NEMO - 'Novel EIT wave Machine Observing'

so-called 'EIT Wave & Dimming Detector'.

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Our aim

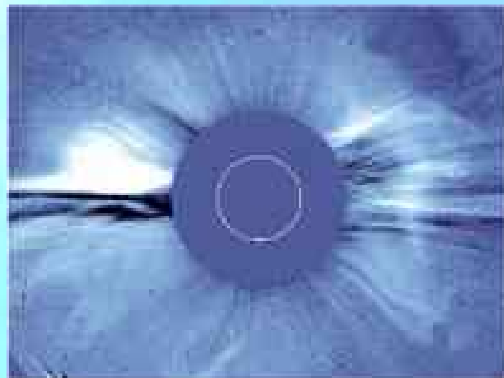
Automatically detect from EUV solar image EIT wave and Dimmings for purposes of space weather forecasting

EIT Wave is the origin of Earth directed CME

Dimming

EIT wave front

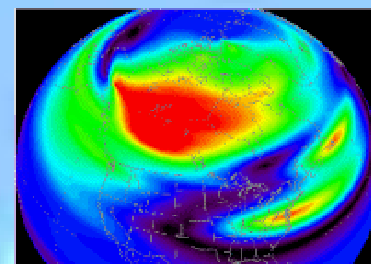
+1-2 h.



Halo Coronal Mass Ejection

+1-3 d.

Geomagnetic Storm:
Break of communications, petroleum pipe accidents



Question

- How many variants of EIT waves do exist?

Our approach

- To study various properties of EIT waves observed by EIT/SOHO

(**CME WATCH PROGRAMM: spectral line195 Å ≈4 images/h.)**

DETECTOR

version 1.00 in MATLAB 7

- **DETECTION of event occurrence**
  - Higher order moments technique (applied to EUV image pixels distribution)
    method to detect coherent large scale structure in white noise
- **DIMMING extraction from EUV image**
  - Progressive Growth of intensive dimming region
- **EIT WAVE extraction from EUV image**
  - Ring Analysis (for automatic calculation of radial velocity of the EIT wave)
  - Angular-Ring Analysis (to quantify the angular rotation of EIT wave)

I
EIT Wave & Dimming Occurrence Detection

Higher-order Moments

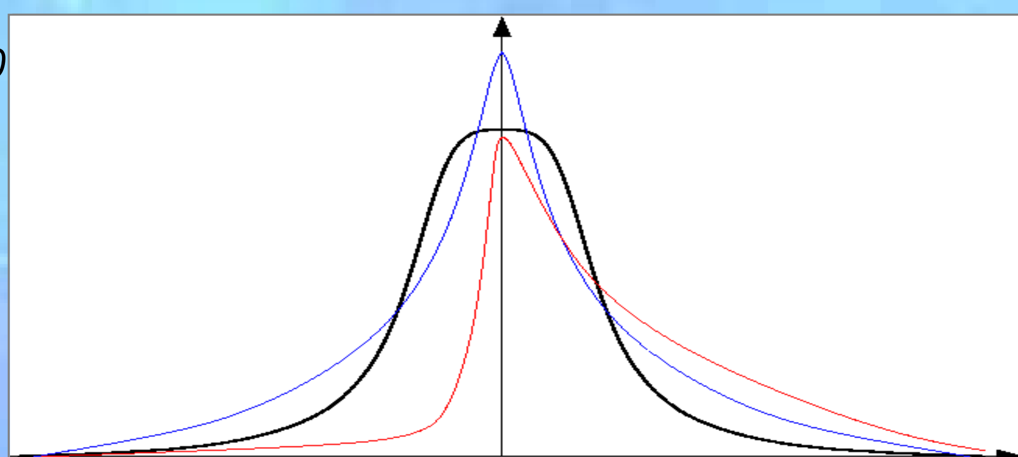
- Centered moment of order *k:*
  - experimental: $$\mu_k = \frac{1}{n}\sum_{i=1}^{n}(x_i - \langle x \rangle)^k$$
  - theoretical: $$\mu_k = \int x^k \overbrace{p(x)}^{\text{PDF}(x_i)}\, dx$$

- Measure of PDF
  - asymmetry: $$\gamma_1 = \frac{\mu_3}{\mu_2^{3/2}}$$ **- Skewness**
  - flatness: $$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3$$ **- Kurtosis**

- ***$\gamma 1, \gamma 2 >> 0$*** computed for pixels distribution of EUV image could be indicators of large scale coherent structures:

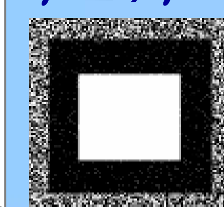
for a Gaussian distribution $\gamma 1 = \gamma 2 = 0$

Gaussian: $\gamma 1 = \gamma 2 = 0$



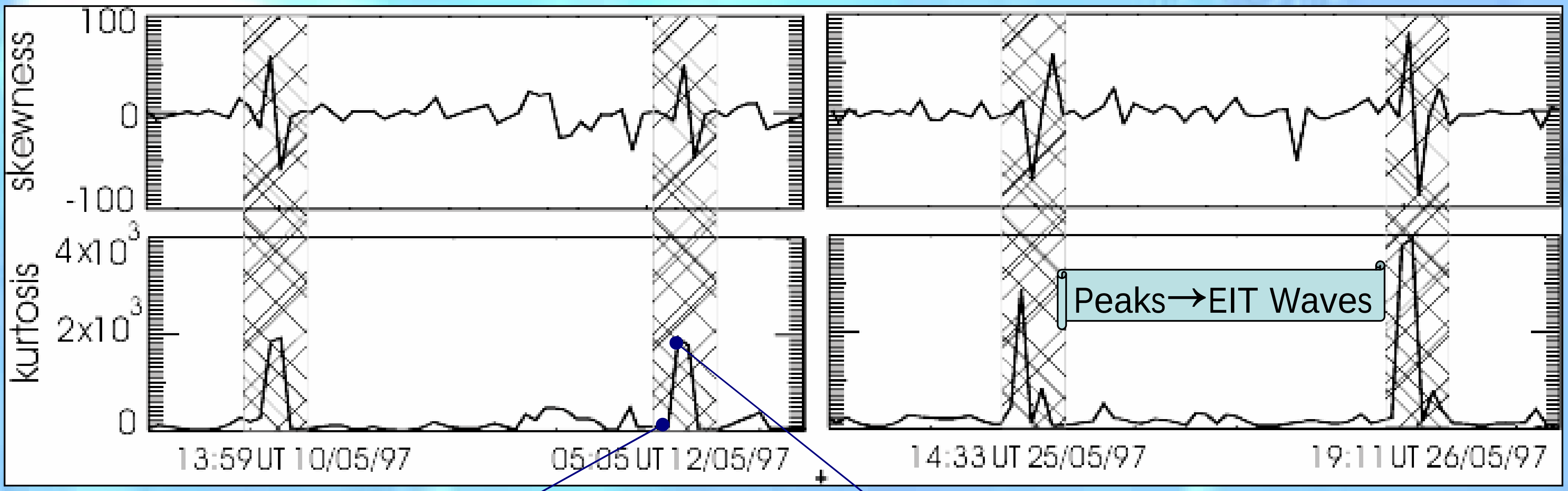
$\gamma 1 = 0$, $\gamma 2 > 0$

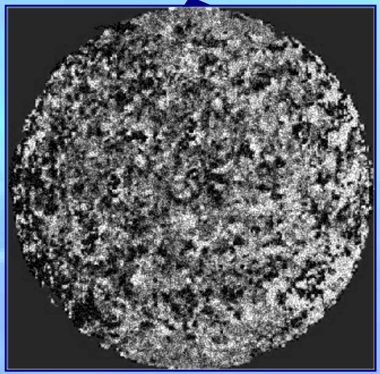
$\gamma 1 > 0$, $\gamma 2 > 0$

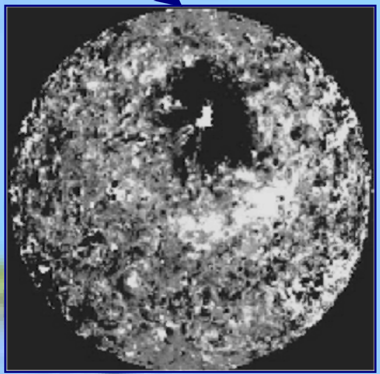


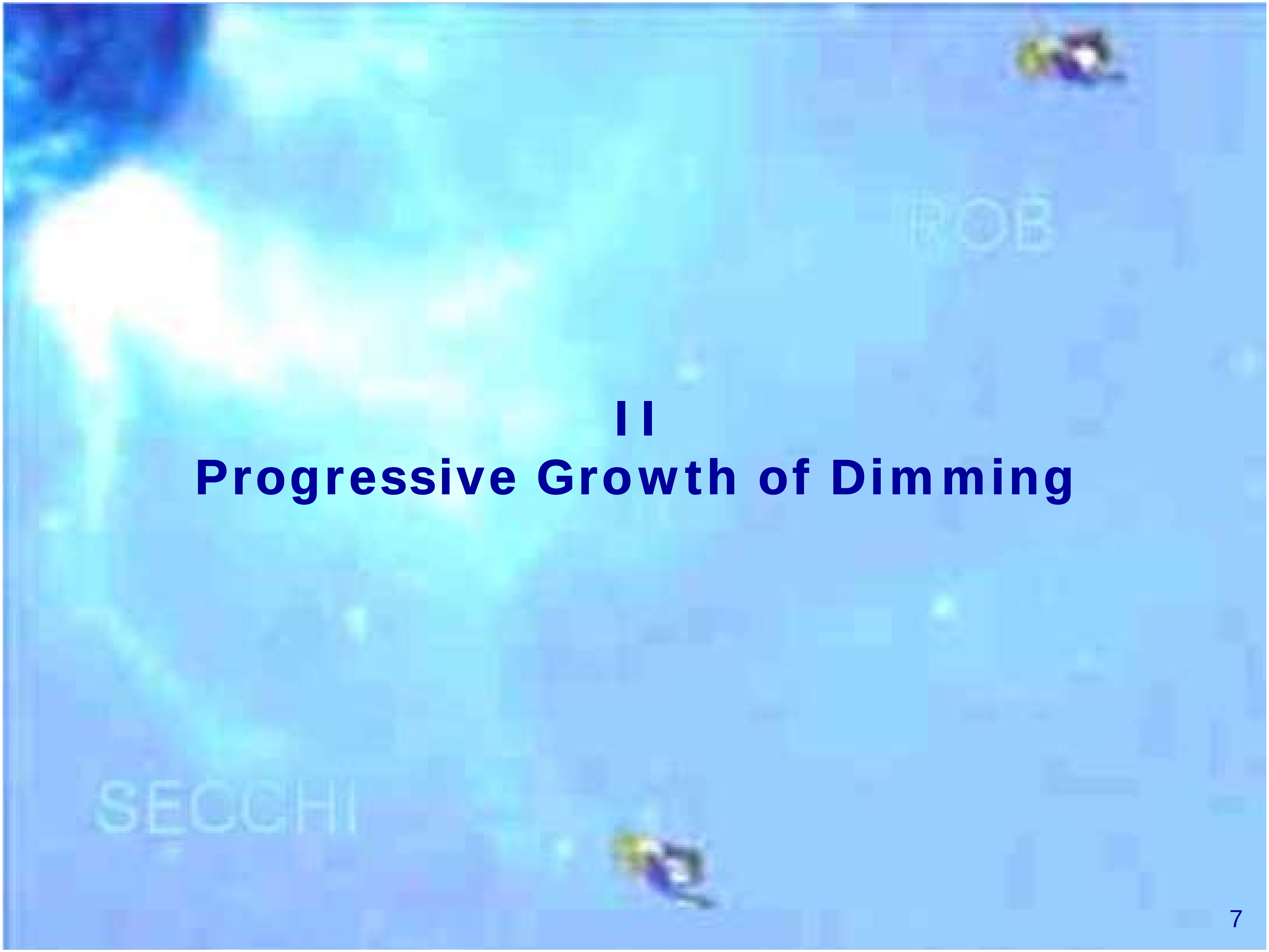
Higher-order moments could be indicators of Dimmings & EIT waves

Moments of running difference intensities









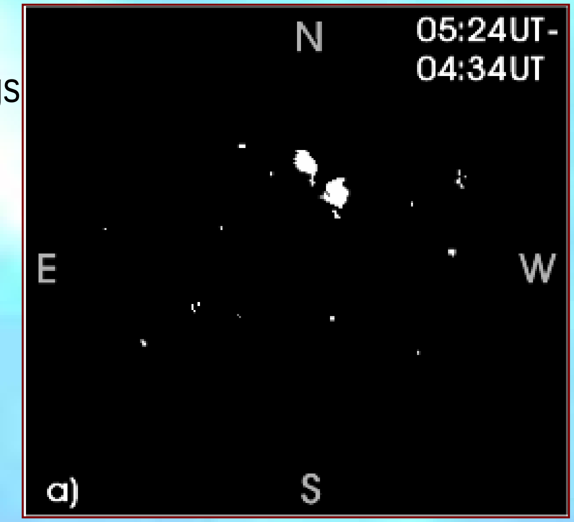
II
Progressive Growth of Dimming

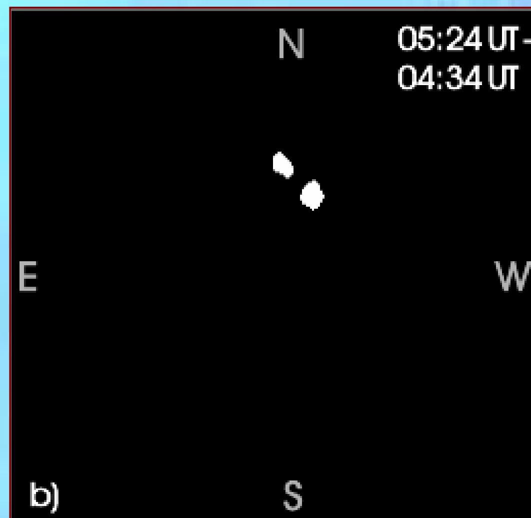
Progressive Growth of dimming

Hypothesis: dimming is simply connected large scale region of sudden decreased intensity of any form

- The subsequent steps of dimmings extraction (from the fixed difference EUV images)

- The deep core of the dimmings together with noise

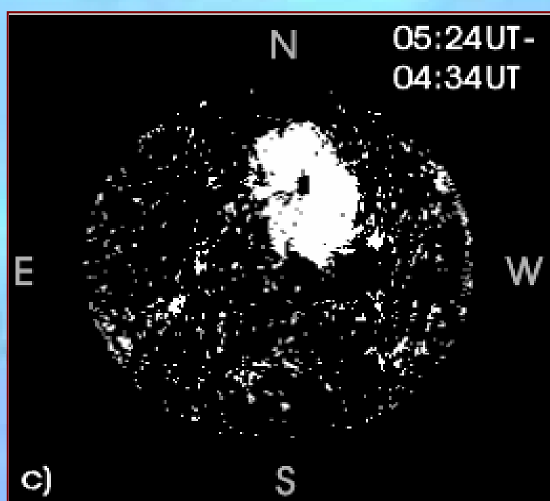




- Dimming core without noise

The basis for the dimming reconstruction

- All regions of negative intensity



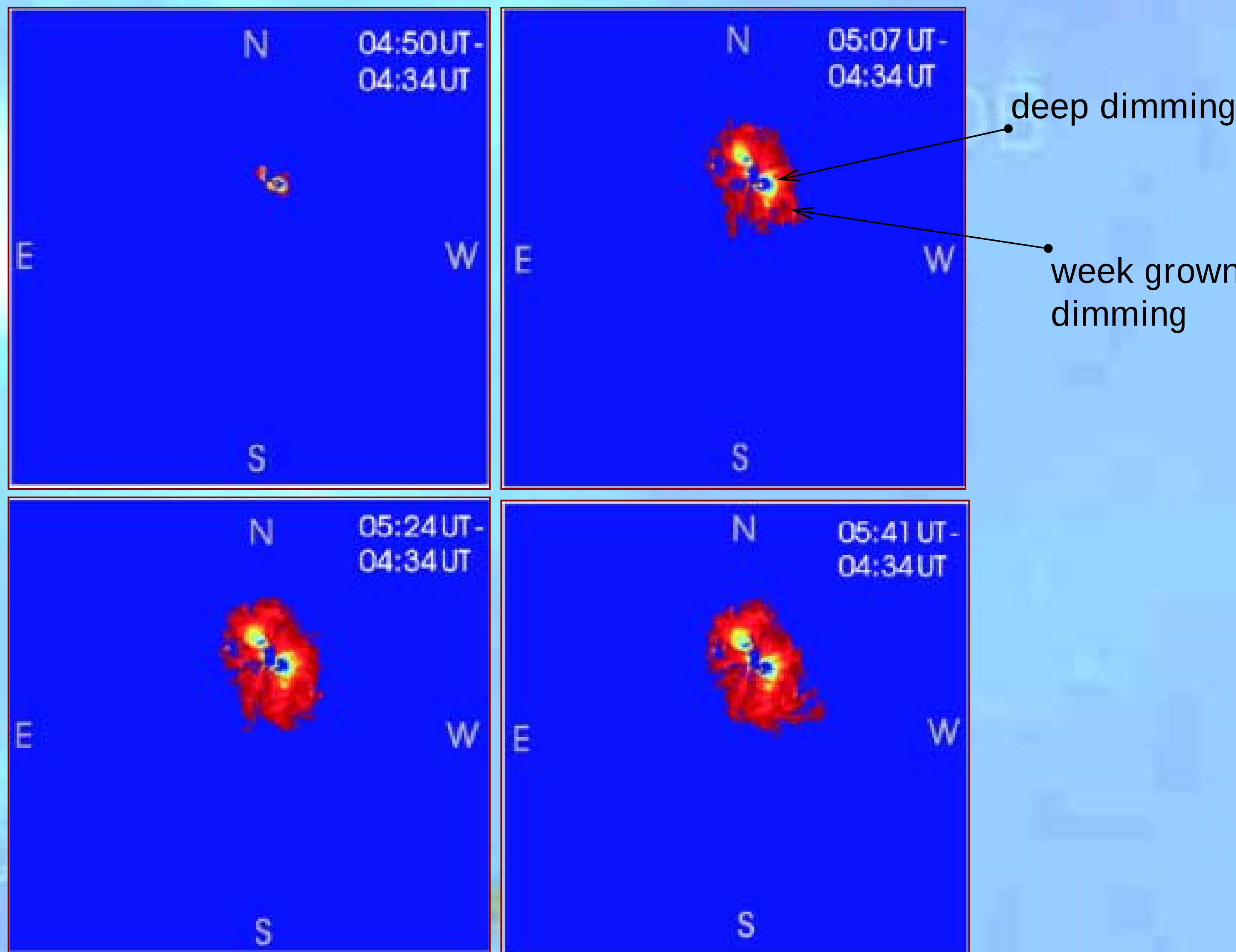
- Full dimming

Growth is done by
the adding to deep dimming all negative neighbor pixels

Example 1: (1/2)
quiet sun, simple magnetic structure

Final Dimming

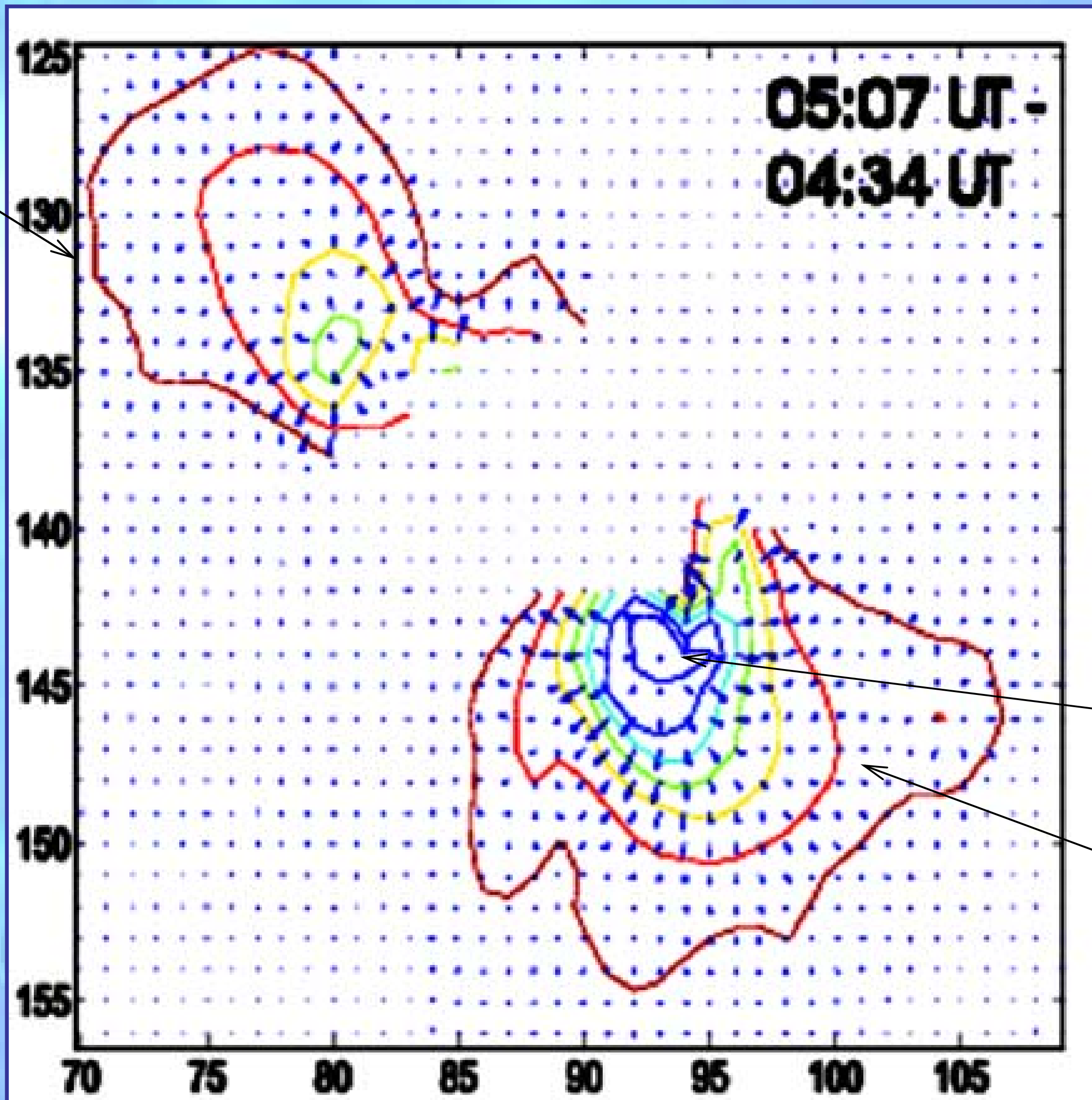
EIT Wave 12 May 1997 (1/2)



Dimming area decreases next 20h like $x^2 \sim t$

Dimming Structure

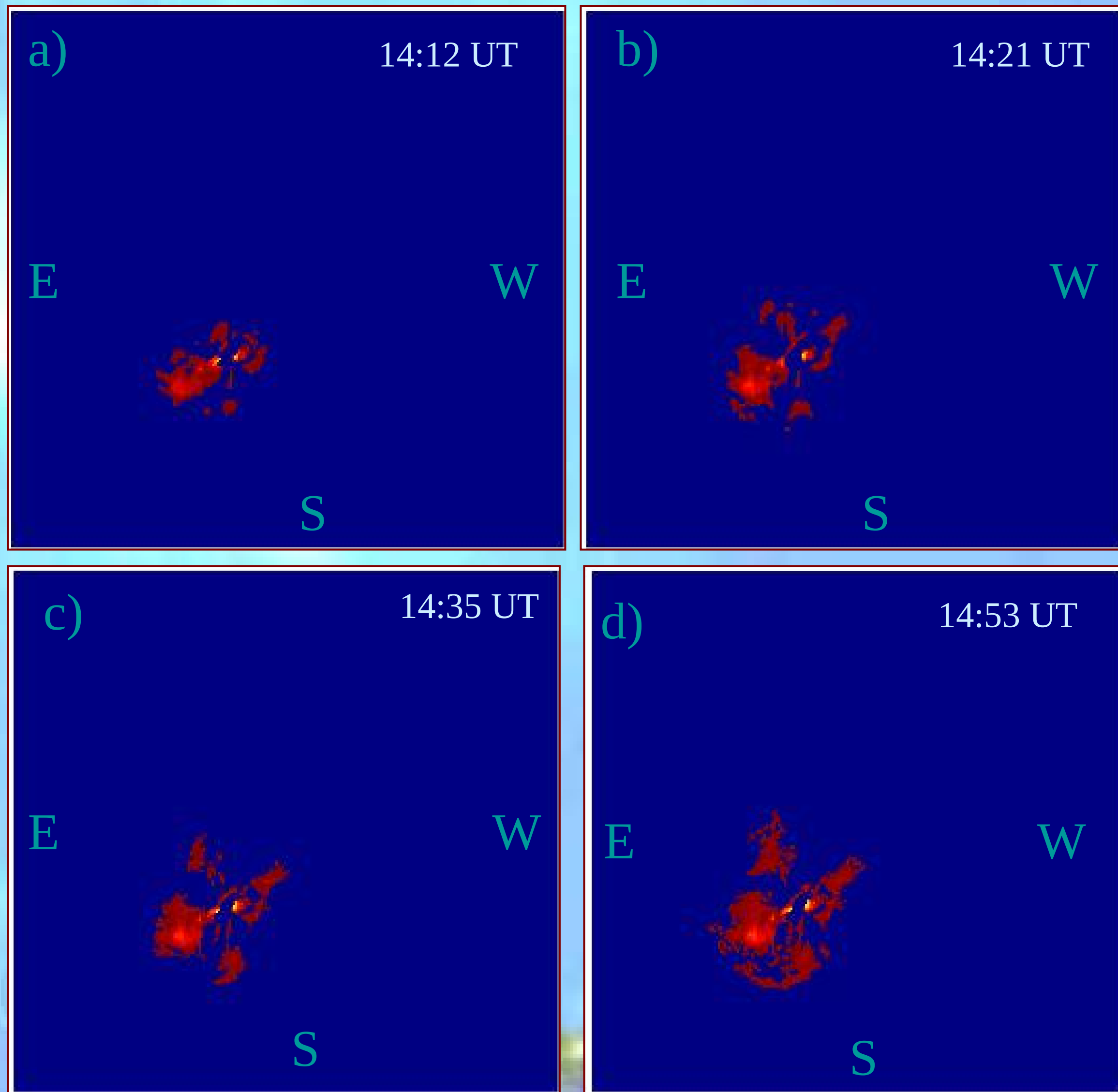
EIT Wave 12 May 1997 (2/2)



Example 2:
quiet sun, complex magnetic structure

Final Dimming

EIT Wave 7 April 1997, long duration event



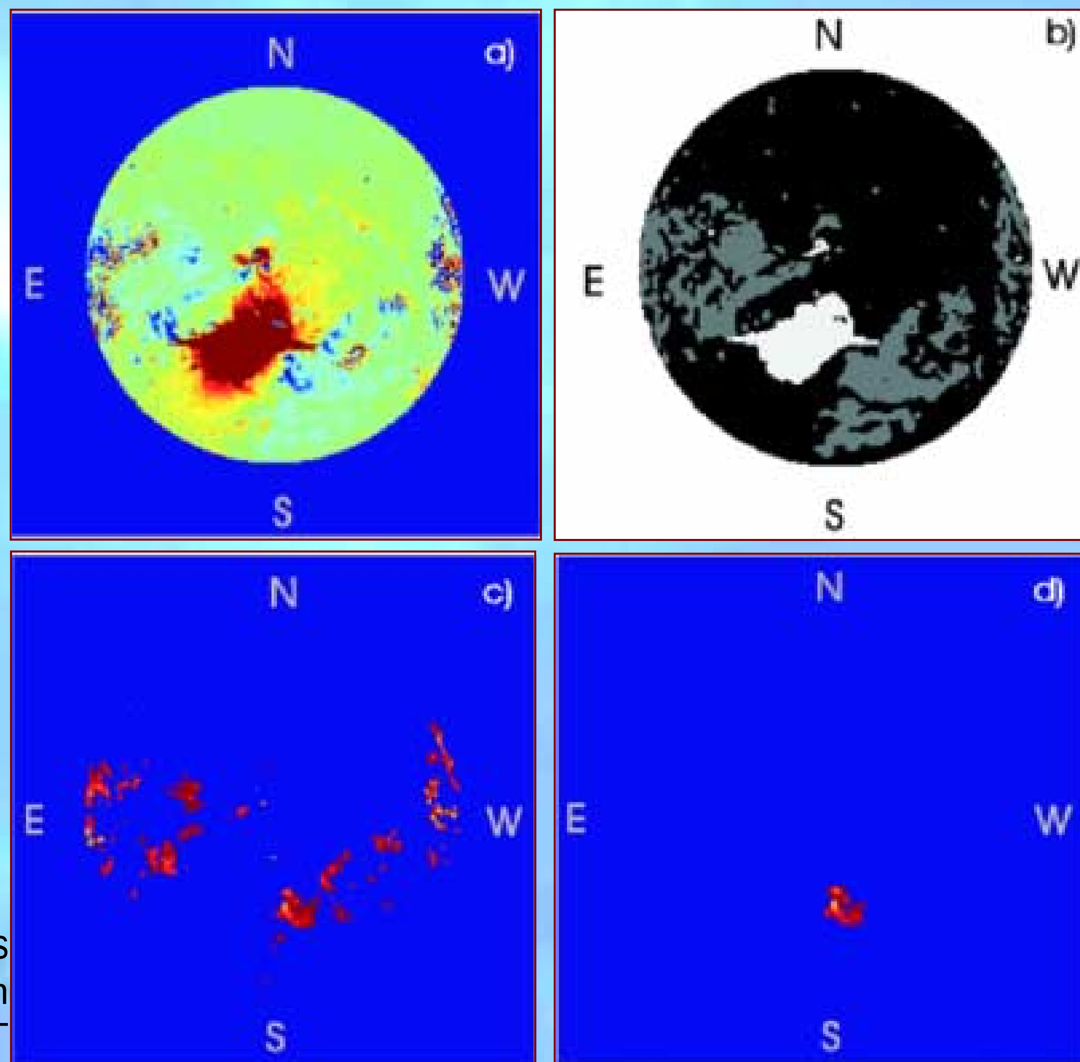
Dimming area increases next 5h like $x \sim t$

Final Dimming

The X-flare and CME of 28 October 2003 at 15:50 UT
no EIT wave

Flare
Difference image

Flare, diminish regions.
Preliminary filtration



All dimmings
appeared on the Sun
at 15:50 UT

Extracted dimming
produced by the eruption

Compact dimming = no EIT wave

Growth technique is finalized. Its efficiency does not depend on solar conditions

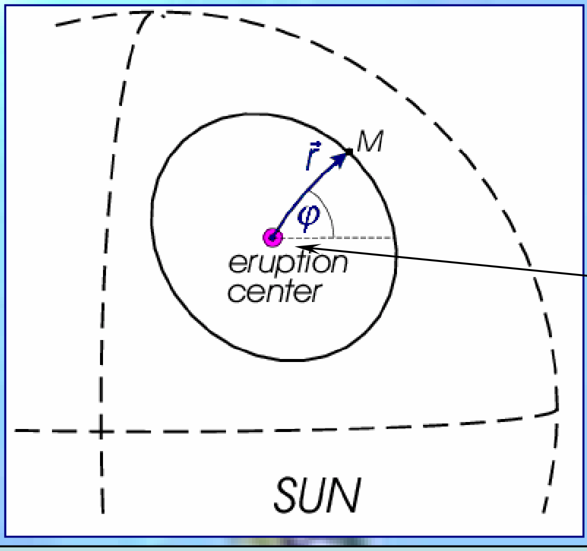
III
EIT WAVE Extraction

Algorithms based on the principles:

- A priori: EIT waves properties may have quasicircular properties:
  - Spherical symmetry around eruption center (free propagation on quiet sun)
  - Nonsymmetrical (active sun, complex magnetic structure)

- EIT wave quantities will depend explicitly on:
  - Distance from eruption center, i.e. length of ***r*** (defined on sphere)
  - Direction of radius-vector φ

- **Special polar coordinate system:**
  - Center: **eruption center**.
  - **Radius vector** on sphere.

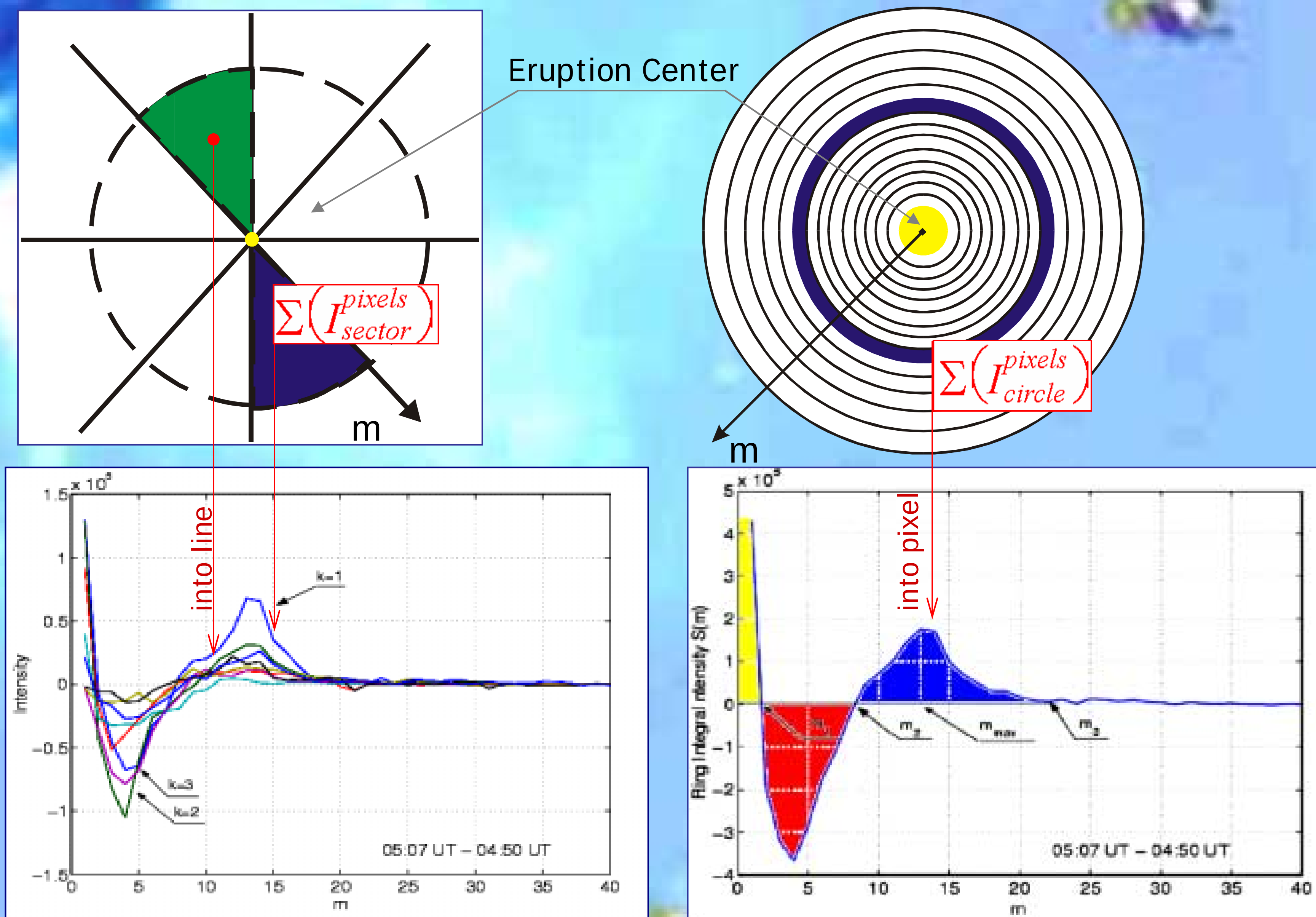


- 1st step: Definition of eruption center (most intensive area)

A posteriori: All complex EIT waves found to be well described in polar coordinates

Angular-Ring Analysis

Ring Analysis

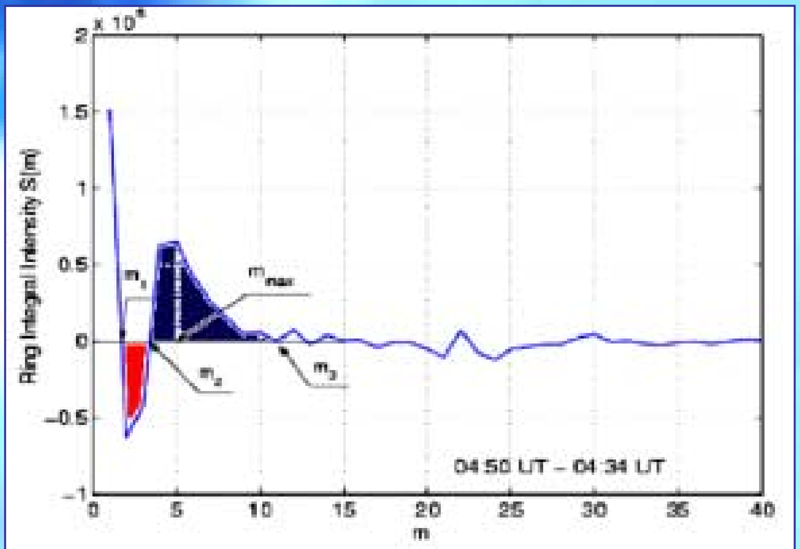


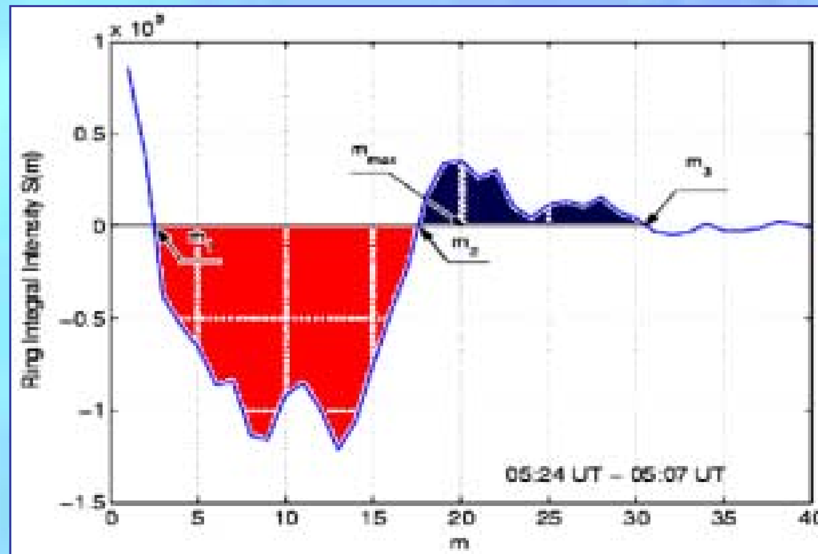
- Synhronous propagation of the peak in sectors
- Ring integral intensity

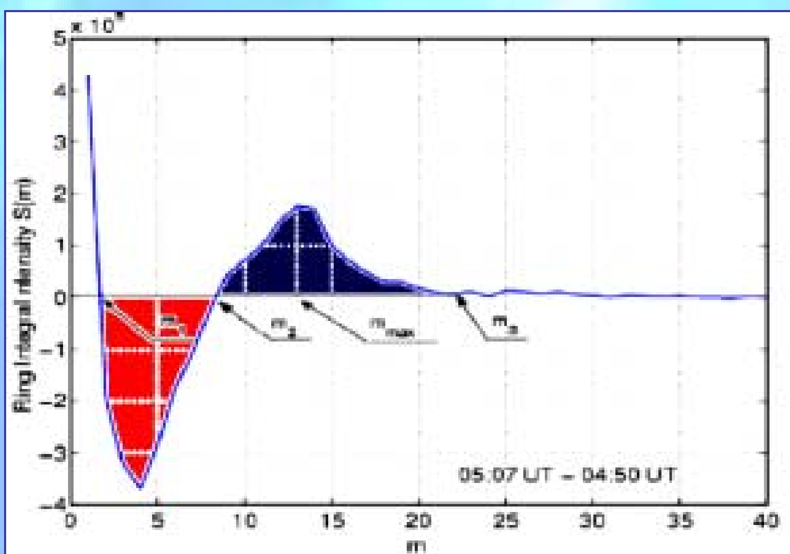
Example 1: (1/4)
simple magnetic structure,
free front propagation

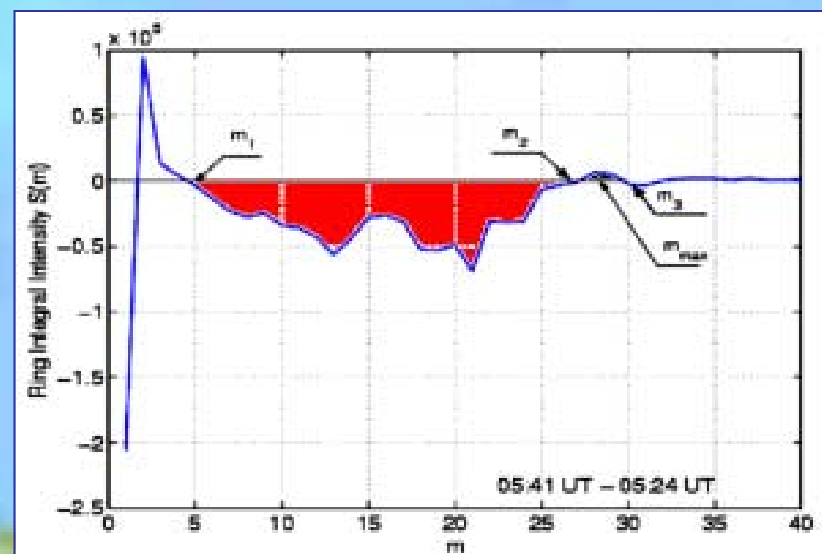
Extracted Front Evolution

EIT Wave 12 May 1997(1/4)





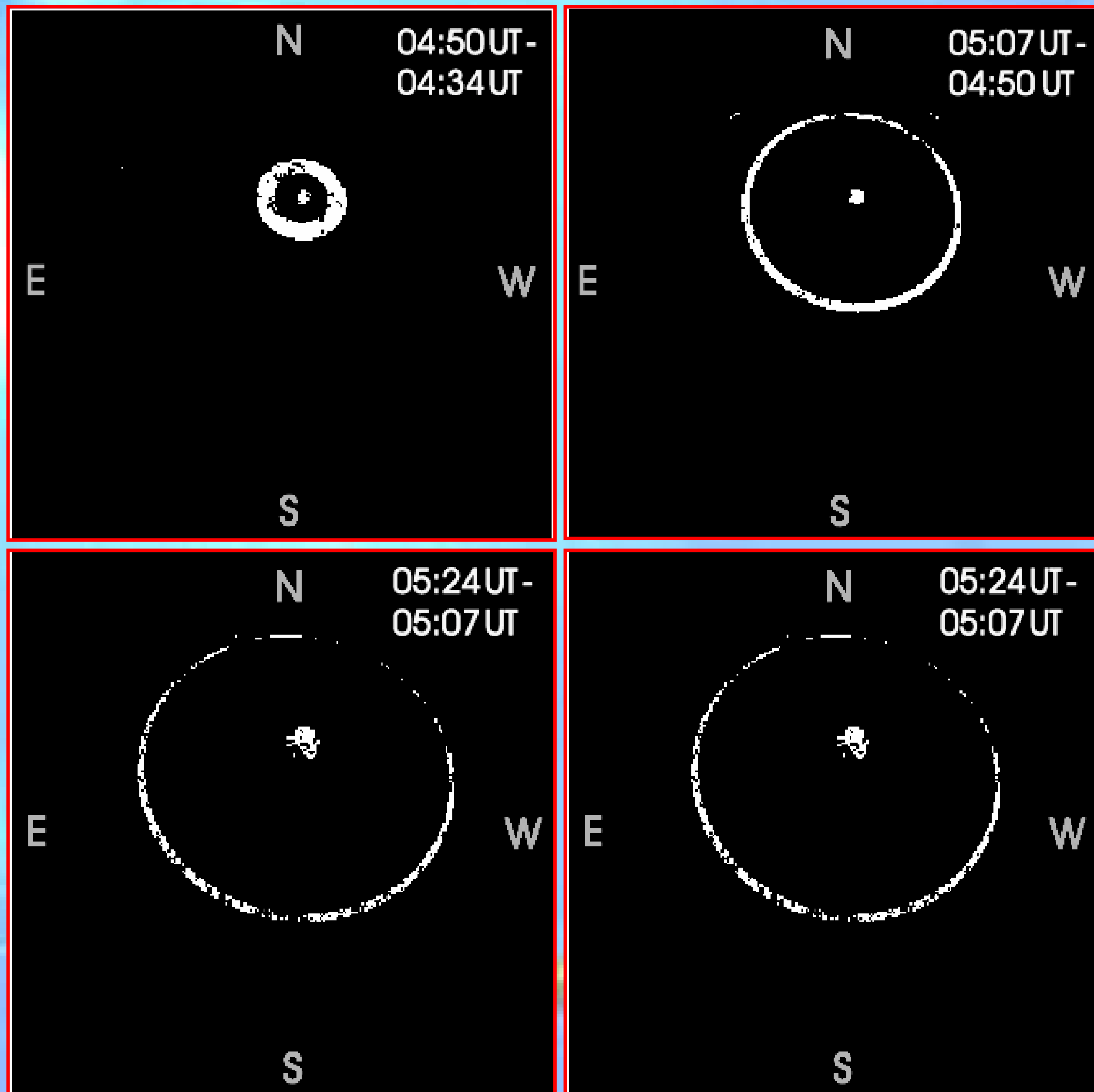




- Peak propagation used for automatic definition of radial velocity

Intensity Peak Evolution

EIT Wave 12 May 1997(2/4)

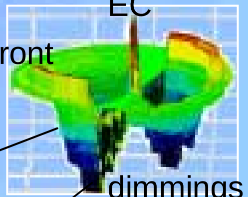


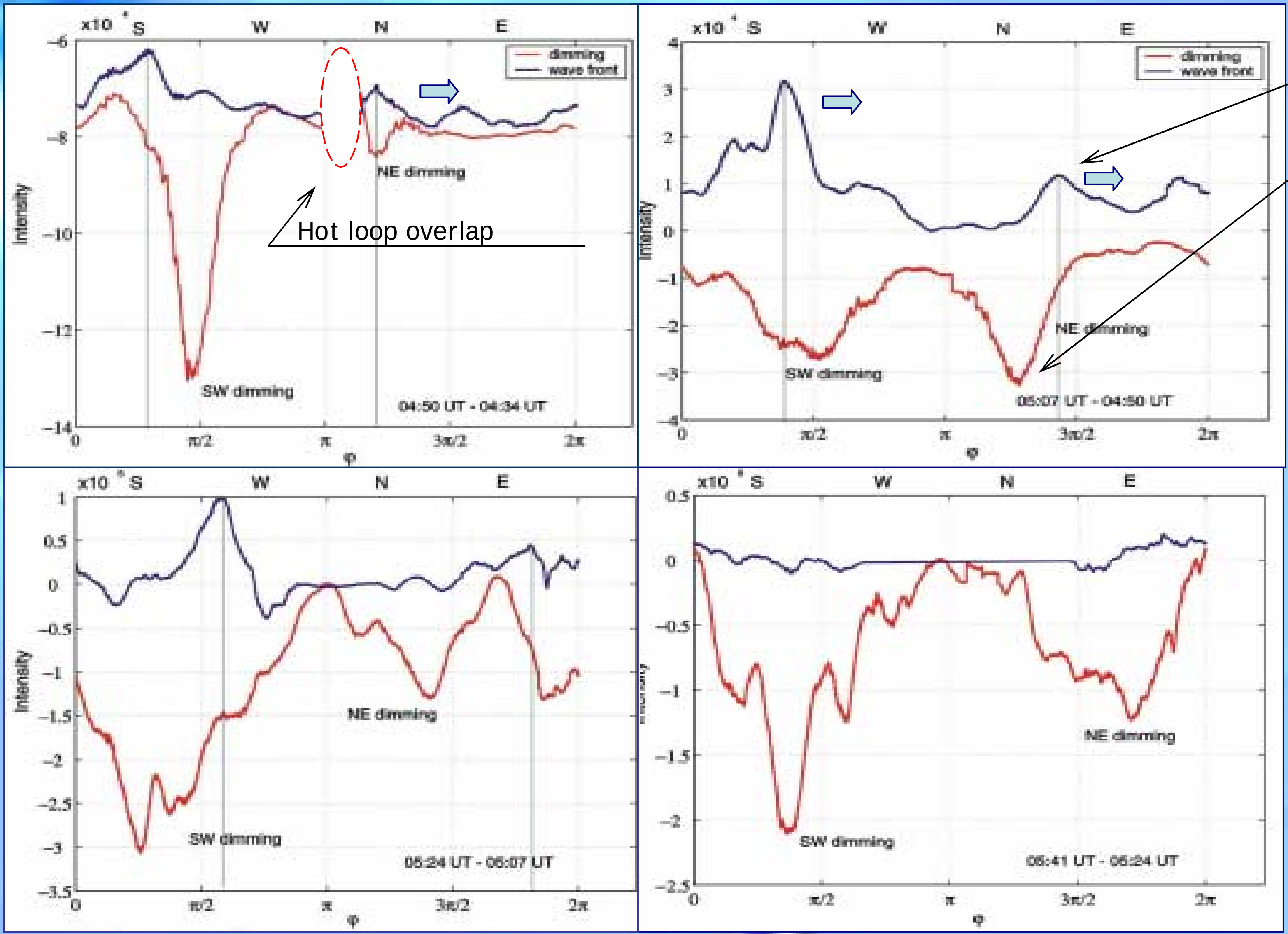
Example 1: (3/4)

simple magnetic structure,
free front propagation

Angular 3D Structure of EIT wave

EIT Wave 12 May 1997 (3/4)



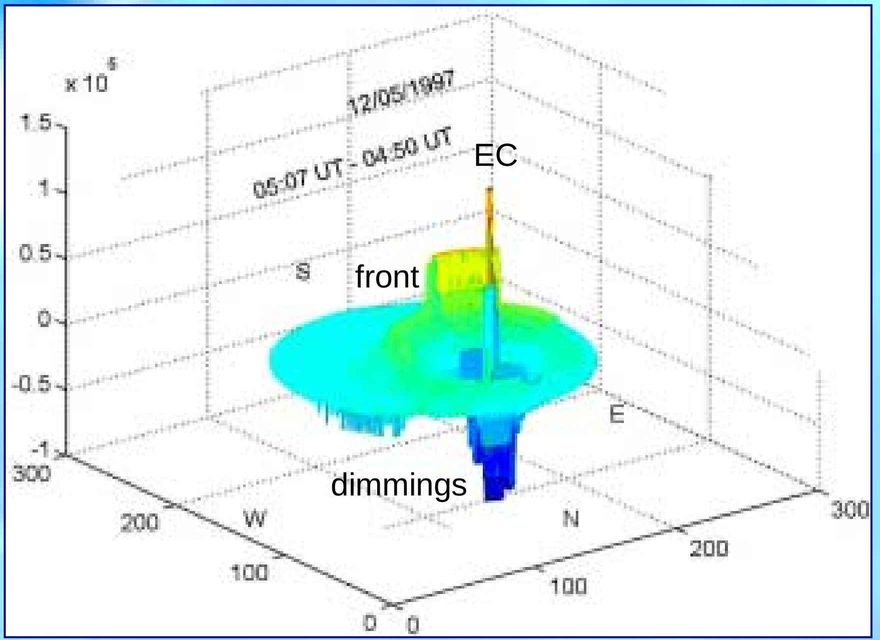


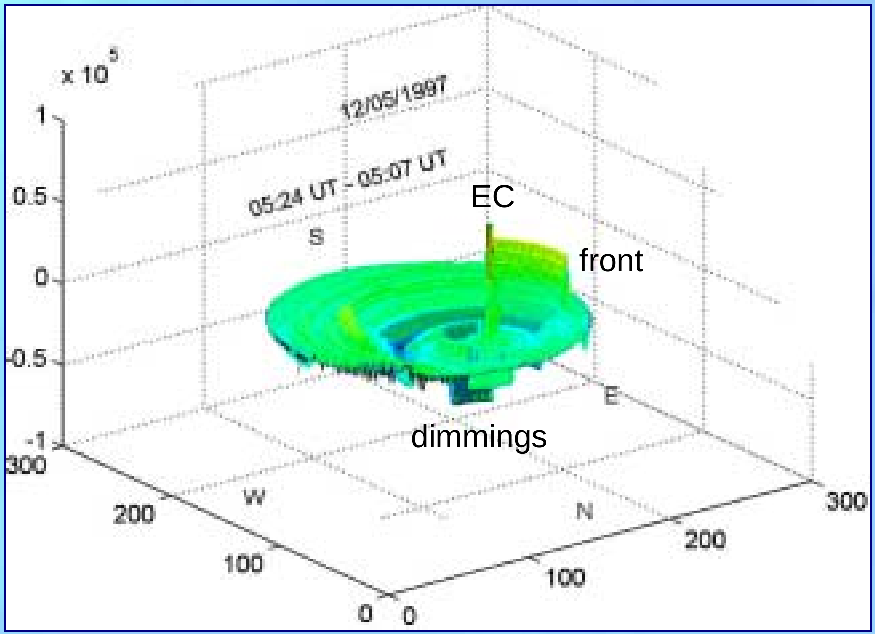
- Rotation of fronts !

- Morphological similarities between fronts and dimmings!

Angular 3D Structure of EIT wave

EIT Wave 12 May 1997 (4/4)



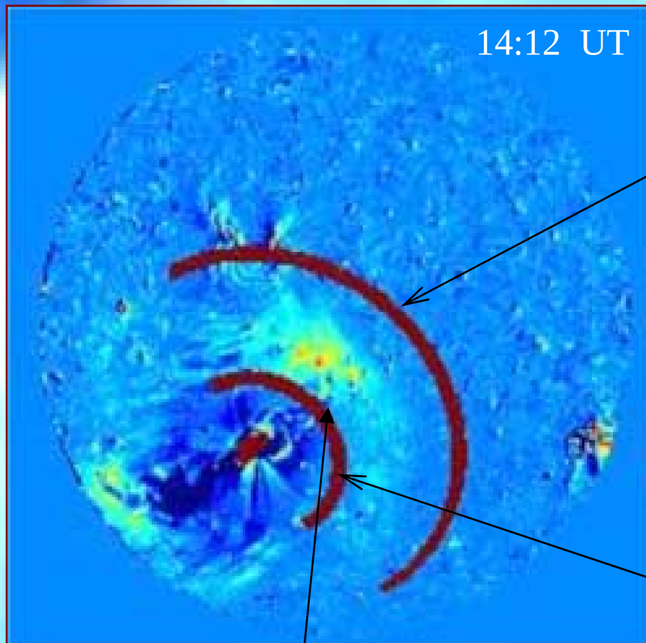


- Under condition of free propagation rotation of EIT wave fronts observed regulary

Example 2:
complex magnetic structure, restricted front propagation

Extracted EIT Wave Front

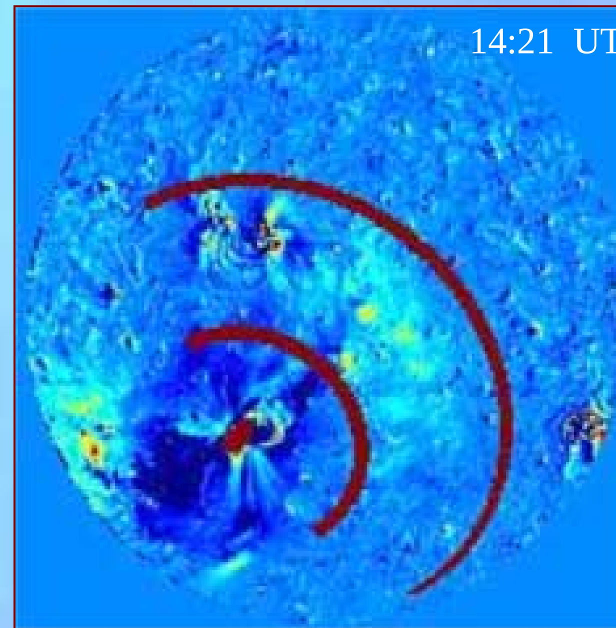
EIT Wave 7 April 1997

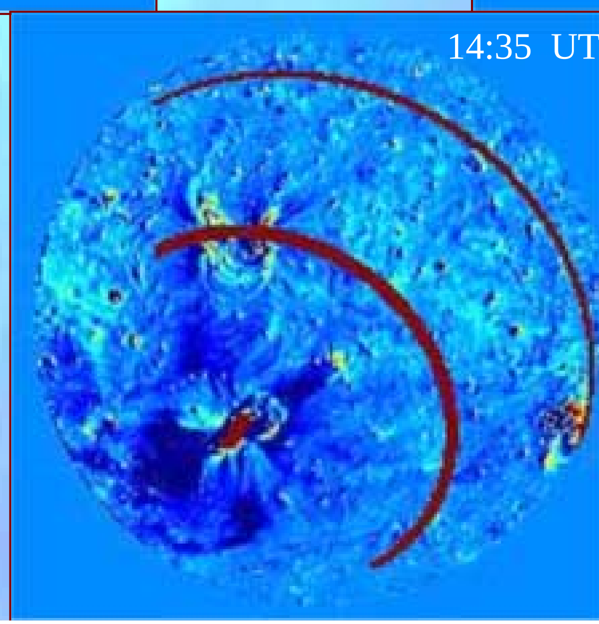


External front boundary

Internal front boundary

EUV microflare





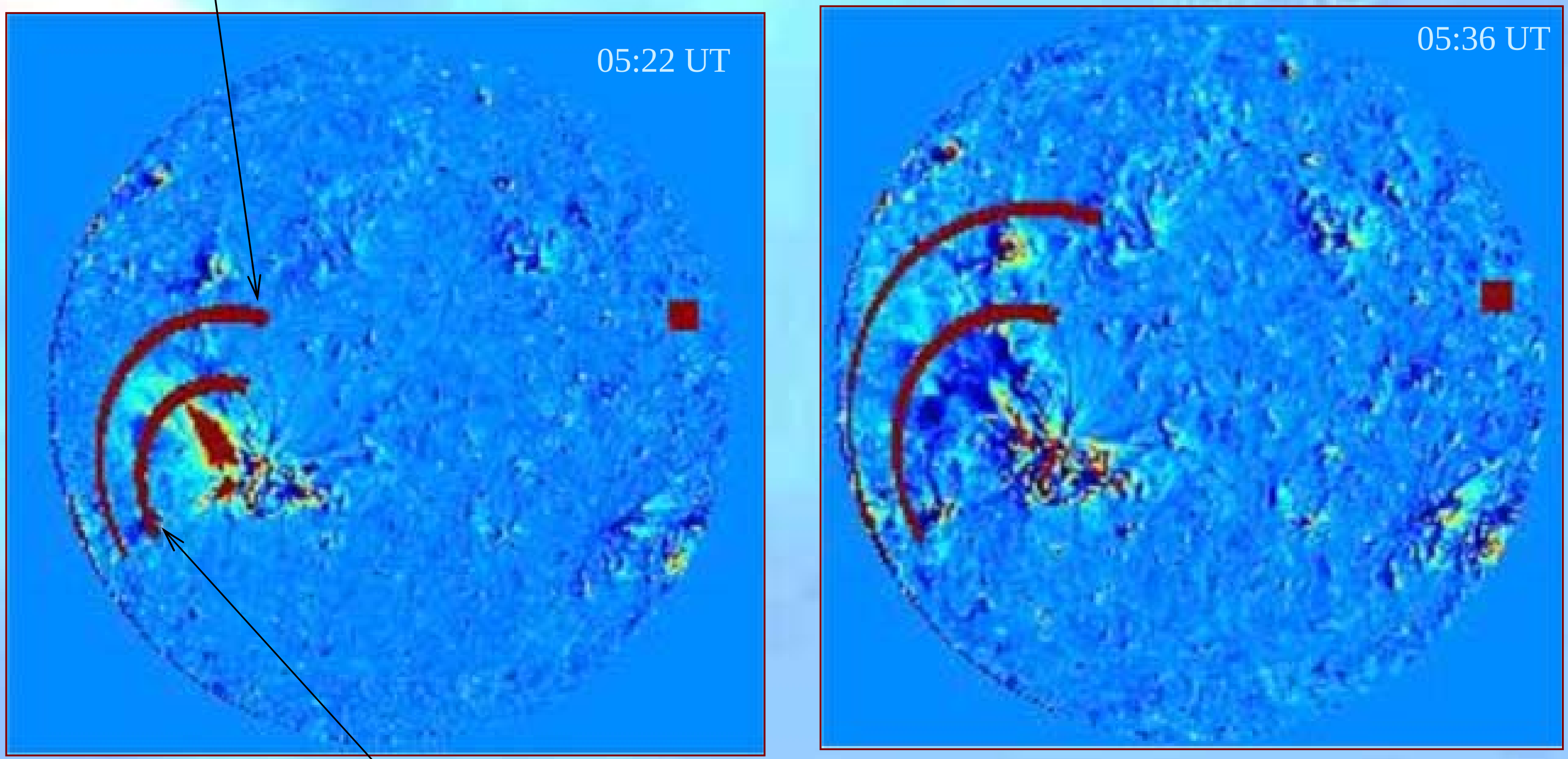
- **Trigger of microflare by the passage of EIT wave front** (statistics in Biesecker & Thompson, APJ 2002)

Example 3:
complex magnetic structure, restricted front propagation

Extracted EIT Wave Front

EIT Wave 29 April 1997

External front boundary

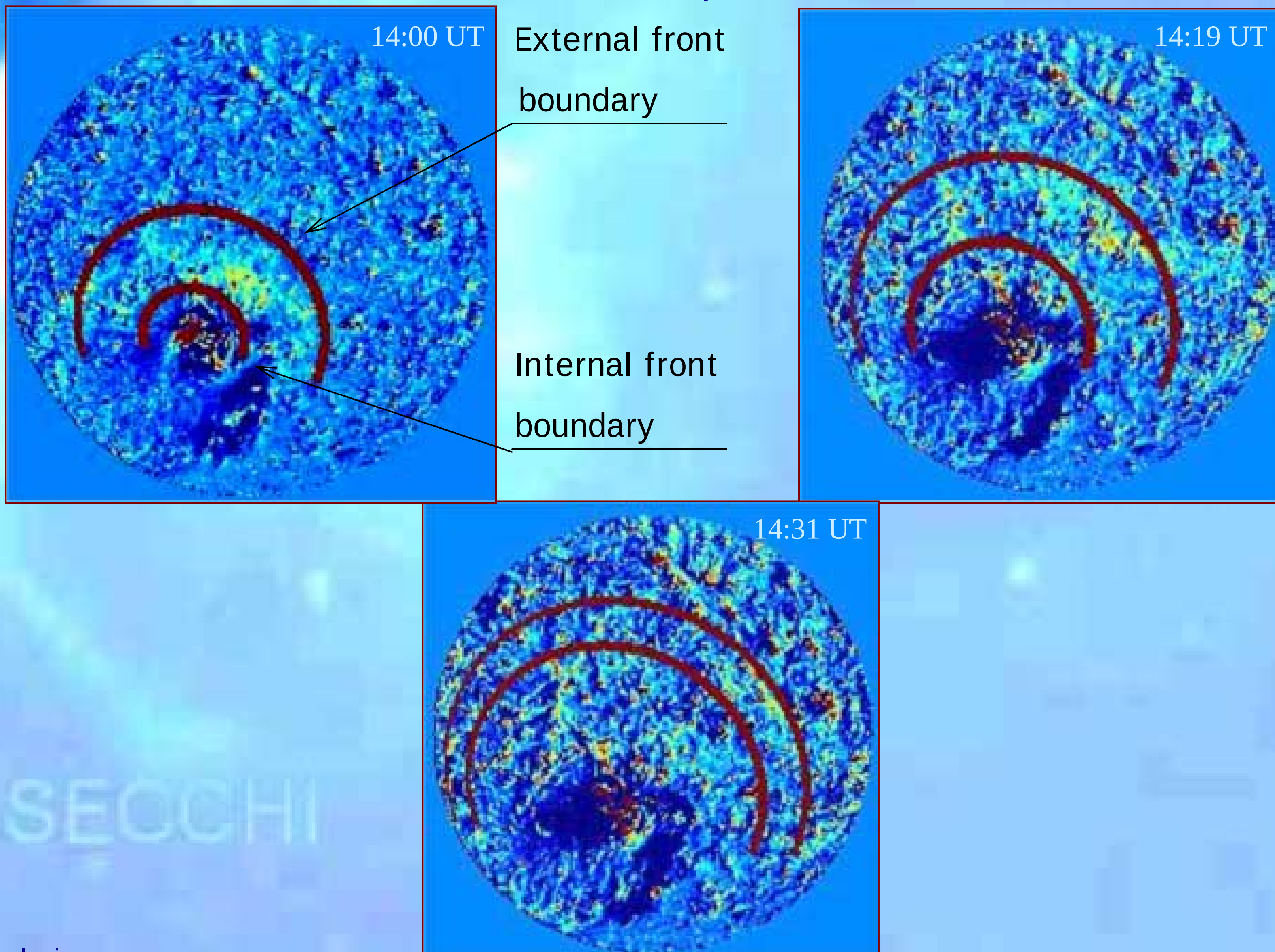


Internal front boundary

Example 4: (1/2)
complex magnetic structure, restricted front propagation

Extracted EIT Wave Front

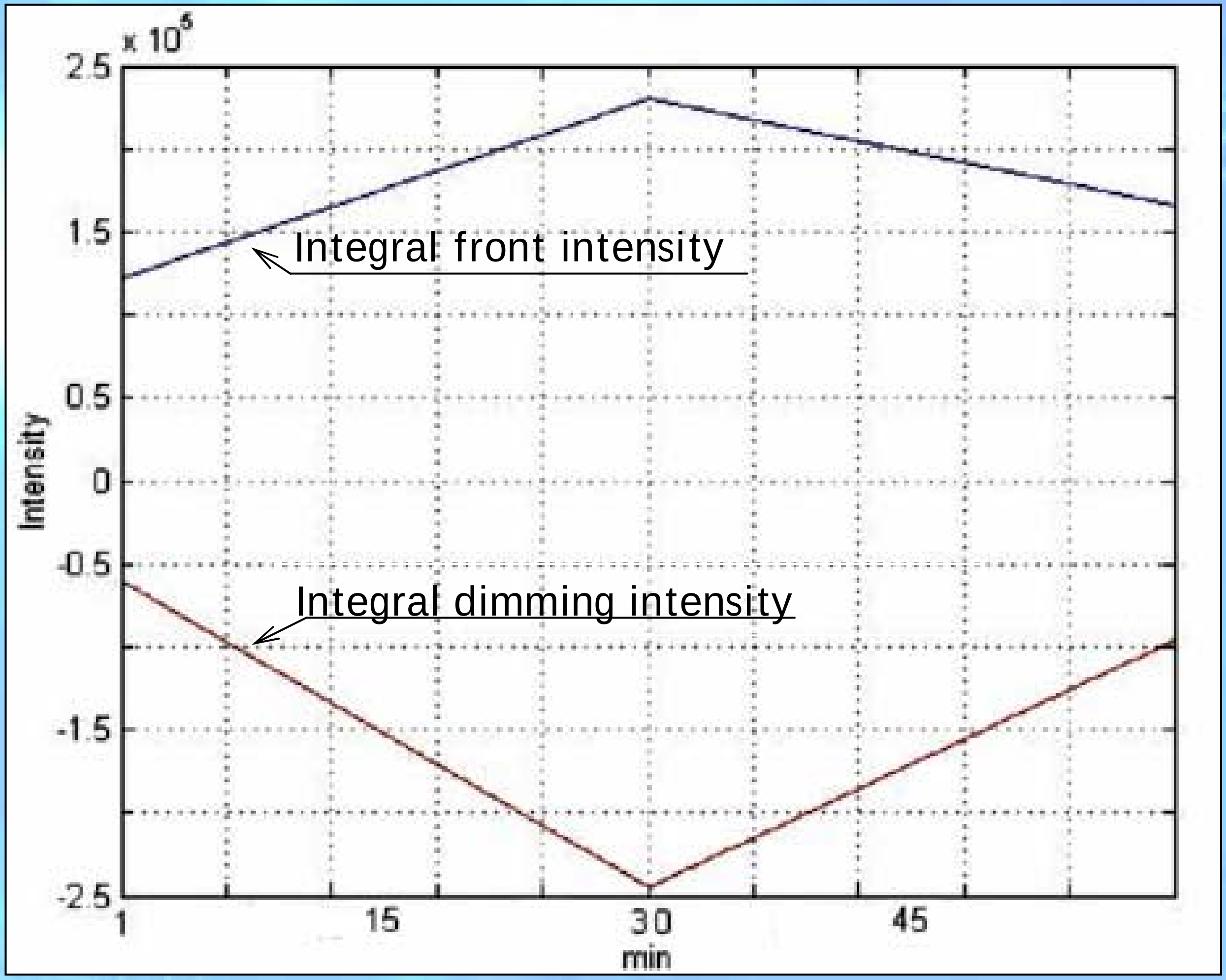
EIT Wave 1 April 1997



Dimmings and EIT front Integral Intensities

EIT Wave 1 April 1997

Example 4: (2/2)
complex magnetic structure, restricted front propagation



- Integral intensity of propagating front grows in time (30 mn) symmetrically with respect decrease of integral dimming intensity – regular peculiarity.

Conclusions

- **EIT Wave and Dimming DETECTOR consists of 4 packages:**
  - HIGHER ORDER MOMENT – event occurrence
  - GROWTH technique of intensive dimming
  - RING–ANALYSIS for front extraction
  - ANGULAR-RING technique, for front structure analysis
- **Detector allows to create SECHHI EIT wave catalog**
- **Provides insight into the physics of EIT waves**
  - Podladchikova & Berghmans Sol.Phys, 2005.
- **Current stage of the project**
  - Numerical analysis and classification of complex events
  - Testing of detection with EIT 195 Å data.

See also: Delouille et al., Sol.Phys 2005 for wavelet analysis of EIT waves.

Plan of future SECHHI EUV Wave catalog

- **EIT waves**
  - Time and date
  - Location of front
  - Radial front velocity
  - Angular front velocity (optionally)
  - Front Integral intensity evolution
- **Dimmings**
  - Time and date
  - Location of dimming
  - 3D structure of dimming (optionally)
  - Area of dimming
  - Dimming Integral intensity evolution

- Other? Please, send suggestions to olenapo@oma.be, david.berghmans@oma.be

Unexpected results

- **MORPHOLOGICAL IDENTITIES between fronts and dimming structures**

- **Regular ROTATION of EIT waves fronts under free propagation** (together with B. Thompson).
  - Sense of rotation is different in the two solar hemispheres

- **Energy supply to EIT wave fronts comes from dimmings**
  - EIT waves have properties reminiscent of **SELF-SIMILAR MODES** propagating in the corona.