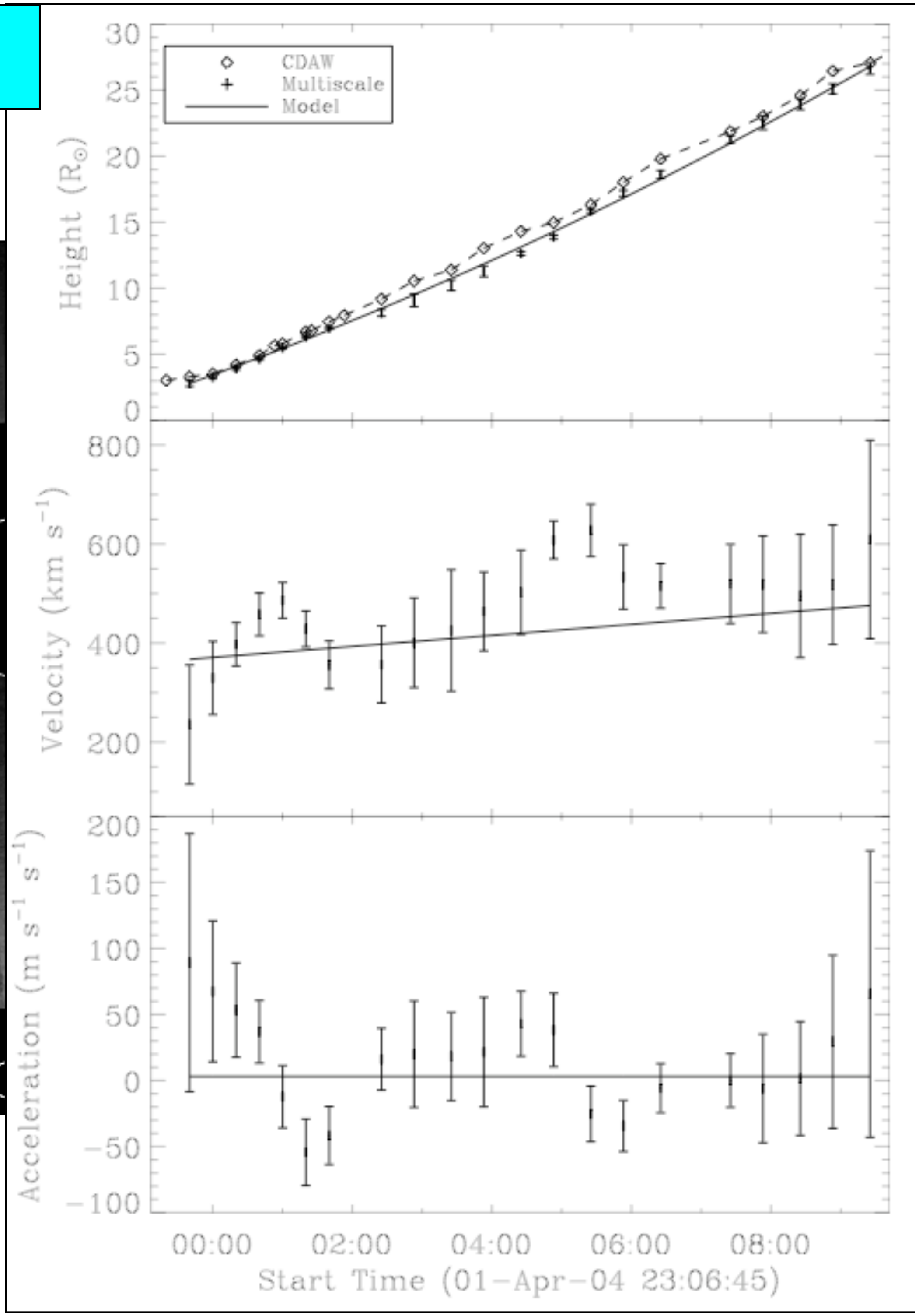
SECCHI/COR1-A 24-Jan-07

5) CME Front Characterisation

Kinematics & Morphology

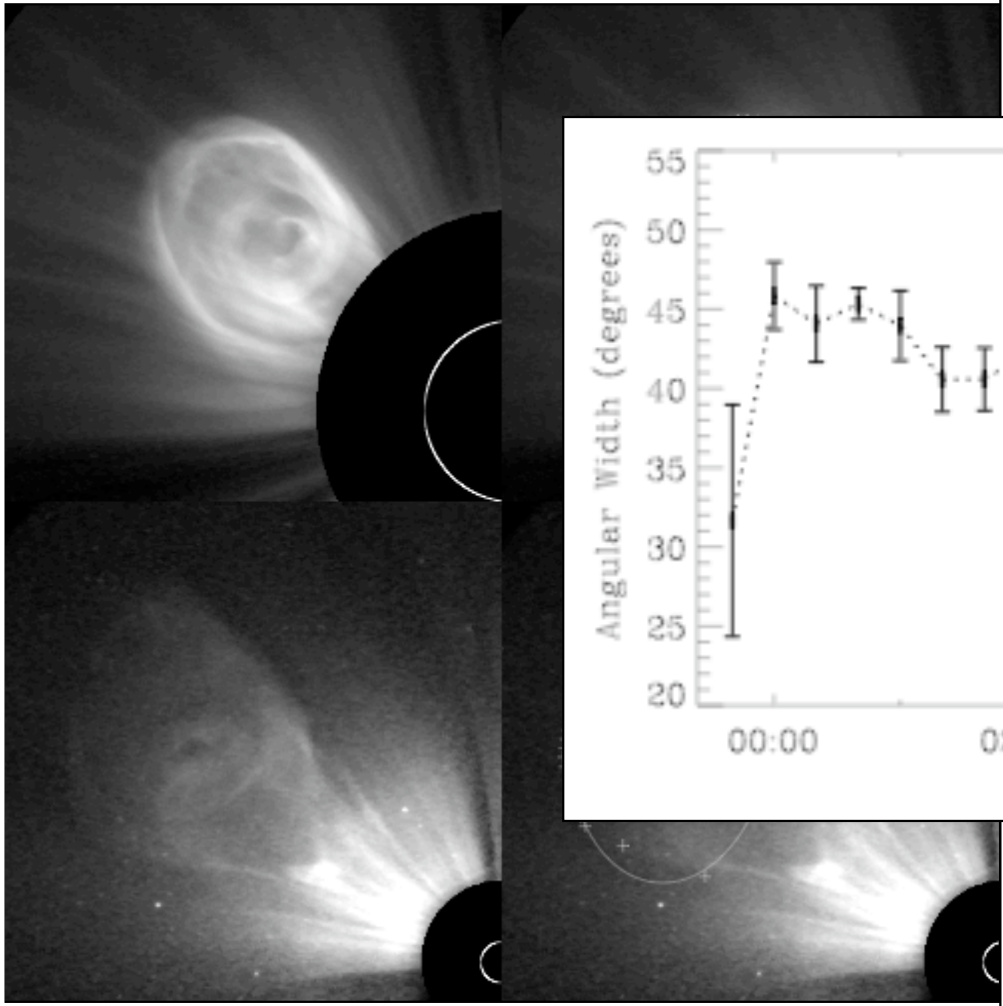


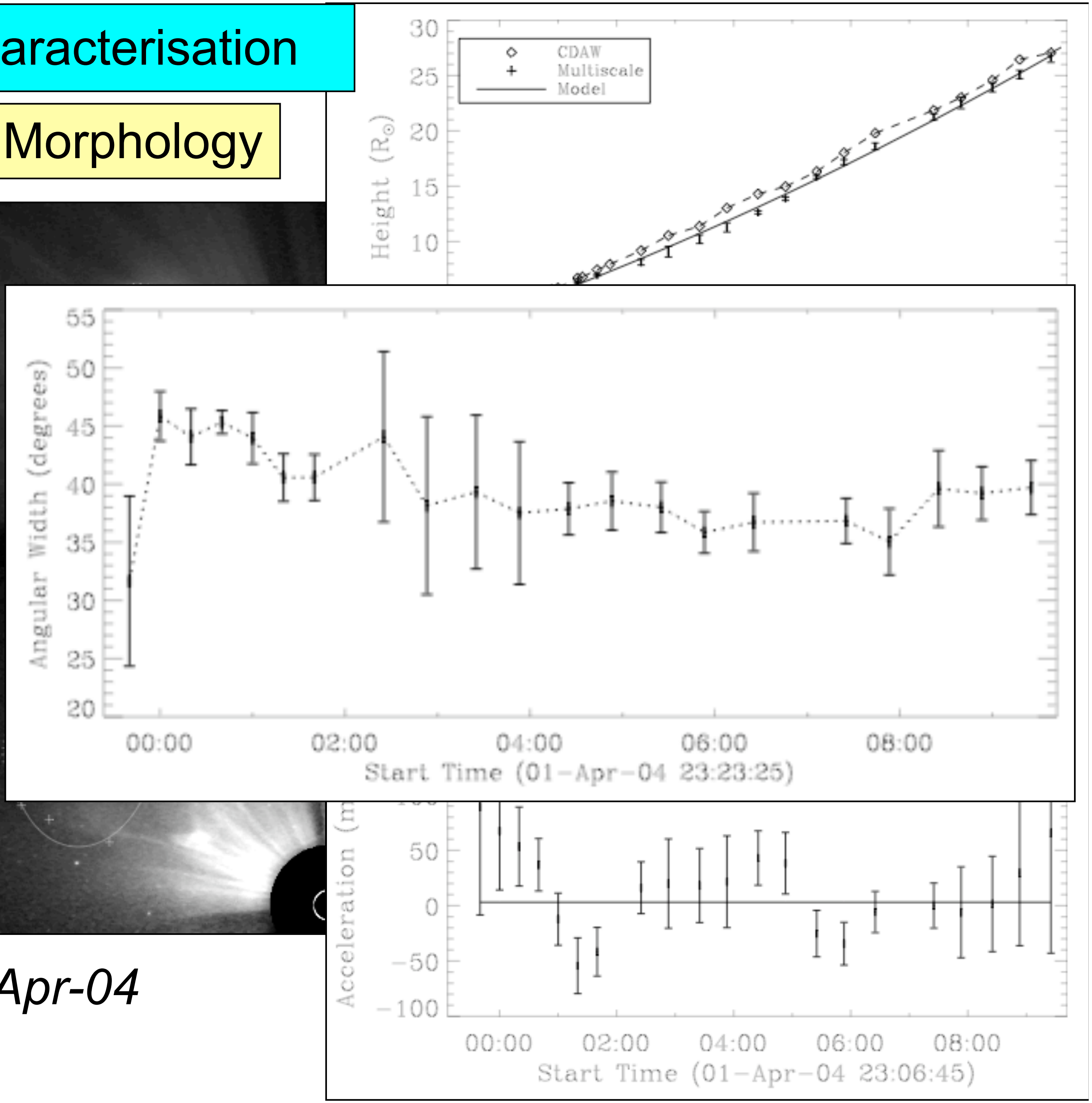
LASCO 01-Apr-04



5) CME Front Characterisation

Kinematics & Morphology

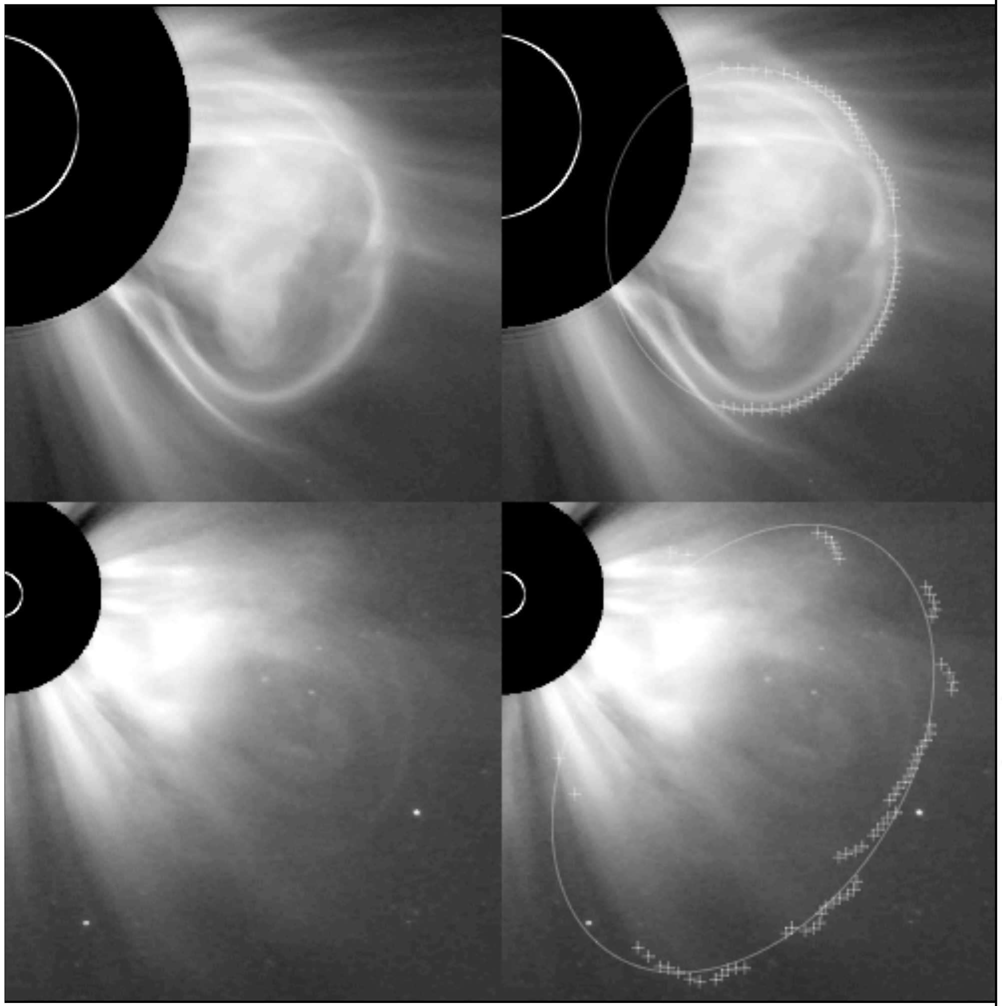




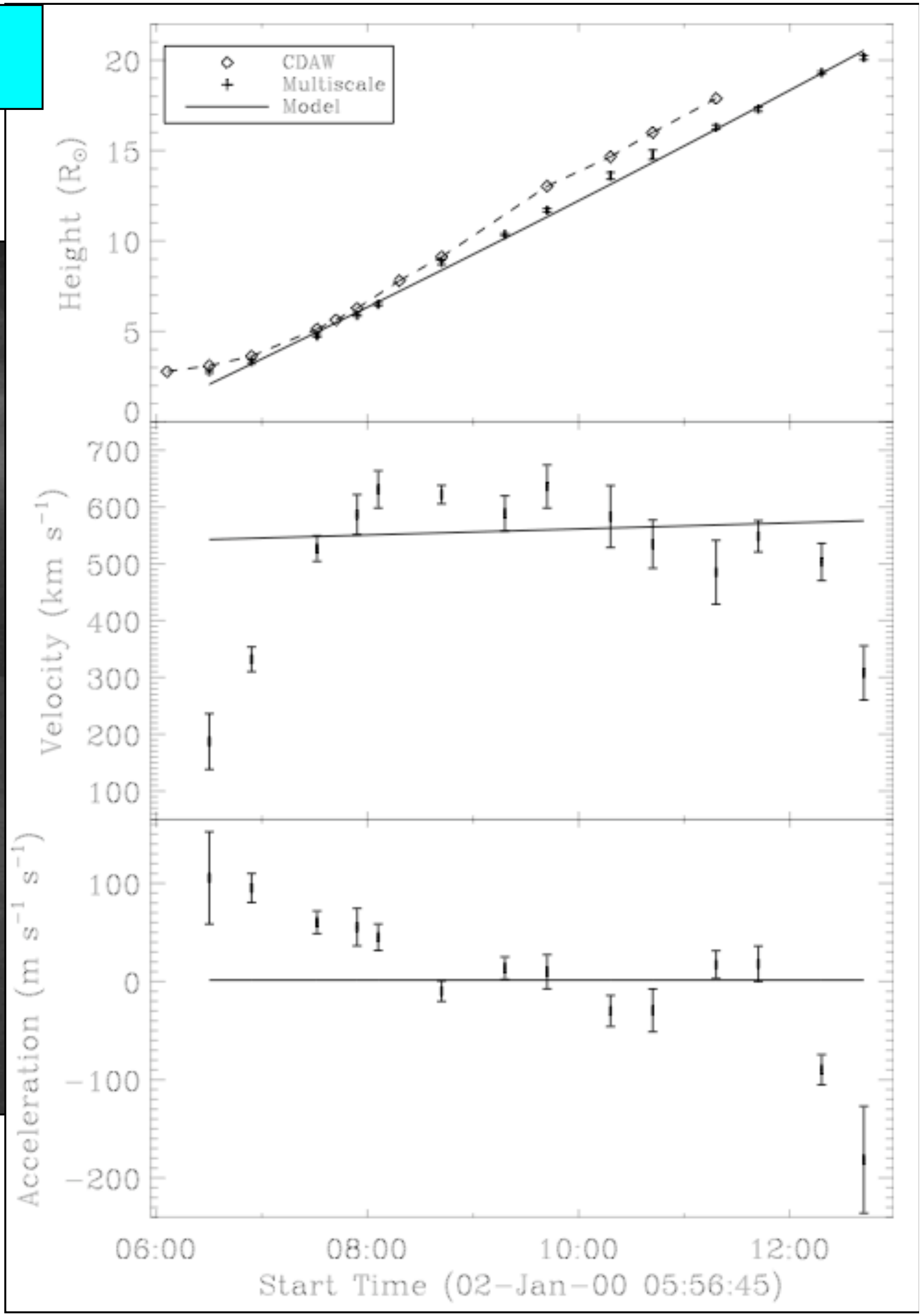
LASCO 01-Apr-04

5) CME Front Characterisation

Kinematics & Morphology

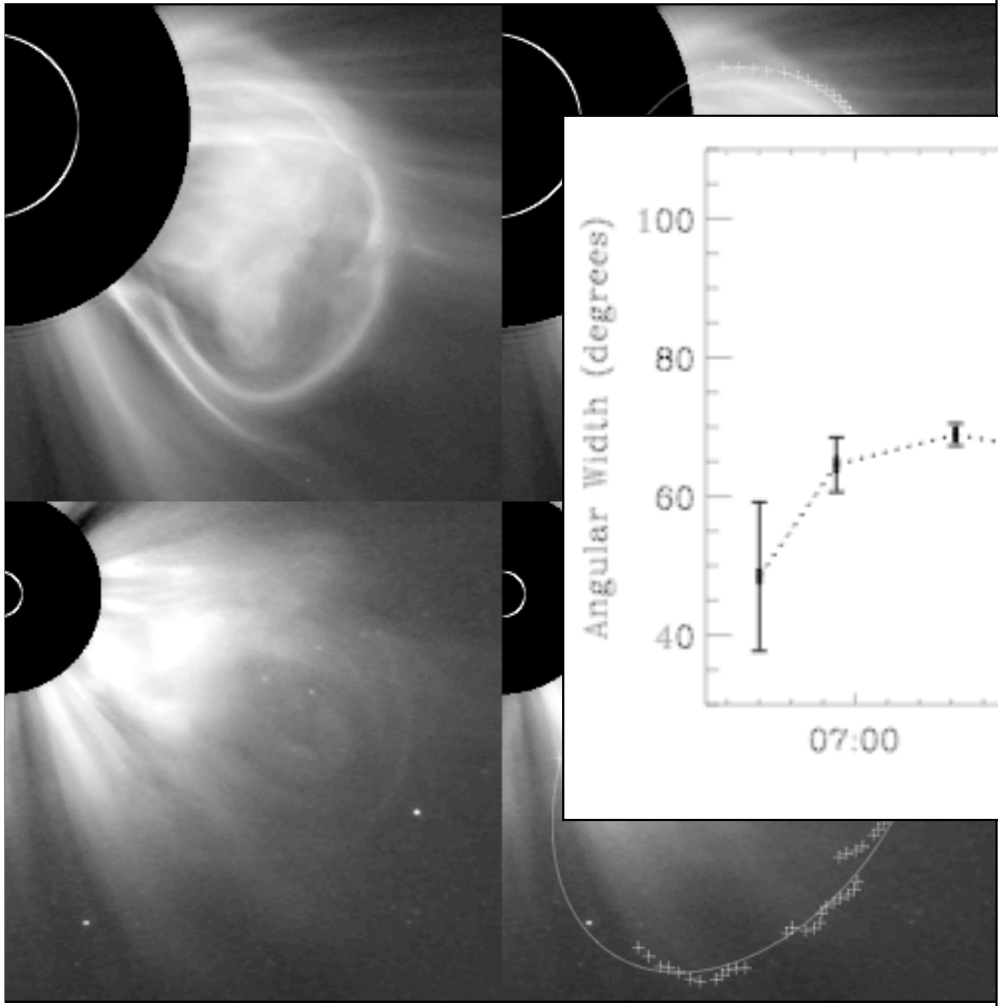


LASCO 02-Jan-00

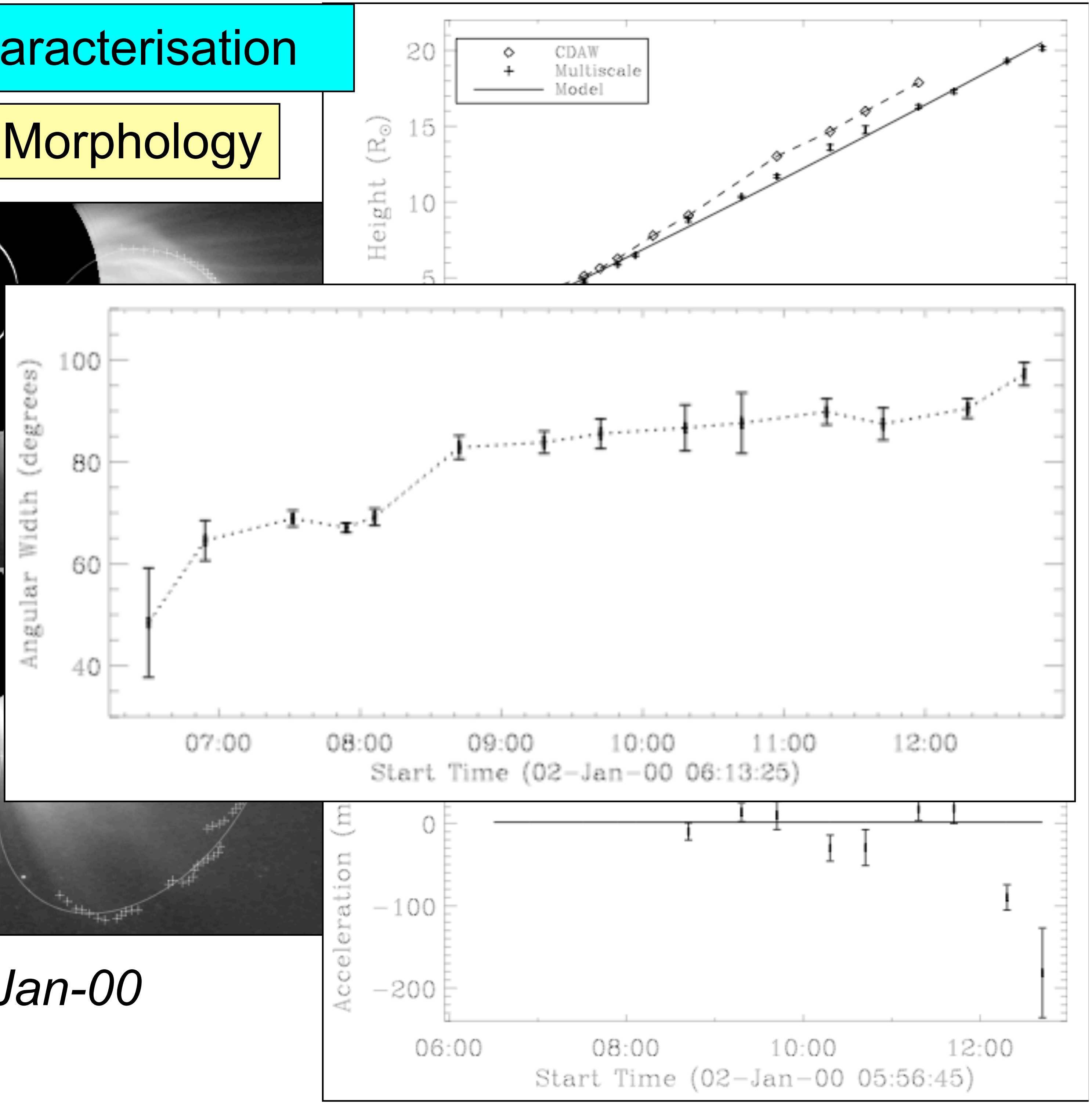


5) CME Front Characterisation

Kinematics & Morphology

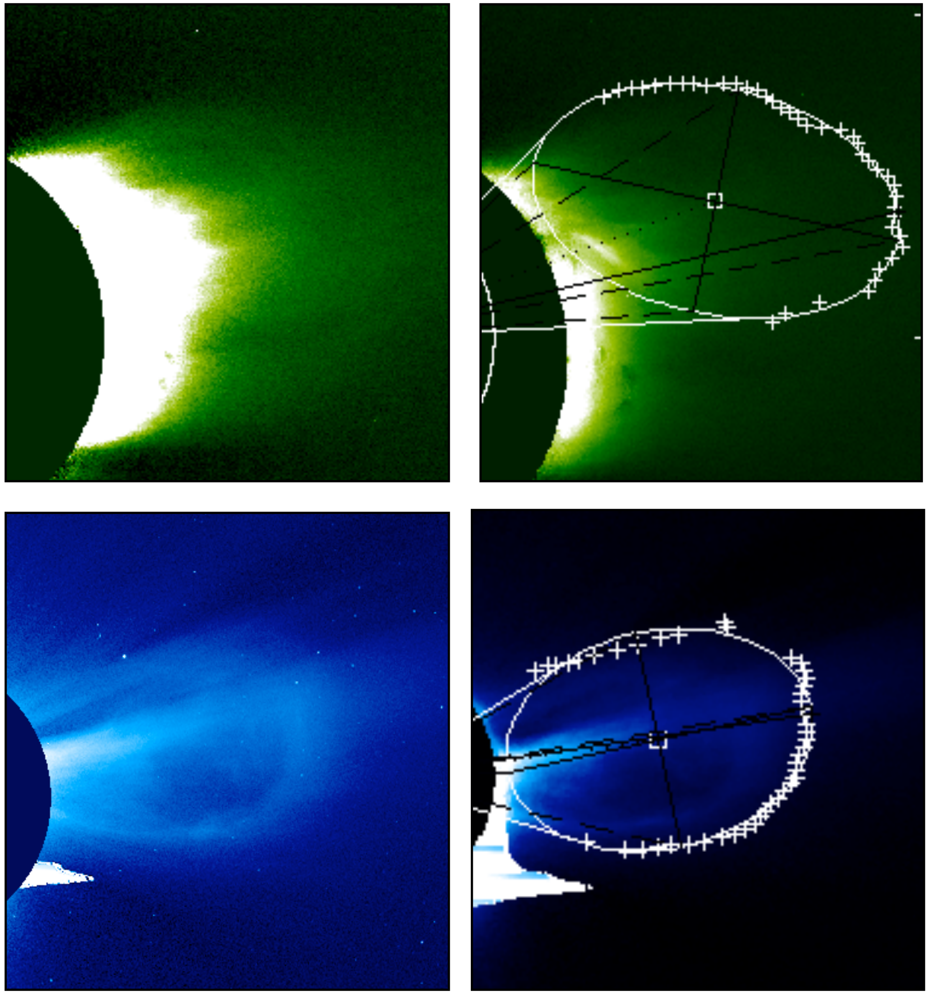


LASCO 02-Jan-00

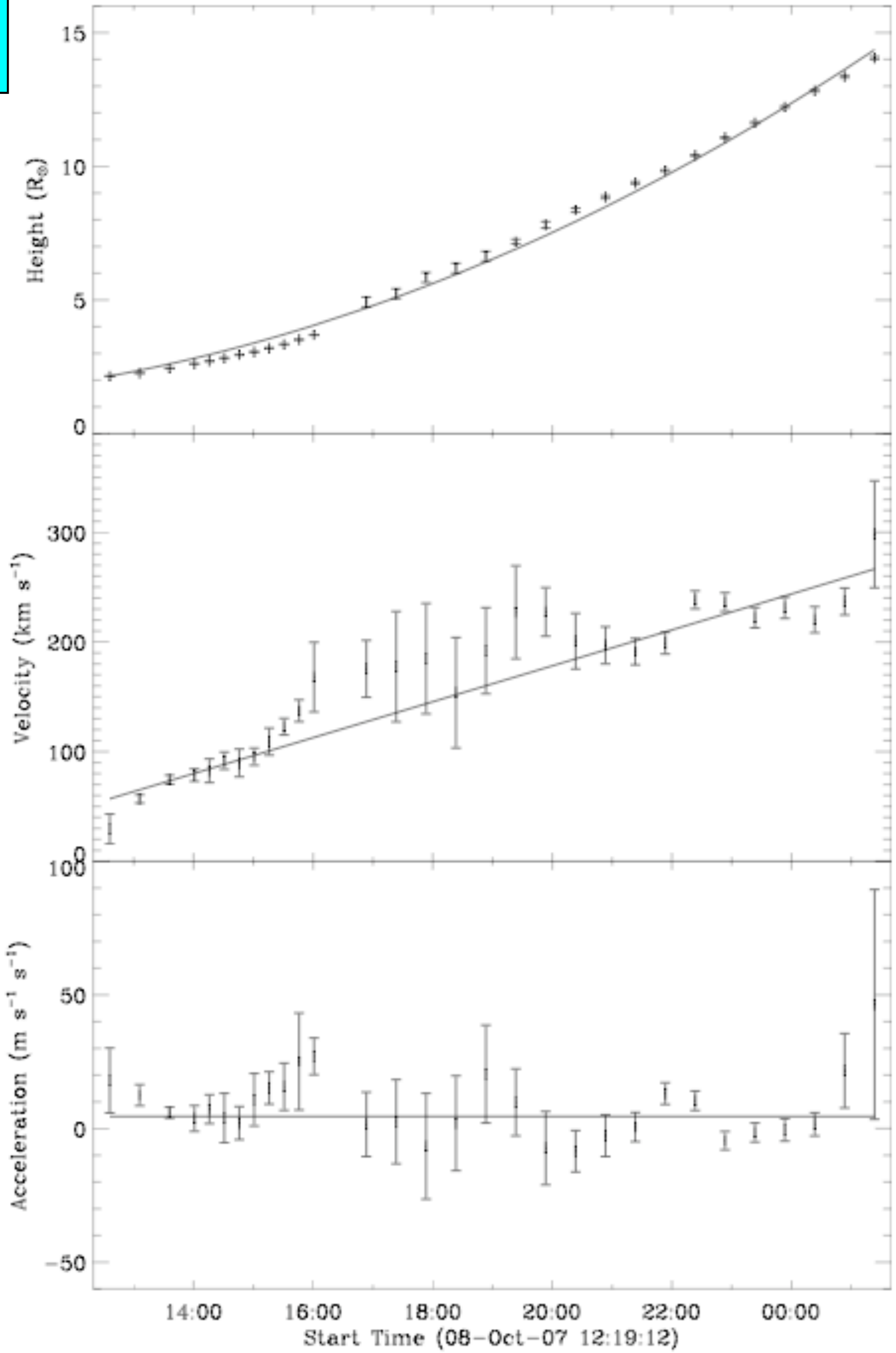


5) CME Front Characterisation

Kinematics & Morphology

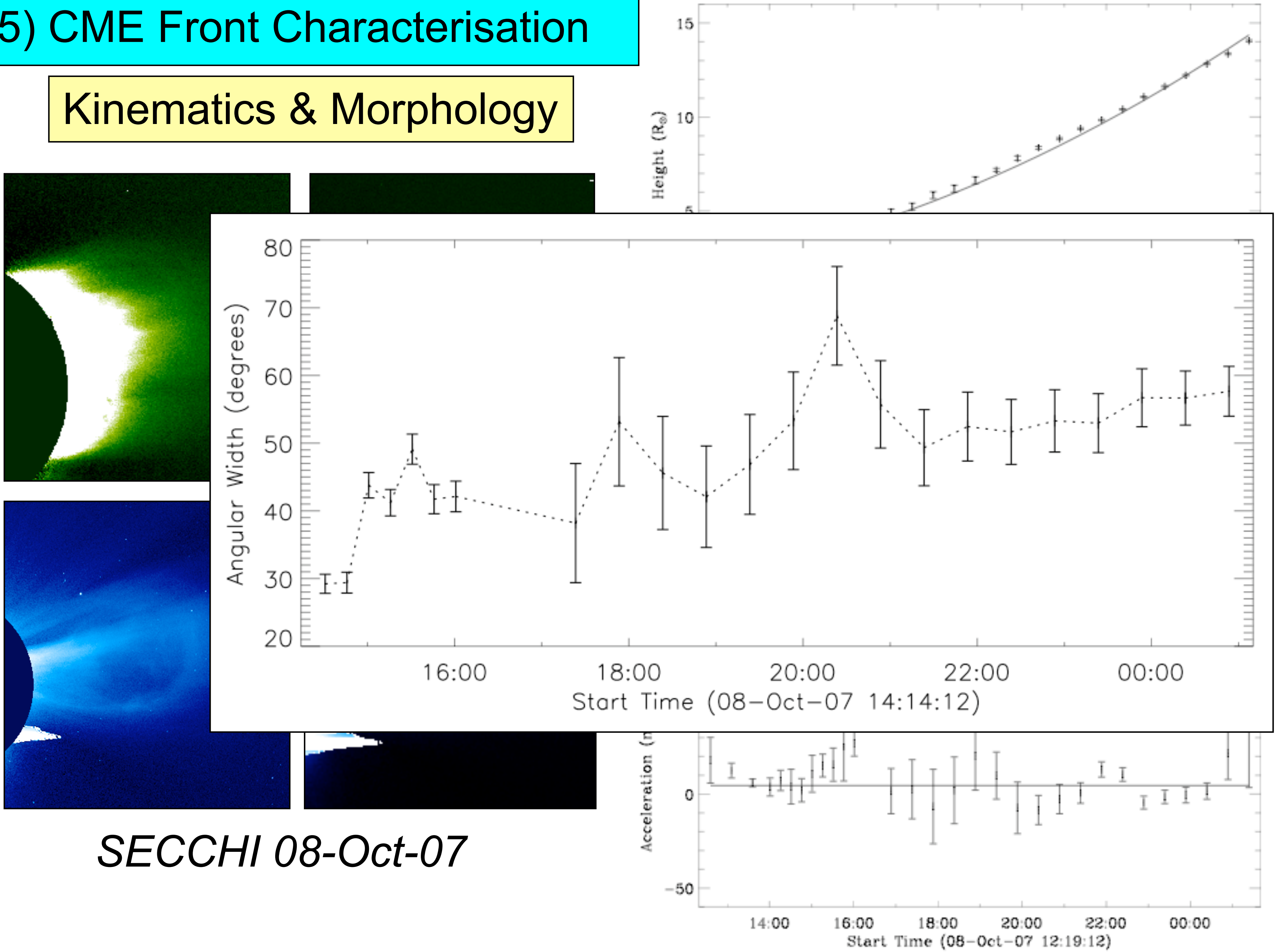


SECCHI 08-Oct-07



5) CME Front Characterisation

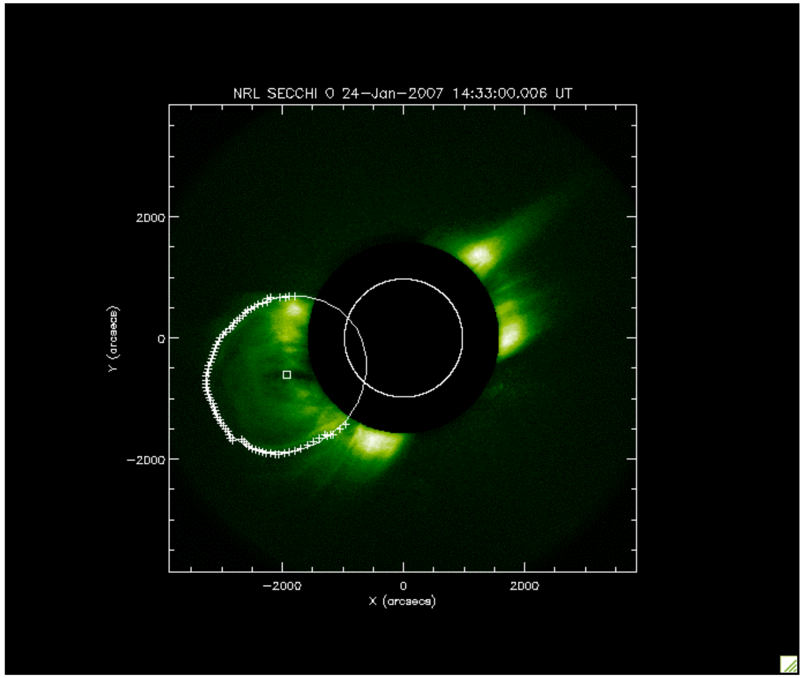
Kinematics & Morphology

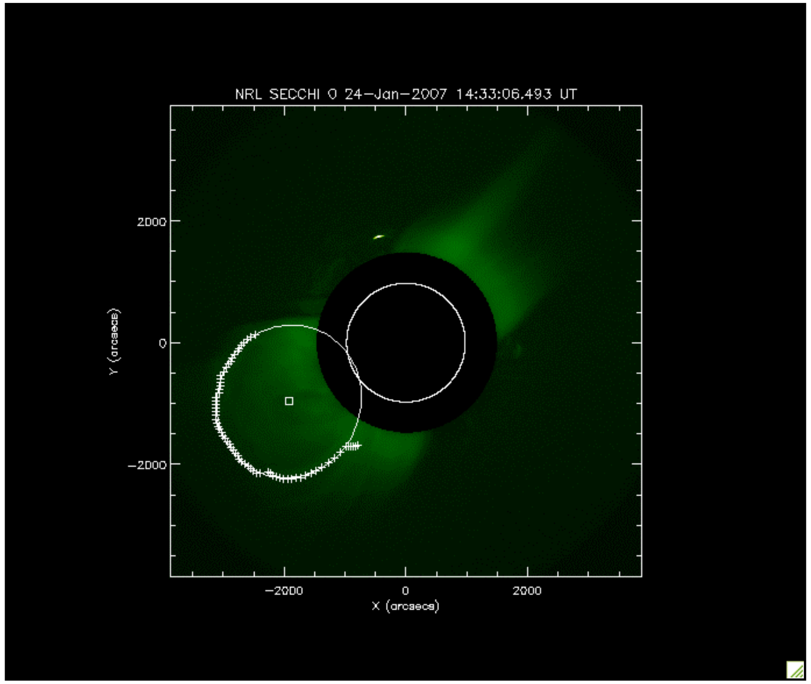


SECCHI 08-Oct-07

Conclusions so far…

- Multiscale methods provide high accuracy edge detections.
- Subsequent CME charaterisation and analysis shows cases of *possible non-constant acceleration*.
- STEREO twin views may alleviate projection effects.
- Algorithm has great potential for automation.





COR1 Ahead & Behind 24-Jan-07

…heading toward Automation!

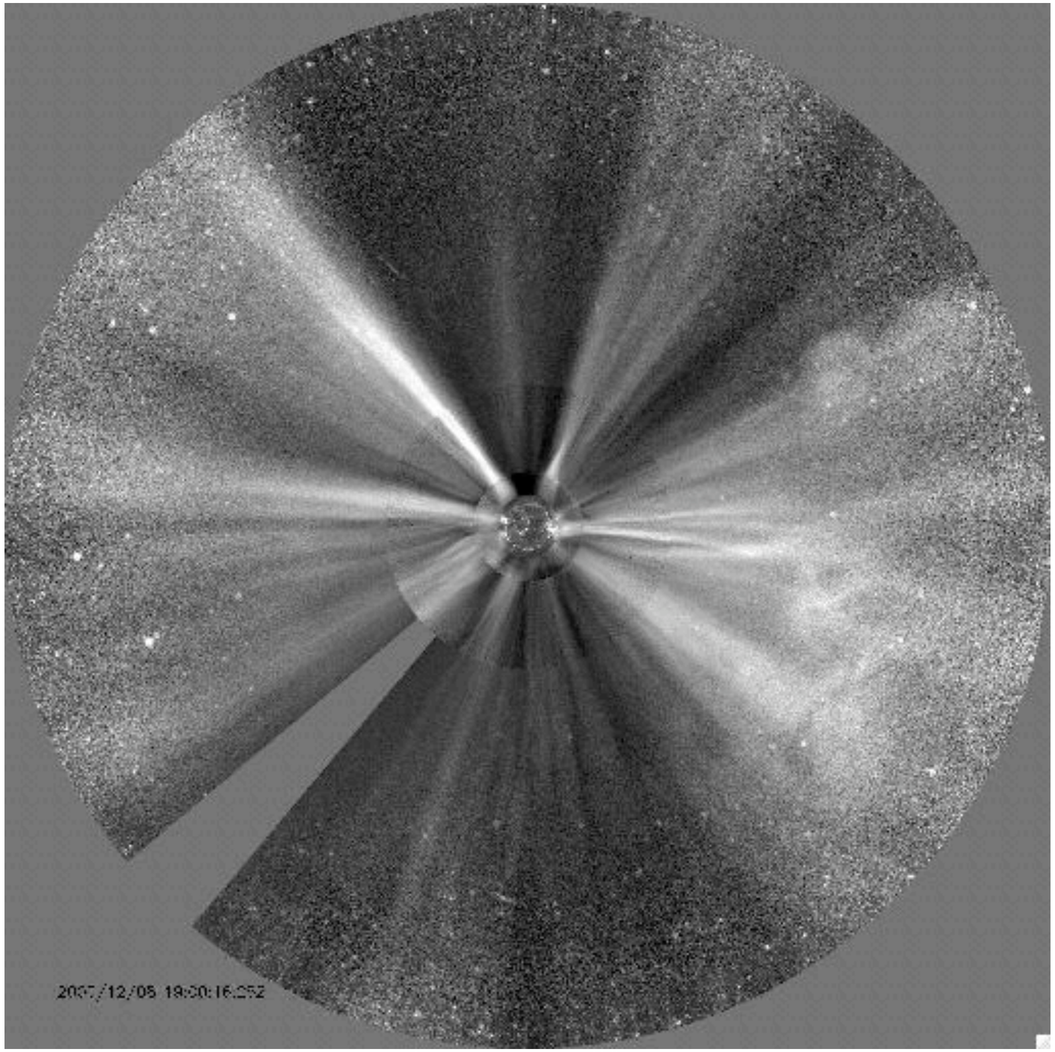
Normalizing Radial Graded Filter

- Radially the coronagraph image intensity drops off steeply.

- The intensity is normalized by subtracting the mean and dividing by the standard deviation.

$$I'(r,\phi) = \frac{I(r,\phi) - I(r)_{<\phi>}}{\sigma(r)_{<\phi>}}$$

…or simply $z = \dfrac{x - \mu}{\sigma}$

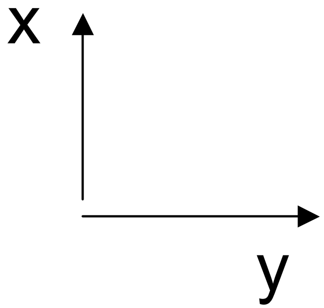


(Morgan et al. 2006)

…heading toward Automation!

Unwrap image

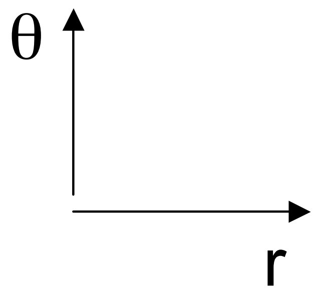
from Cartesian



...heading toward Automation!

Unwrap image

to polar coords



…heading toward Automation!

Unwrapped CME:

mov_row1_plot.html
cme_detect_20040401_c2.html

Chaining through scales:

cme_detect_20040401_C2_image 3.html
cme_detect_20000131_C2_image 8.html

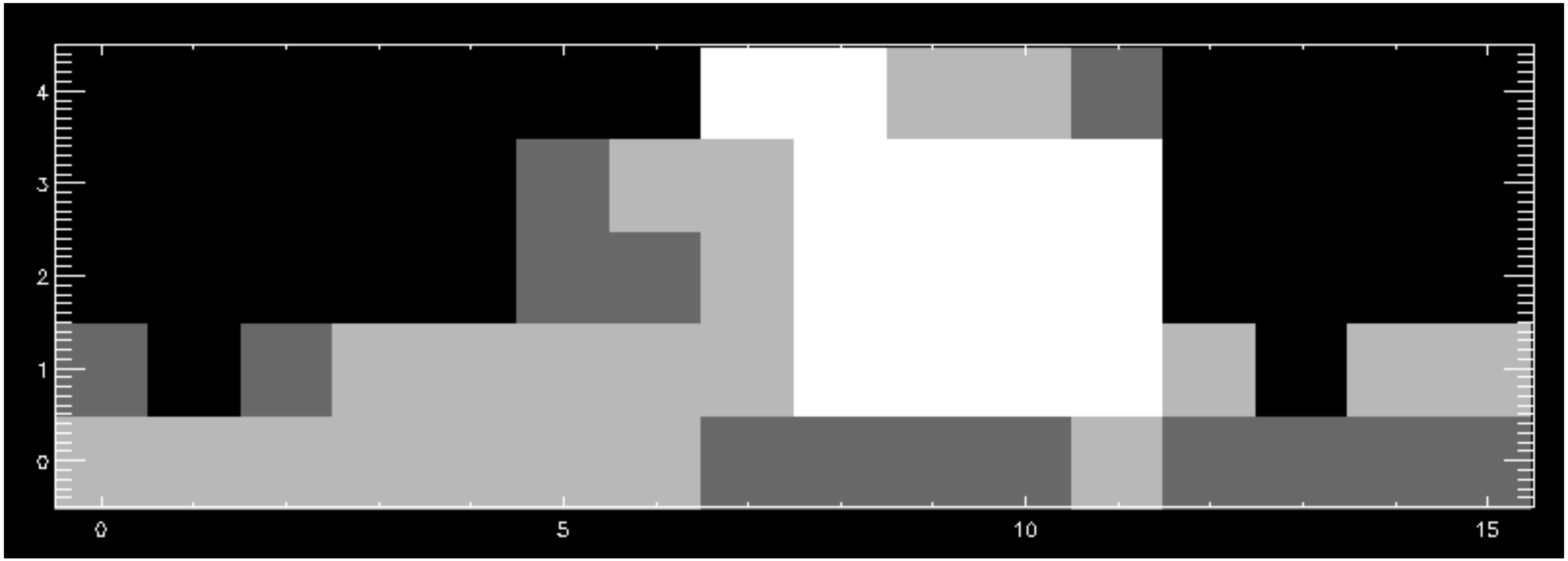
…heading toward Automation!

Unwrapped CME:

mov_row1_plot.html
cme_detect_20040401_c2.html

Chaining through scales:

cme_detect_20040401_C2_image 3.html
cme_detect_20000131_C2_image 8.html



…heading toward Automation!

CME mask / window:

cme_detect_20000211_C2_image 4.html <-- streamer deflection & interference
cme_detect_20000211_C2_contours 4.html
cme_detect_20000211_C2_masks 4.html

But C3 gets very noisy:

cme_detect_20040402_C3_pol.html
cme_detect_20000102_C3_masks 0.html

…heading toward Automation!

CME mask / window:

cme_detect_20000211_C2_image 4.html <-- streamer deflection & interference
cme_detect_20000211_C2_contours 4.html
cme_detect_20000211_C2_masks 4.html

But C3 gets very noisy:

cme_detect_20040402_C3_pol.html
cme_detect_20000102_C3_masks 0.html

Ideas / future work:

1. Improve thresholding of CME angles.
2. Defining outer edges in CME mask (automated characterisation).
3. Remove streamers within mask: region thinning / pixel chaining, and angle thresholding.
4. How can latter part of C3 field-of-view be analysed automatically with so much noise?
5. Application to STEREO: possibly SECCHI/COR2 has better SNR than LASCO/C3.