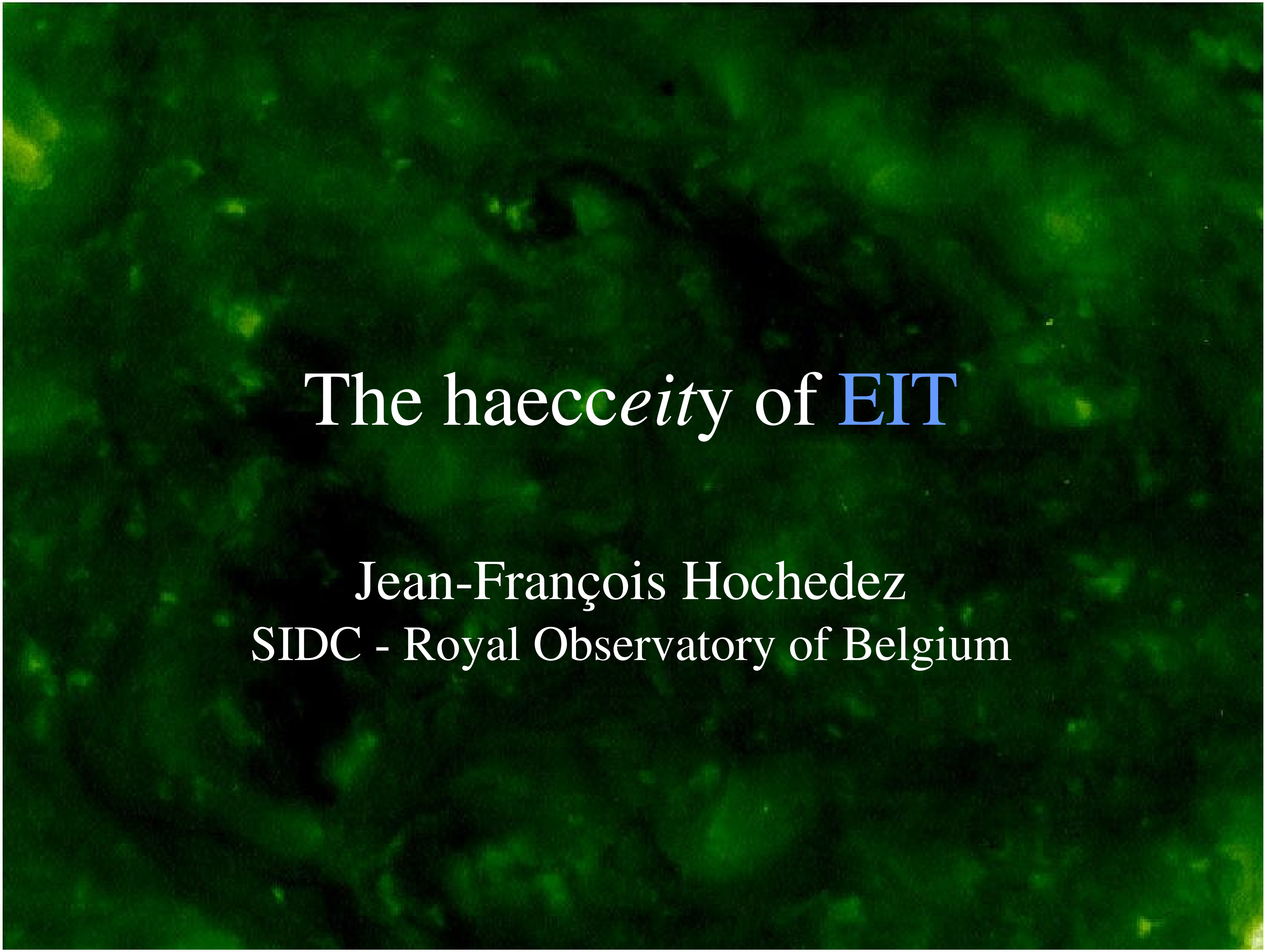

The haecc*eit*y of EIT
Jean-François Hochedez
SIDC - Royal Observatory of Belgium

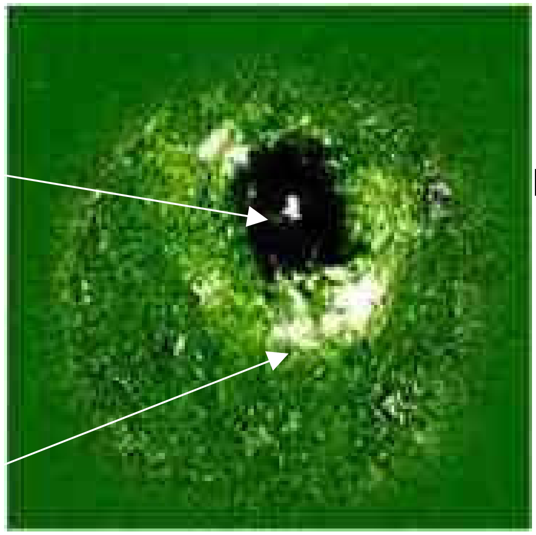
Why study EIT waves?

Usually very geoeffective.

Unsolved fundamental questions

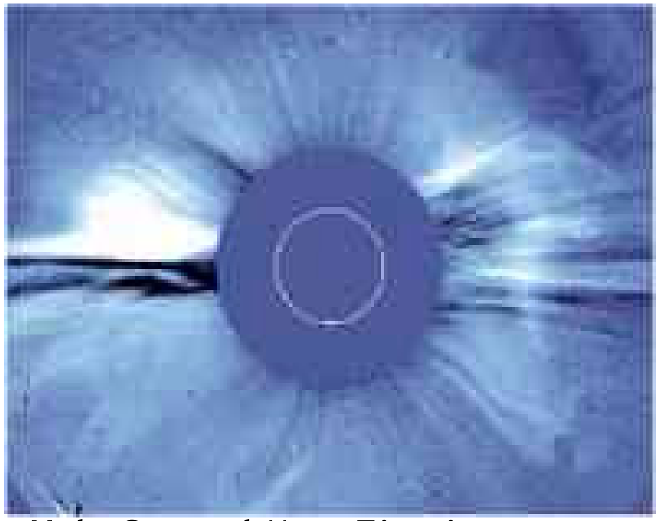
Dimming

EIT wave front



Earlier alert

+1-2 h.



Halo Coronal Mass Ejection

But one has to cope with :

- Phenomenological diversity
- Signal weakness on top of **dynamical** backgrounds

DEPARTMENT OF REDUNDANCY DEPARTMENT

The most important issues

- EIT wave:

'Fast magnetoacoustic linear wave/shock'

'piston driven shock', 'blast wave'

'quasicircular expanding structure'

'plasma compression on separatrix'

'snow-plow effect'

'nonlinear fast'

' why too slow?'

'loop opening'

'expanding footpoints'

'separatrix emits waves'

'stationary fronts'

'TCH'

- Dimmings:

Many types of coronal dimmings.

'slow dimmings'.

'natural dimmings'.

'dimming stops, but EIT wave propagates (yes/no)'.

'canalized dimmings'.

…

EIT waves without dimmings

Courtesy of Podladchikova & Berghmans

Among earlier approaches

systematic facts coming from 2 approaches:

- Visual inspection

-B.Thompson (97-98) EIT wave catalog: rated Q5-0(prob:100%-5%)

-Hudson & Webb 1997 (dimming classification)

-Thompson et al. 1999, Zhukov & Auchère 2004, Slemzin et al.2005 (observation of EIT waves in different bandpasses), +SXR

- Encountering an active region EIT waves produce:

    -Reflection or refraction of the EIT wave

    - go around strong magnetic features [Ofman & Thompson 2002]

- Simulations

- Chen et al. 2000-2005. Piston driven fast magnetoacoustic shock. The boundary of EIT bright fronts corresponds to expanding dimming region and each EIT wave front is just the source of a new perturbation that emits fast-mode waves.

Courtesy of Podladchikova & Berghmans

a quantitative investigation

Podladchikova & Berghmans, 2005

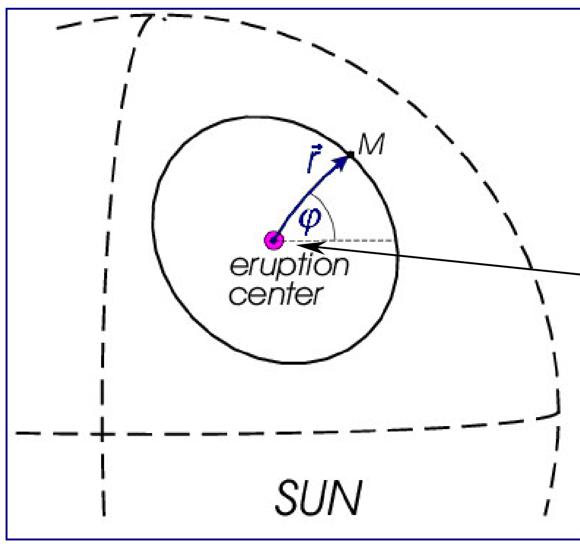
- **DIMMING extraction from EUV image**
  - Ring Analysis
  - Progressive Region Growing
- **EIT WAVE extraction from EUV image**
  - Ring Analysis
    - radial velocities in the EIT wave
  - Angular-Ring Analysis
    - for potential angular displacements

Royal Observatory of Belgium

EIT WAVE front extraction

- A priori: quasicircular properties
  - Spherical symmetry around eruption center (free propagation on quiet sun)
    - Distance r from eruption center (in heliographic coordinates)
  - Nonsymmetries can stem from magnetic structures
    - Direction of radius-vector φ

- **Polar coordinate system:**
  - Center @ **eruption center**
  - **Radius vector** (heliographic)



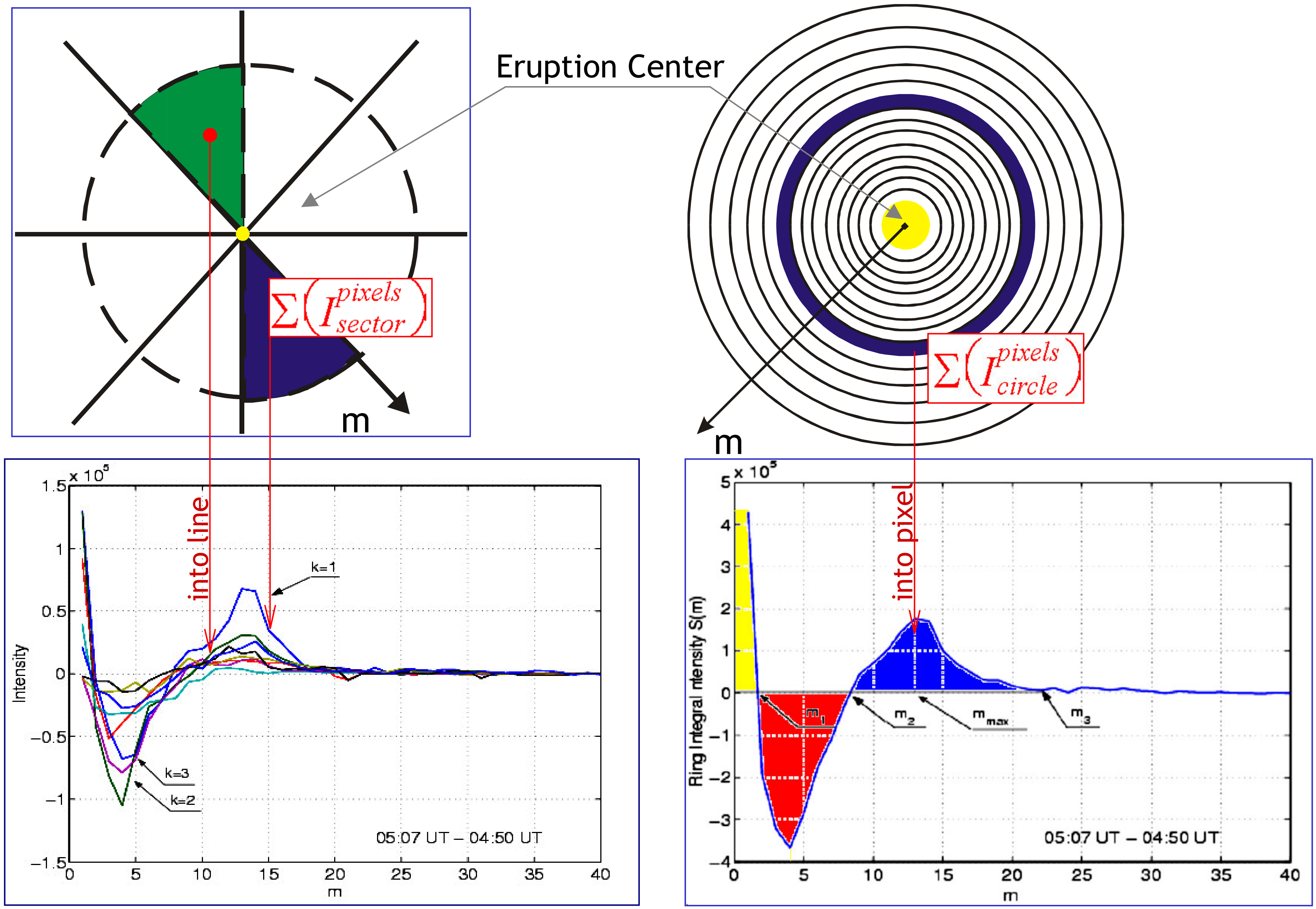
1st step:
Definition of the Eruption Center
(most intense point)

A posteriori: All EIT waves well described in polar coordinates

Courtesy of Podladchikova & Berghmans

Angular-Ring Analysis

Ring Analysis



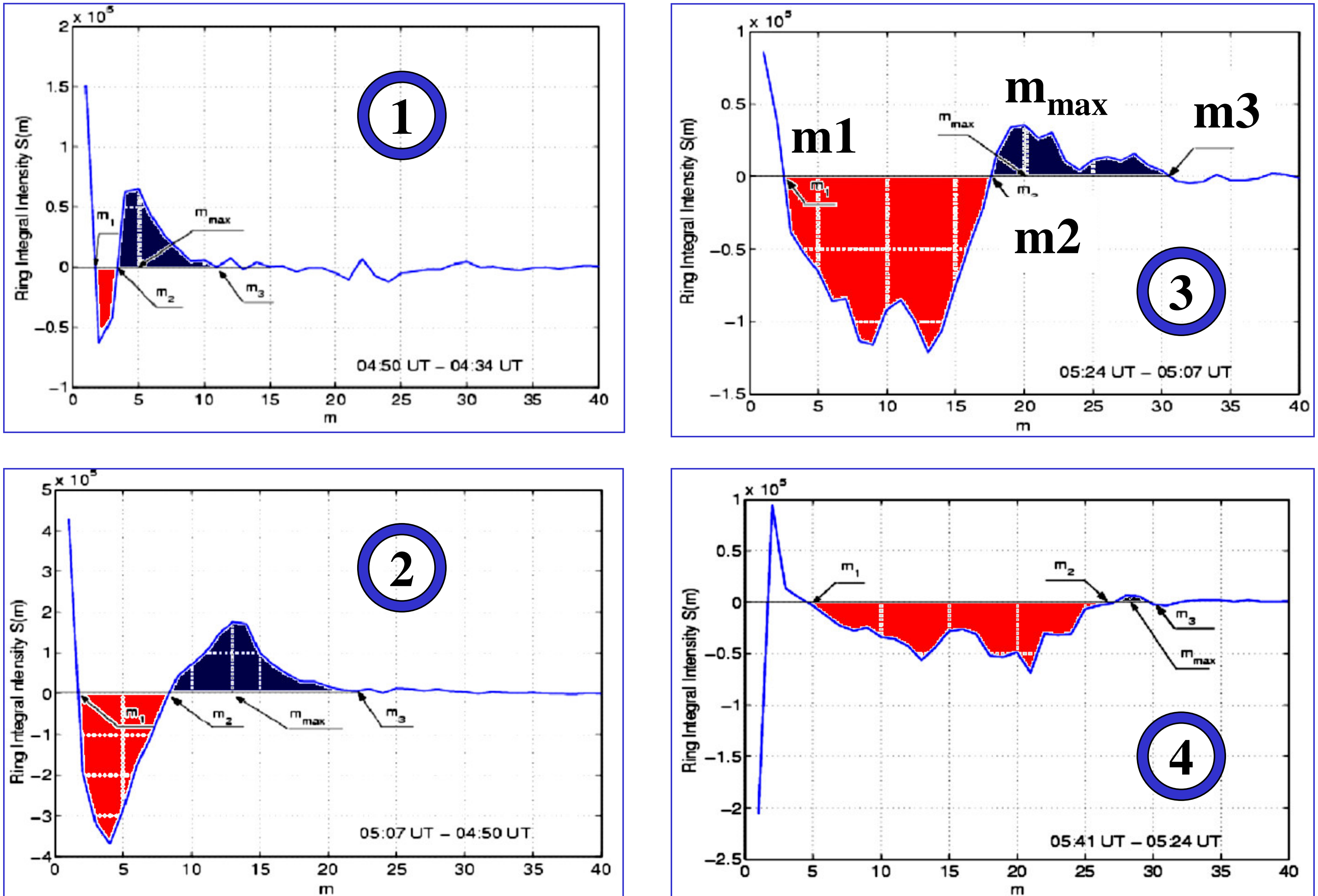
- Synchronous propagation at all angles (here)
- External dimming border ~ Internal front border
- Dimming-front proportionality (or even balance) in the first minutes

- Ring integral intensity

Courtesy of Podladchikova & Berghmans

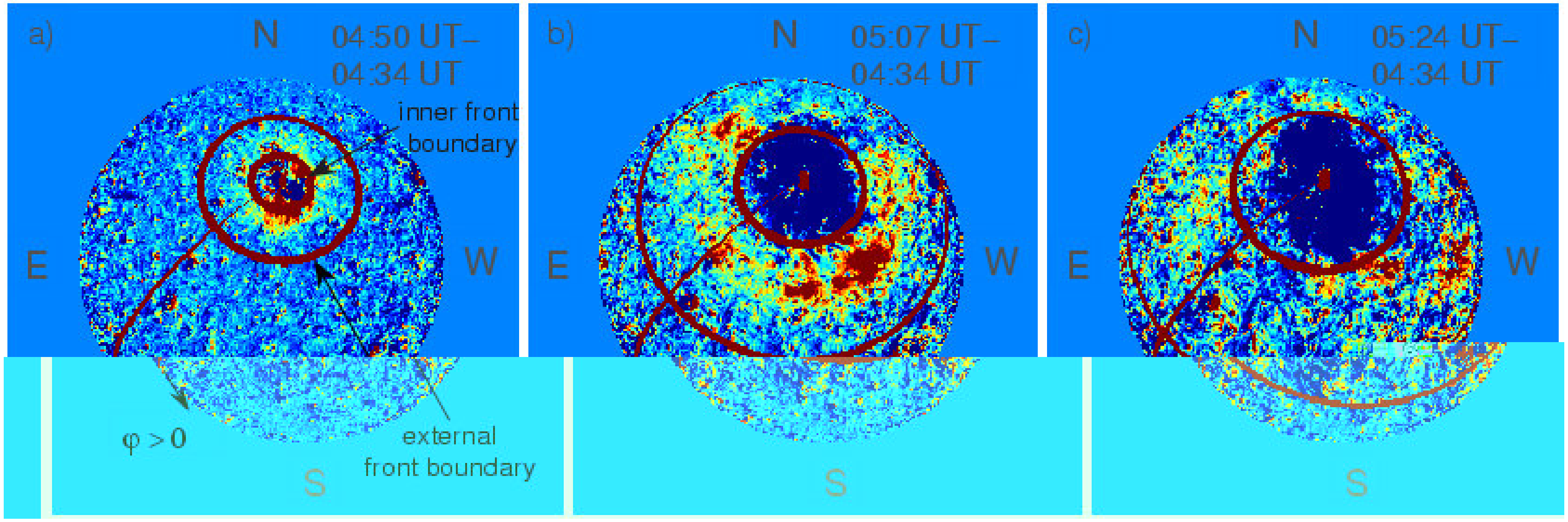
Front Evolution EIT Wave of 12 May 1997

simple magnetic structure,
(free front propagation)

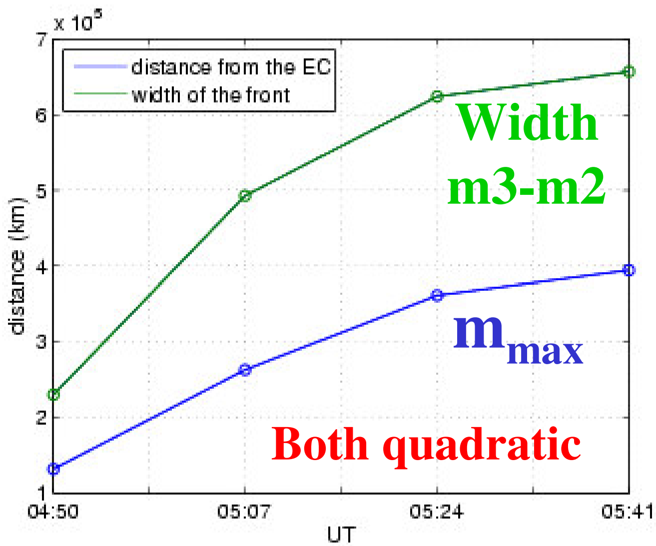


- radial velocity defined by <u>peak</u> propagation (m_{max})

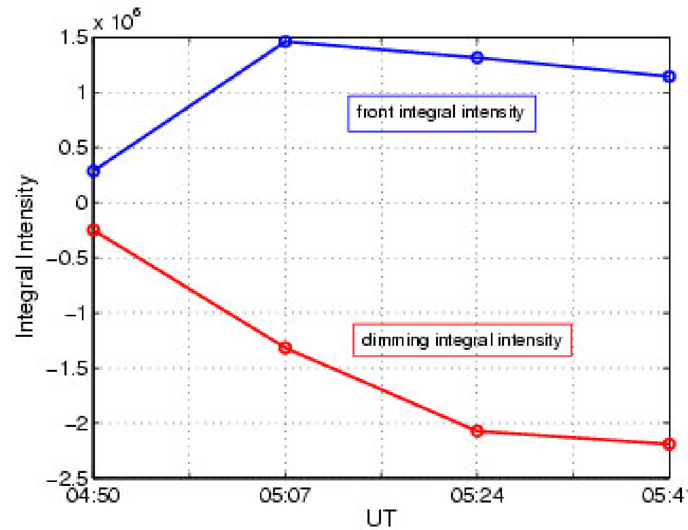
Courtesy of Podladchikova & Berghmans



12 May 1997



Distances vs Time



Integrated signals vs Time

Courtesy of Podladchikova & Berghmans

Higher-order Moments

- Centered moment of order *k*:

  - theoretical :

    PDF = distribution = histogram

    $$\mu_k = \int x^k \overbrace{p(x)}\, dx$$

  - experimental:

    $$\mu_k = \frac{1}{n}\sum_{i=1}^{n}(x_i - \langle x \rangle)^k$$

asymmetry = **Skewness** :

$$\gamma_1 = \frac{\mu_3}{\mu_2^{3/2}}$$

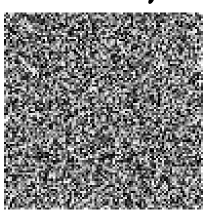
Flatness = **Kurtosis** :

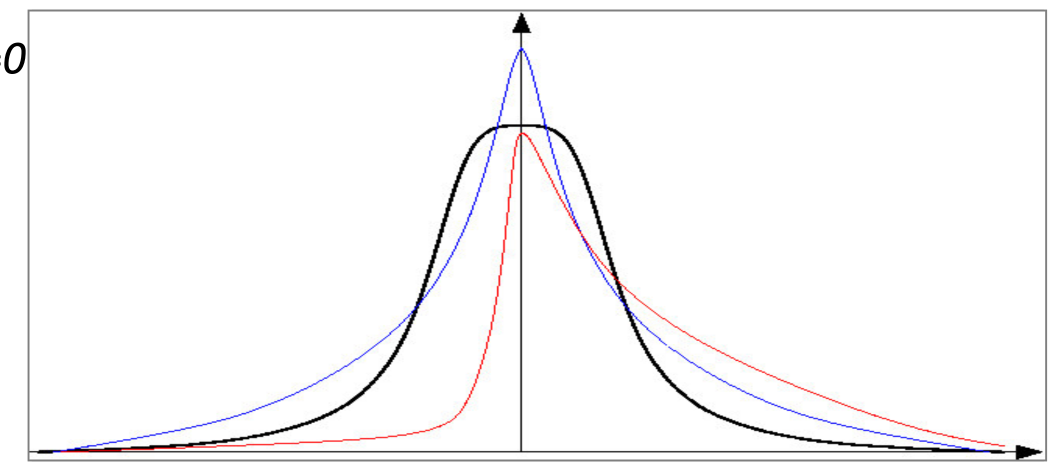
$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3$$

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

- ***$\gamma 1, \gamma 2 >> 0$*** (of signal histogram) can be indicators of large scale coherent structures:

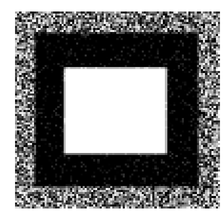
Gaussian: $\gamma 1 = \gamma 2 = 0$





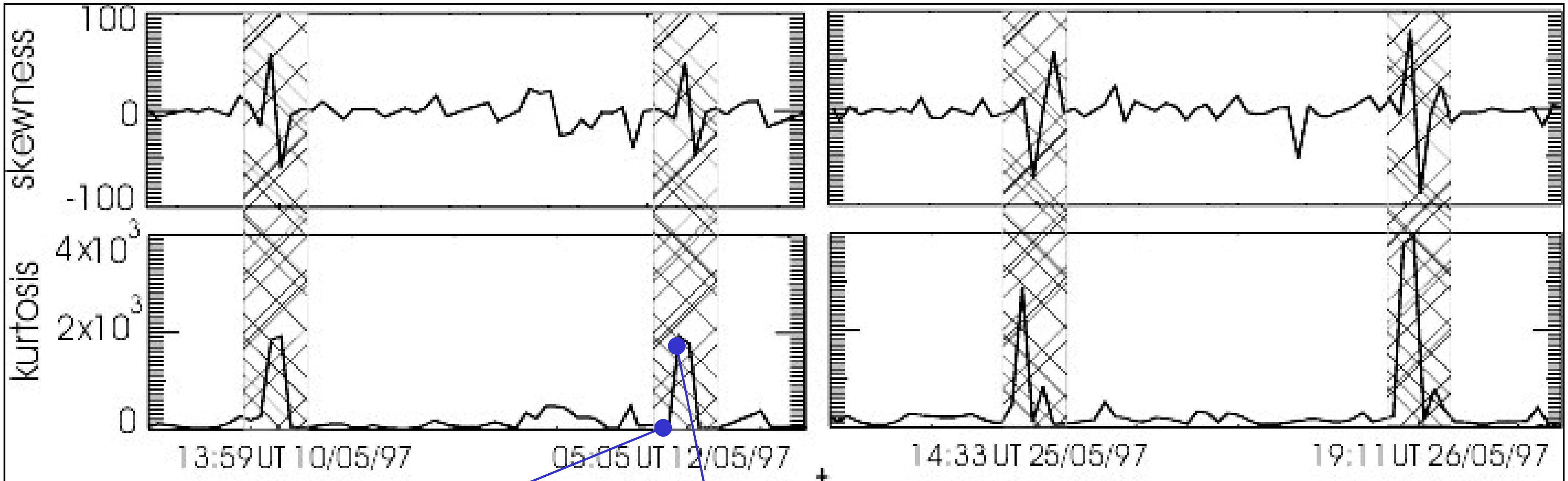
$\gamma 1 = 0,\ \gamma 2 > 0$

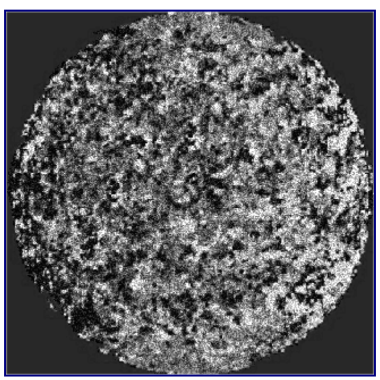
$\gamma 1 > 0,\ \gamma 2 > 0$

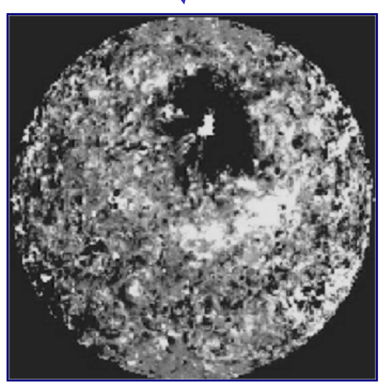


Courtesy of Podladchikova & Berghmans

Skewness & Kurtosis of PDF of difference image versus time







Simultaneous peaks
+ dimming area criteria
→ EIT Waves!

Courtesy of Podladchikova & Berghmans

Some statistics

- April-June 1997 and May 2005 analyzed

  - 50 events analyzed automatically.
  - 35 of them analyzed visually

  Depending on thresholds :

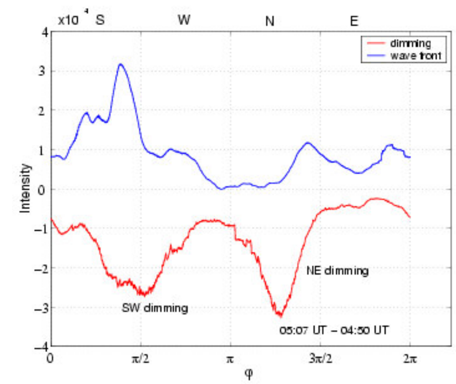
    - 5 events not detected but no false alerts (wrong negatives)
    - All events detected, 4 false alerts (wrong positives)

Thresholds to be optimised to minimize false alerts and missed events.

Courtesy of Podladchikova & Berghmans

Royal Observatory of Belgium

Results



1. **Anisotropy** of wavefront observed even **without obstacles**. Correlation with the associated dimming;
2. Outer border of the dimming **coincides** with inner border of the EIT wave front for homogeneous and anisotropic propagations and in all radial directions;
3. Width of the front grows ~**quadratically** in time;
4. The integrated intensity of wave front **grows** during > 1/2 hr after the eruption. If EIT waves were linear magnetoacoustic waves propagating from the flare source, one would expect the front intensity to **decrease** with time;
5. The integrated positive intensity of **the front balances** the integrated negative intensity of the **dimmings** in the early life of EIT waves.

Conclusions

This suggests that the energy supply to the **EIT wave fronts** possibly **originates directly from the dimmings**.

Read more on this study

Podladchikova & Berghmans, *Automated Detection of EIT waves and dimmings*,
2005, Sol.Phys, 228, 267

Podladchikova & Berghmans, *Energetic dynamics of EIT Wave structure analyzed by EIT Wave Detector*,
2005a, ESA-592, SOHO 16/SW 11.

Podladchikova & Berghmans, *Interaction of EIT wave with AR on the Sun*,
2005b, ESA-592, SOHO 16/SW 11.

Quantify *motion* <u>together with</u> intrinsic *brightness variation* in EIT image sequences

Hochedez & Gissot, 2005

VELOCIRAPTOR

VELOCIty & b**R**ightness v**A**riations ma**P**s construc**TOR**

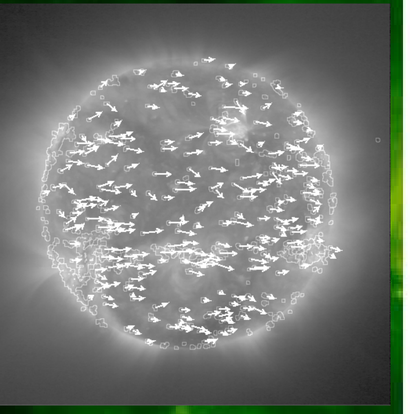
Inputs & outputs

Image $I_n(x,y)$

e.g. EIT "CME Watch"

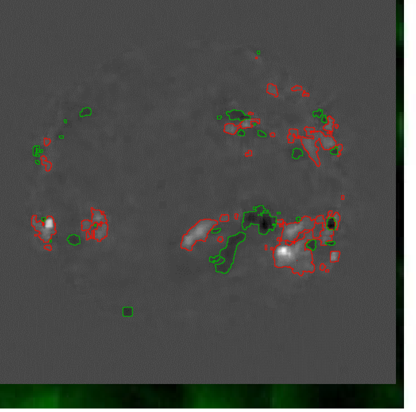
Image $I_{n+1}(x,y)$

Velocity field



1. Similarity field between $I_n(x,y)$ (warped) and $I_{n+1}(x,y)$
2. Local "texture"
3. Residuals

Brightness Variation field



Hochedez & Gissot

Royal Observatory of Belgium

Brightness Constancy Assumption

$$\frac{\mathrm{d}}{\mathrm{dt}} I(x(t), y(t)) = 0$$

Optical Flow Constraint Equation

$$\vec{\nabla} I . \vec{v} + \frac{\partial I}{\partial t} = I_x . v_x + I_y . v_y + I_t = 0$$

$$I_k = \frac{\partial}{\partial k} I$$

for k=x,y,t

1 equation but 2 unknowns

1 equation is missing!

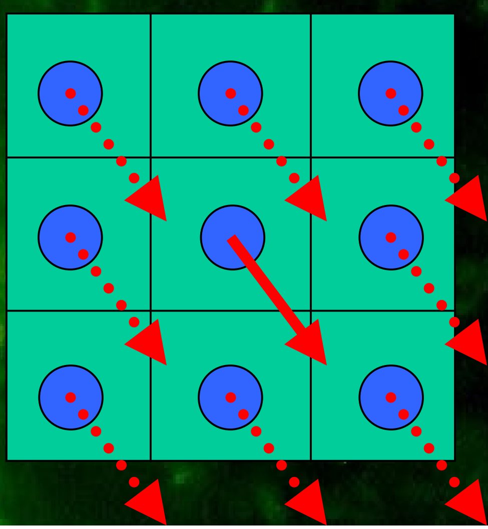
Hochedez & Gissot

Hochedez & Gissot

2^{nd} equation: the LUCAS-KANADE algorithm

The Lucas-Kanade assumption
(*locally uniform motion*)
provides extra-equations

8 new equations for a 3x3 neighborhood



Possible to add unknown(s) ☺

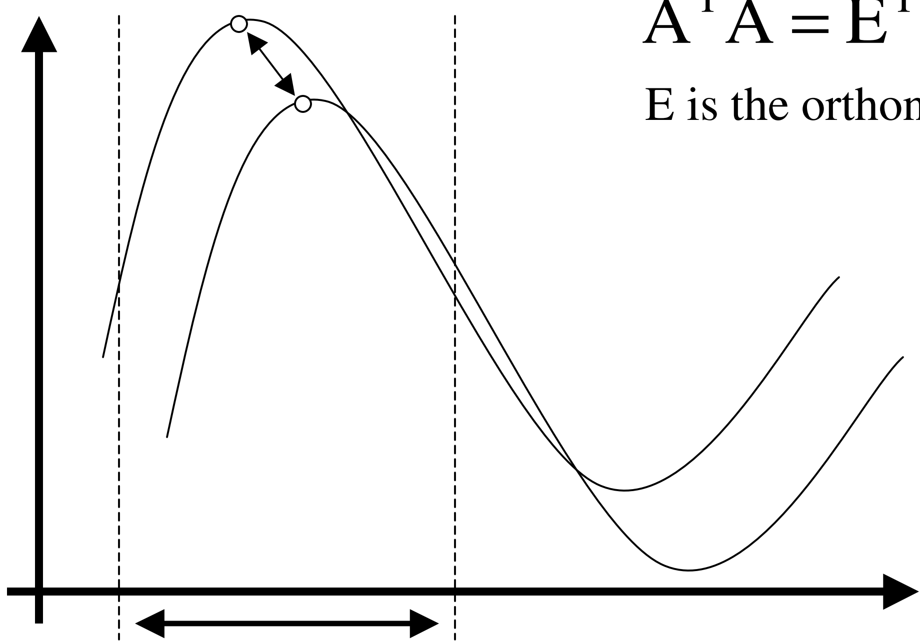
such as:

- **Brightness Variation (this study!)**
- **Contrast variation, shear, etc.**

Is the common estimation of **BV** and **v** possible ?
If yes, where?

OF Reformulation

A . (vx,vy,BV) = b, with: $A^T = \begin{pmatrix} I_x(\vec{x}_0) & \cdots & I_x(\vec{x}_{N-1}) \\ I_y(\vec{x}_0) & \cdots & I_y(\vec{x}_{N-1}) \\ 1 & \cdots & 1 \end{pmatrix}$ $\vec{b}^T = (I_t(\vec{x}_0) \cdots I_t(\vec{x}_{N-1}))$



Neighborhood of least-squares estimation

$$A^T A = E^T M E$$

E is the orthonormal eigenvector matrix

$$M = \begin{pmatrix} \lambda 1 & & \\ & \lambda 2 & \\ & & \lambda 3 \end{pmatrix}$$

Least square formulation

$$(\hat{v}_x, \hat{v}_y, \hat{\delta I})_{LS} = \underset{v_x, v_y, \delta I}{\operatorname{argmin}} \sum_{x,y \in R} (I_x . v_x + I_y . v_y + I_t + \delta I)^2$$

$$(\hat{v}_x, \hat{v}_y, \hat{\delta I})_{LS}^T = -M^{-1} A^T b$$

Hochedez & Gissot

Royal Observatory of Belgium


Is this going to be **useful** to Solar Physics one day?
Have mercy! **No equation**, please JF!
Wow..
Rrrr..
SORTIE
SORTIE

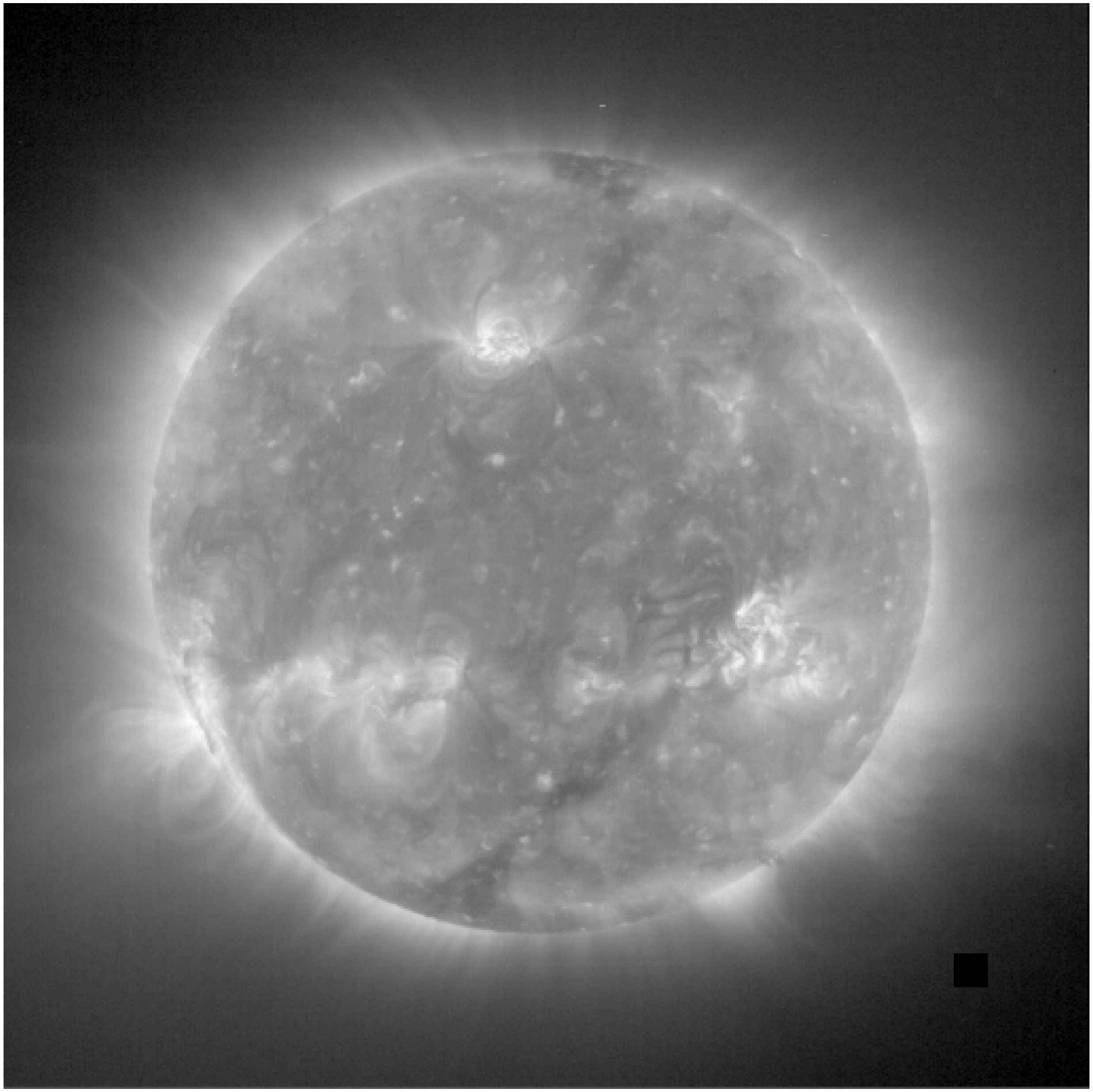
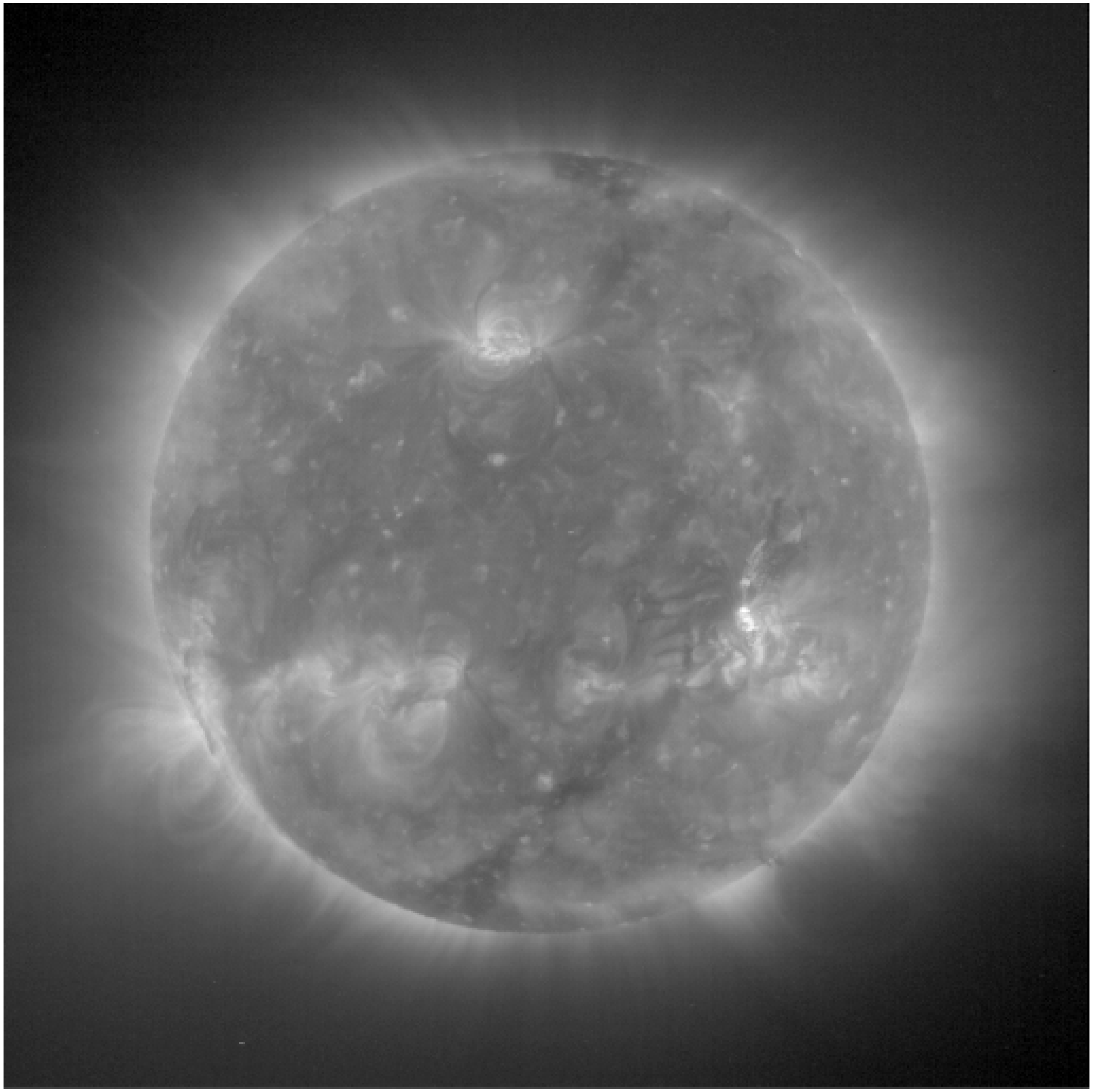
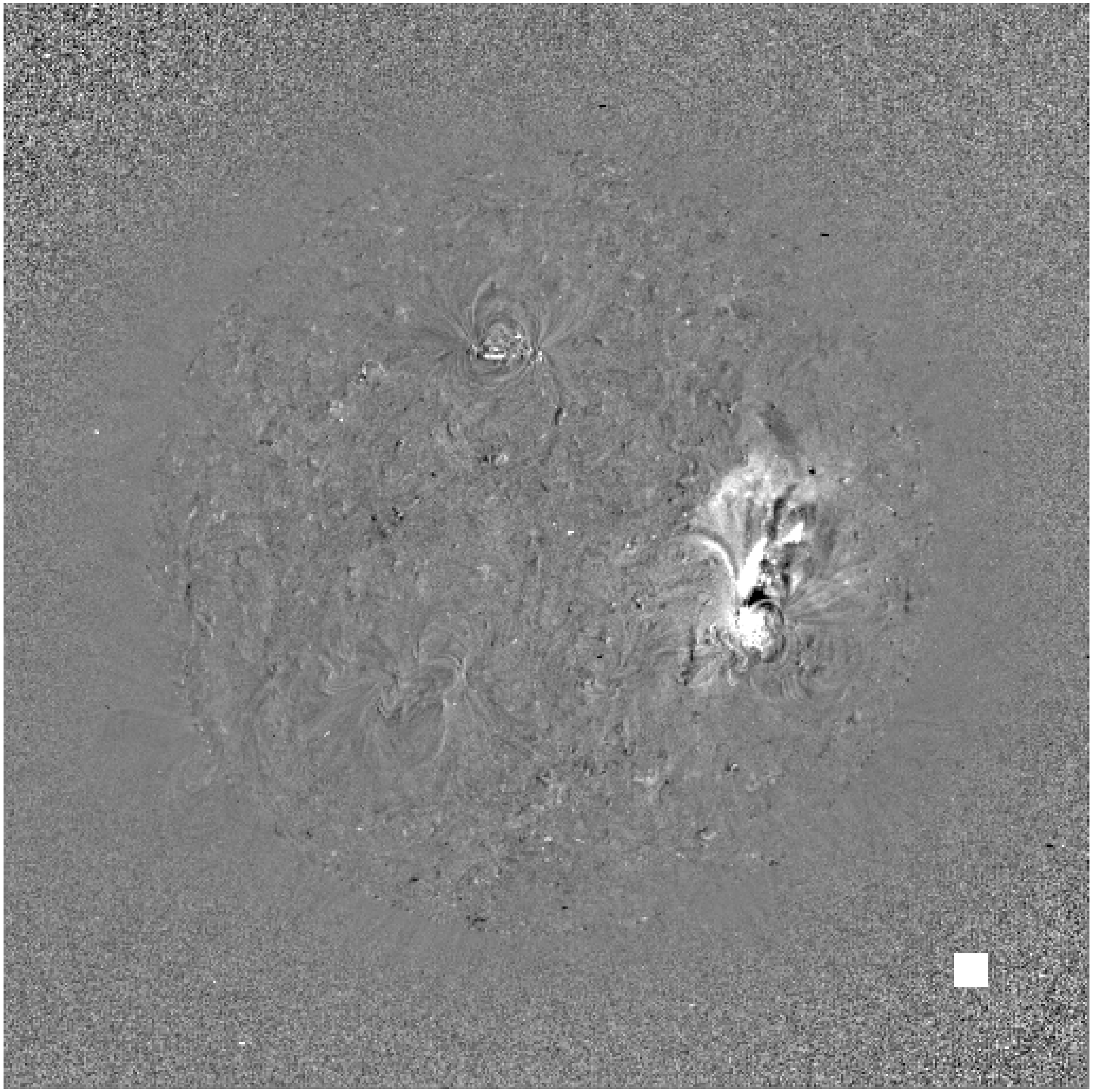


Image 1
3 May 98

Image 2
3 May 98



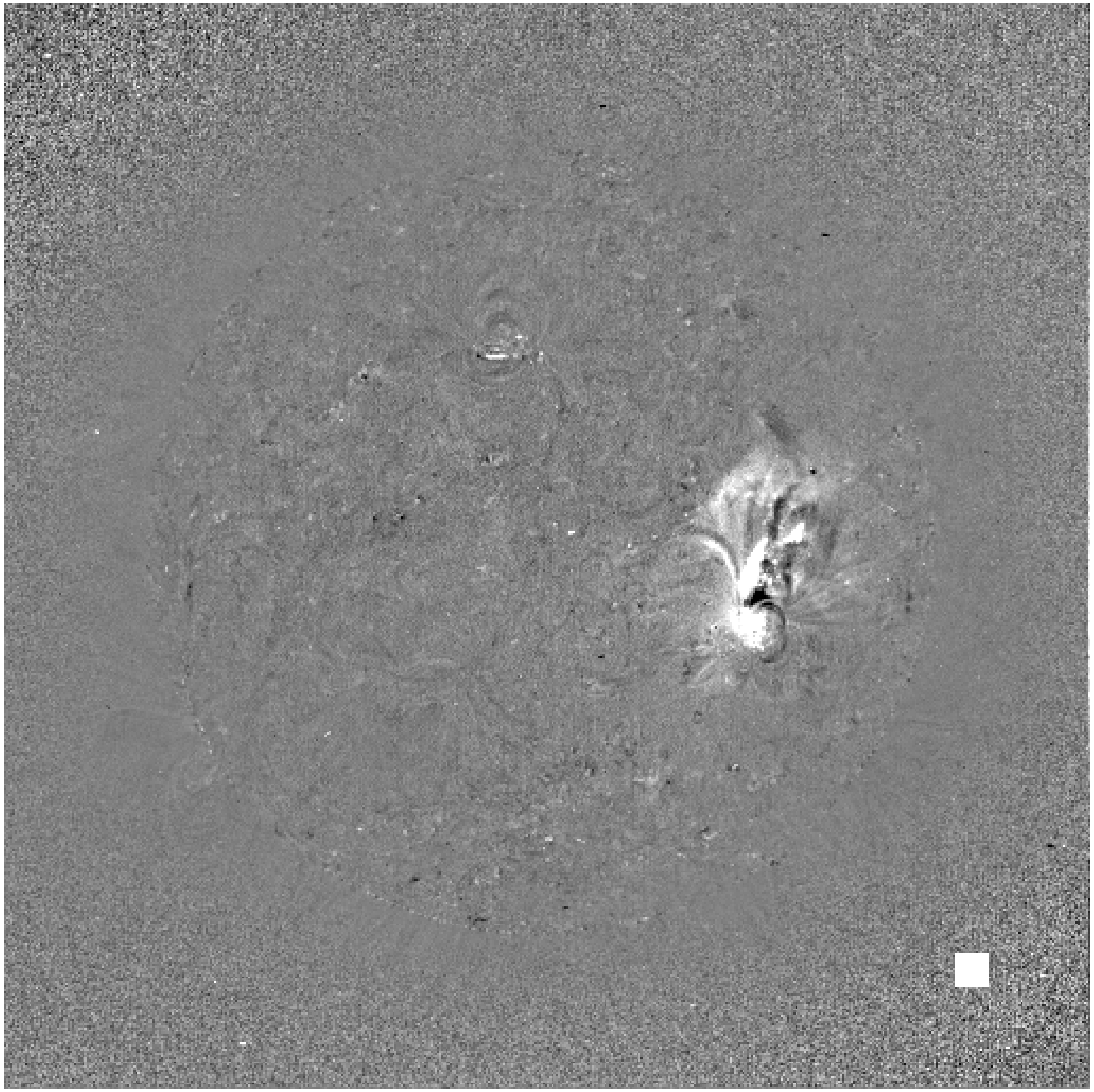
1998-05-03 21:22:37 (512x512 rebinned)



Difference image

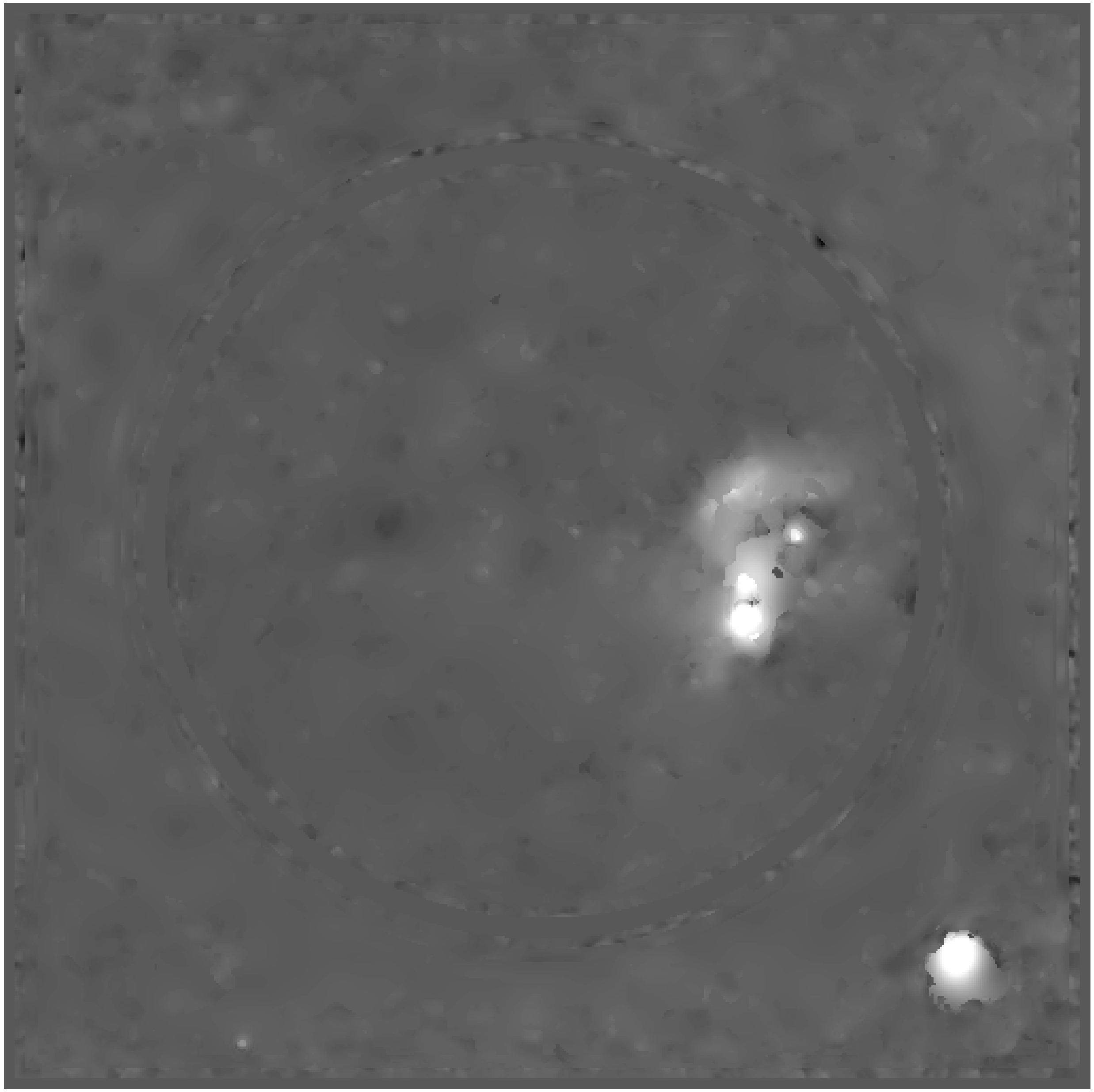
3-2
0.5

3-2
0.5
Diff rot cor

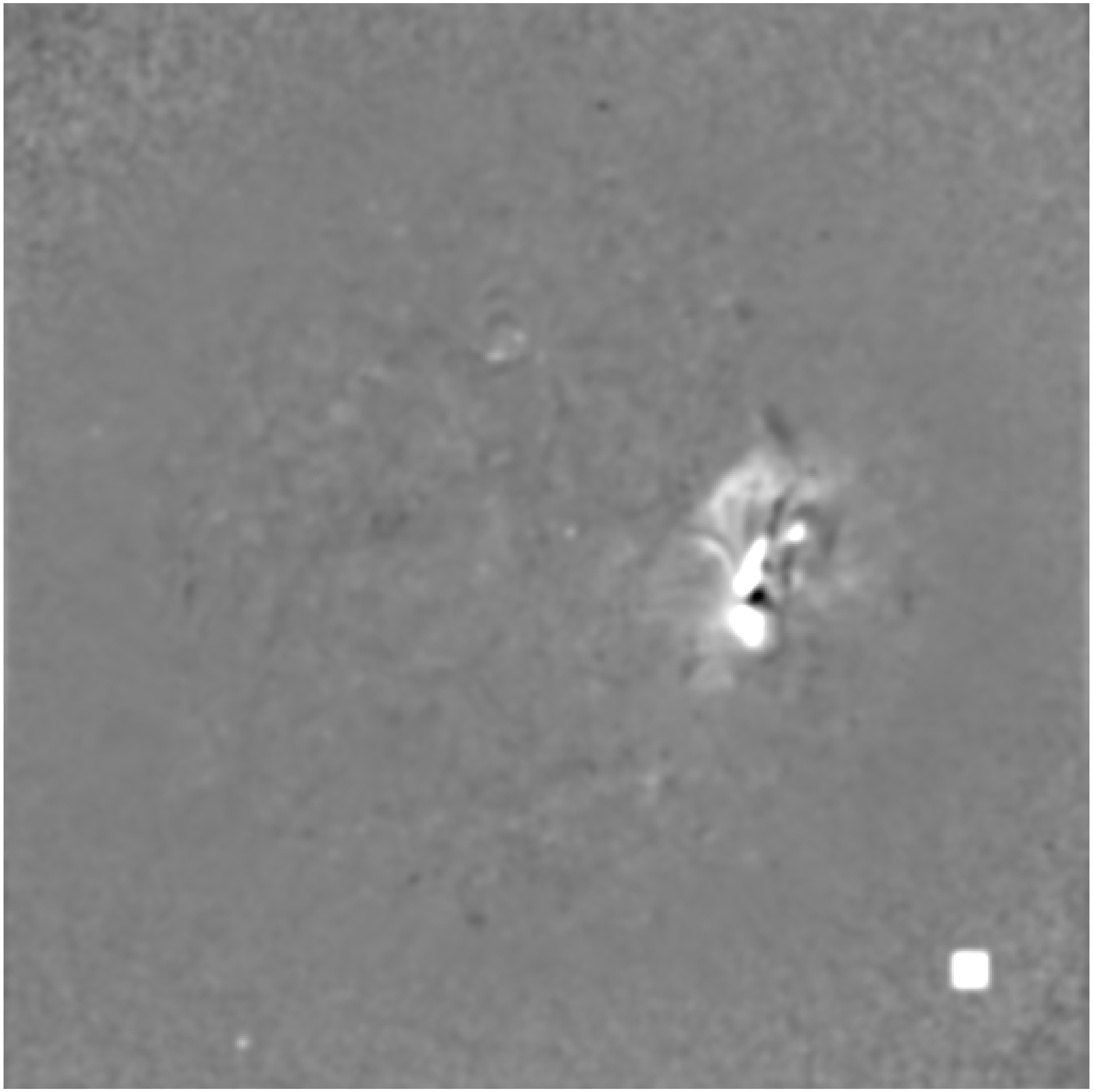


Difference image corrected for differential rotation

3-2
0.5
bv

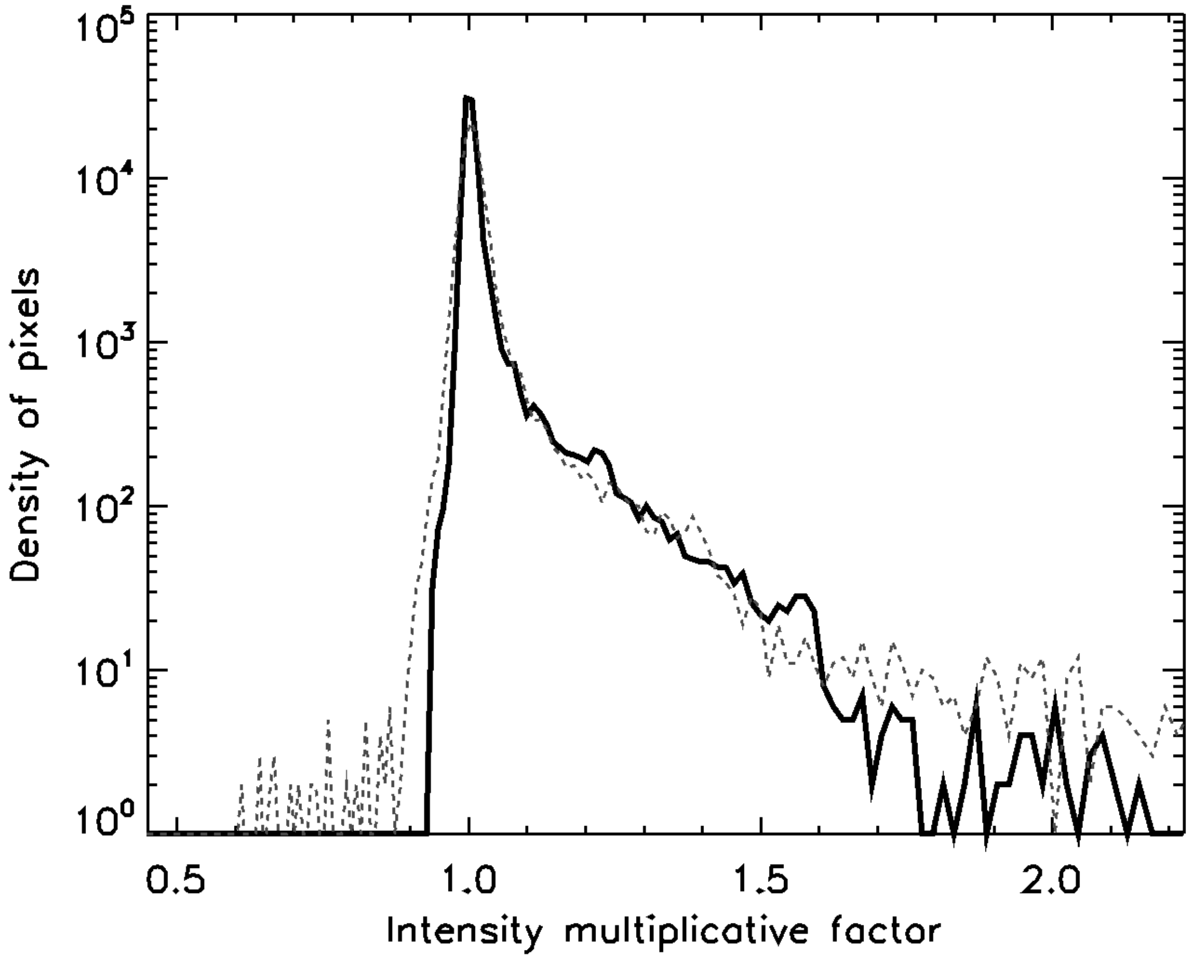


Brightness variation map

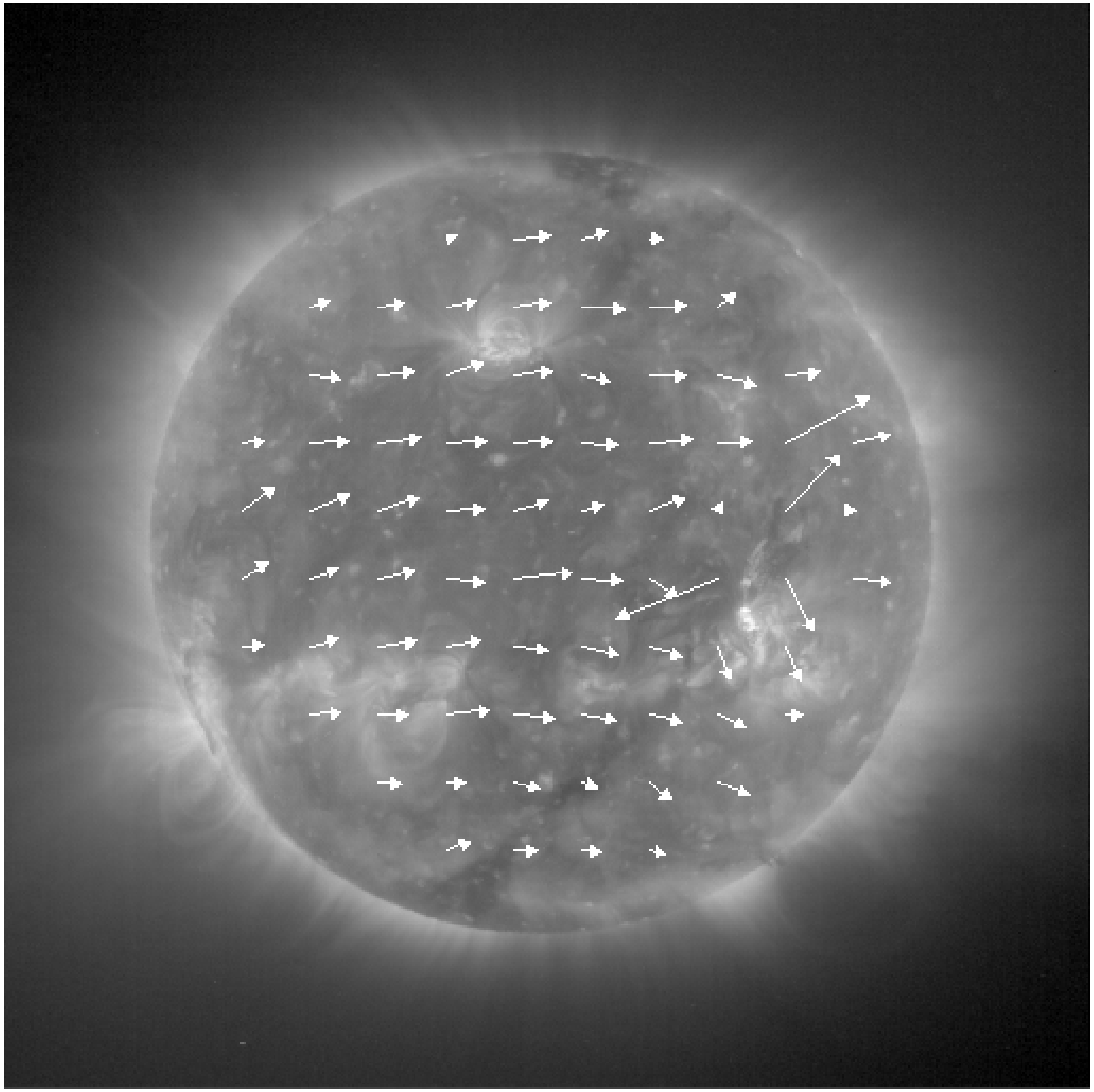


3-2
0.5
Diff rot cor convol

Diff. image cor. for dif. Rot. & gaussian filtered

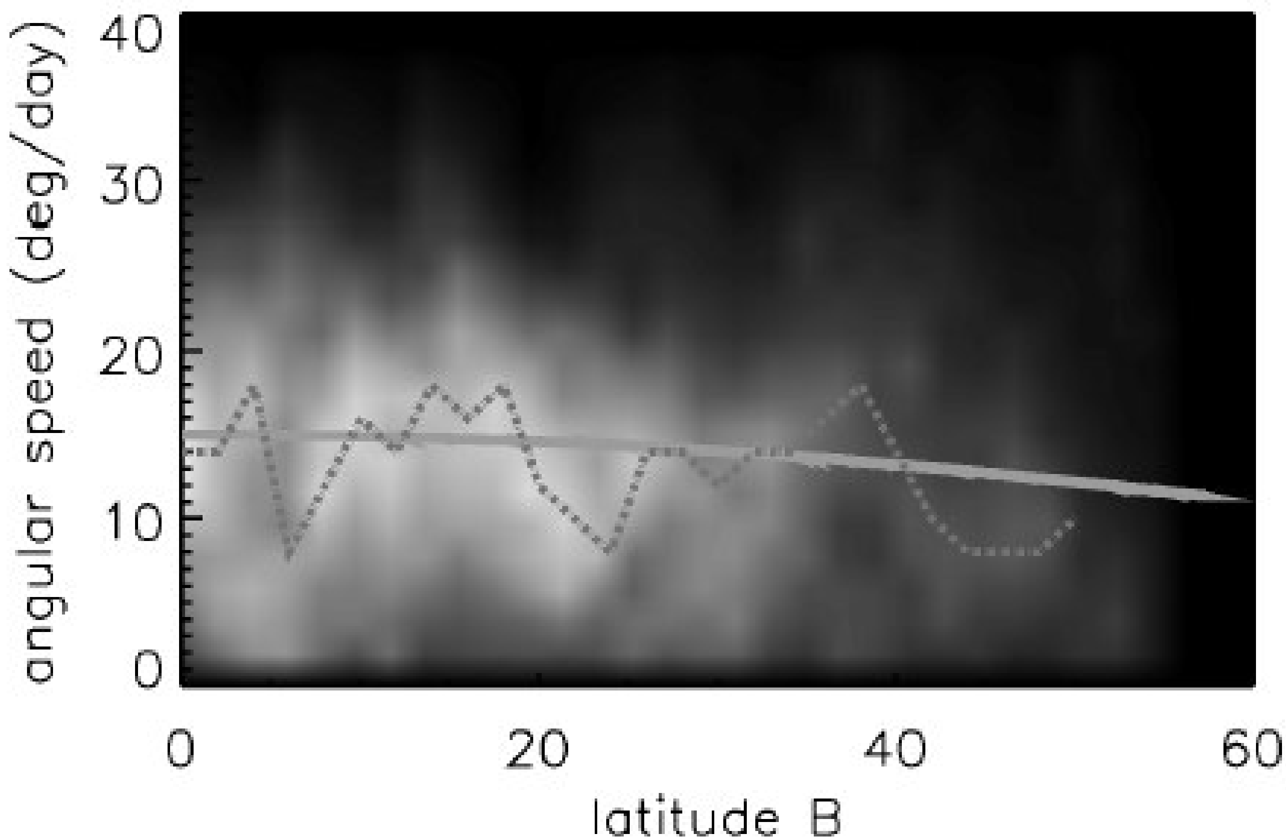


PDF of BV versus [dif.rot corrected + gauss.fltrd]

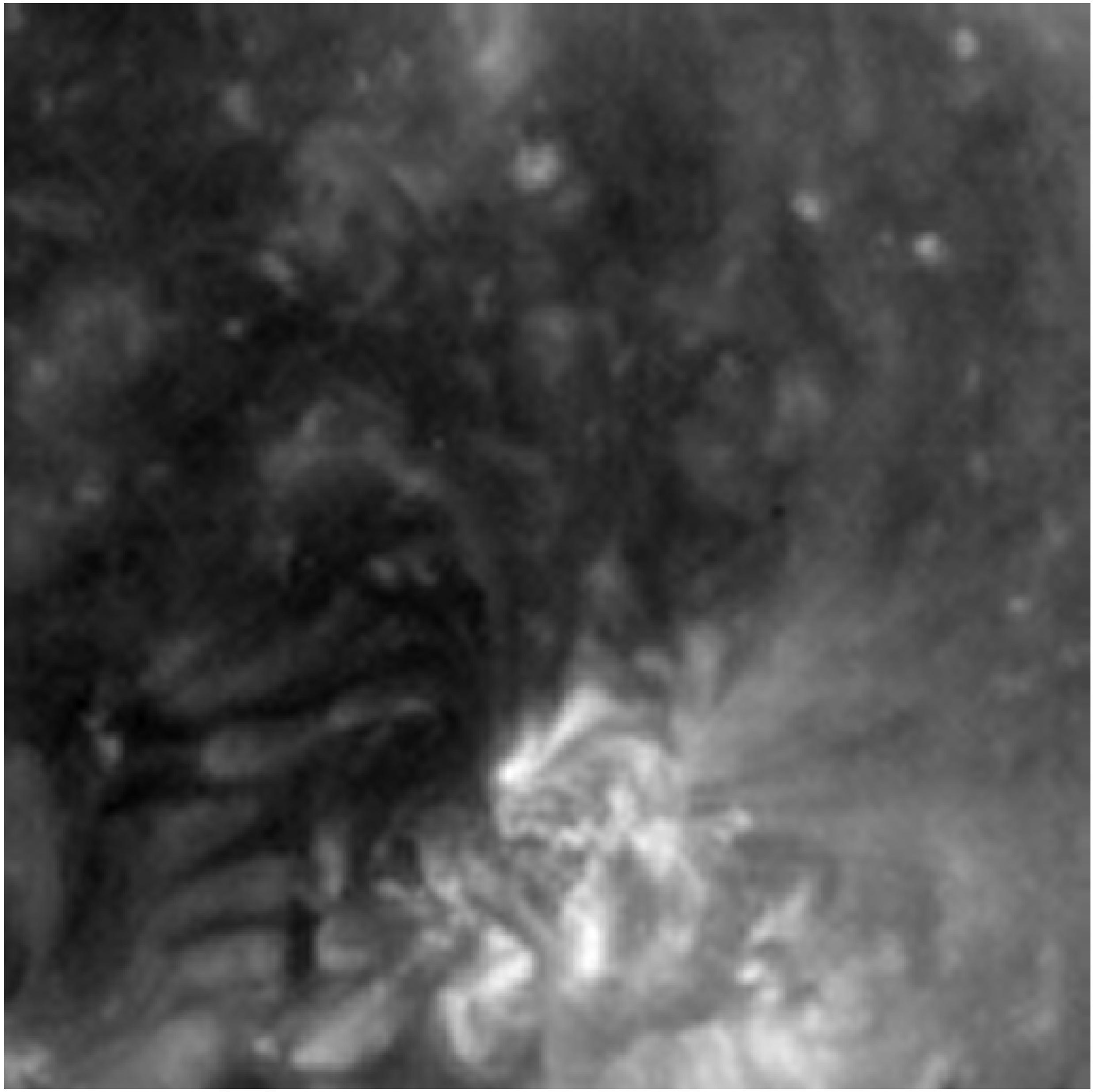


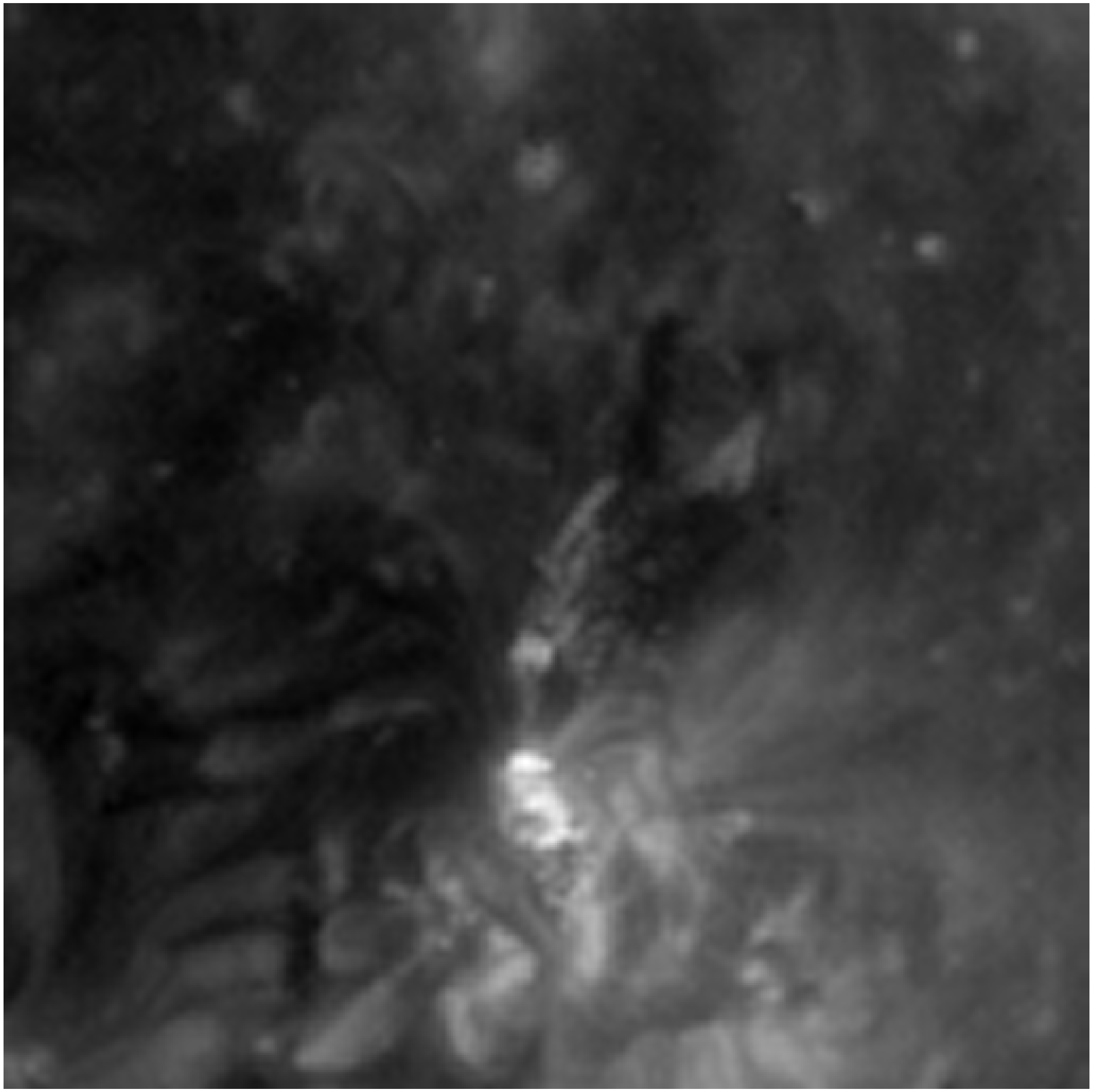
Velocity Map

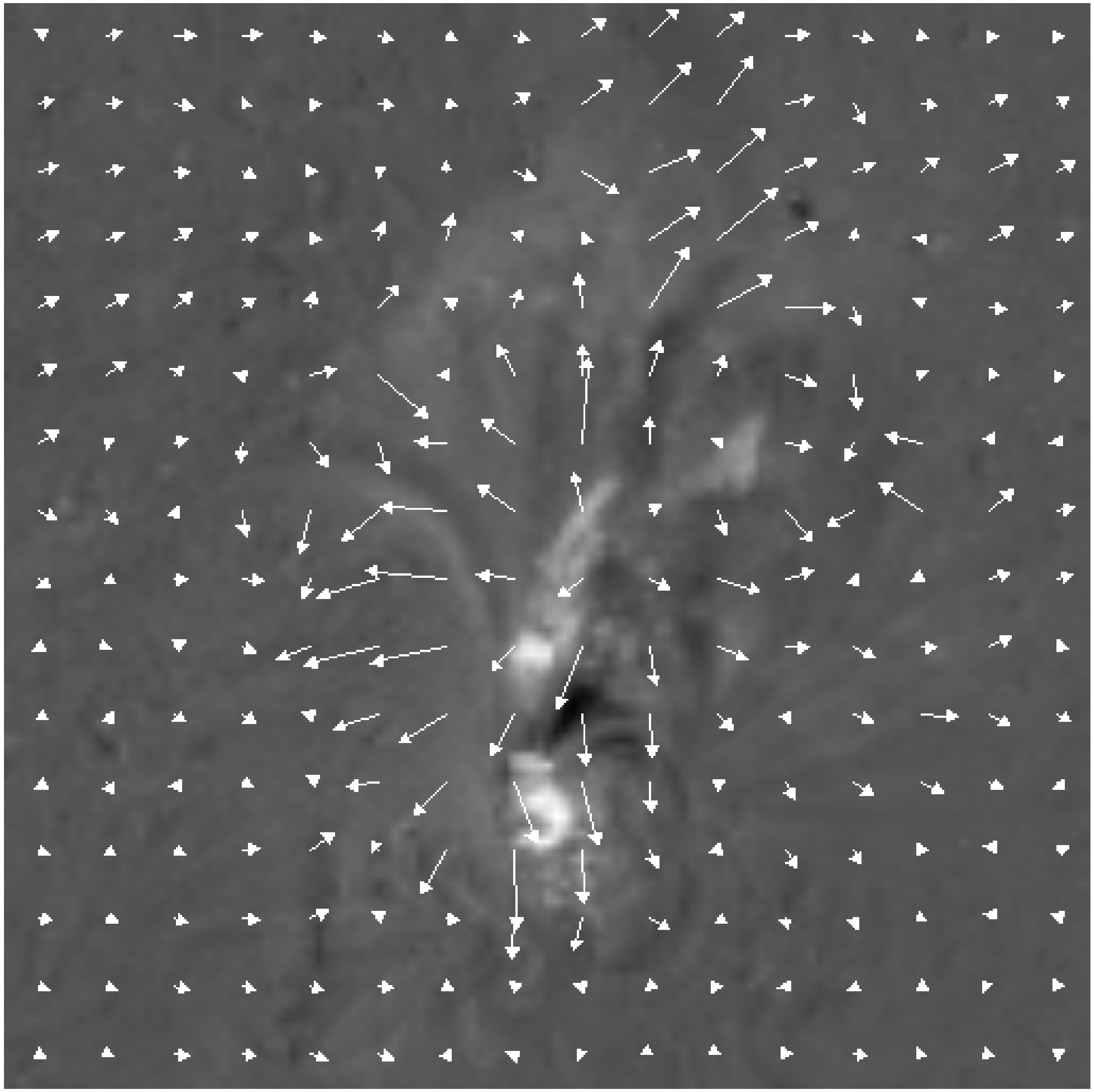
Differential rotation recovered from a couple of EIT images

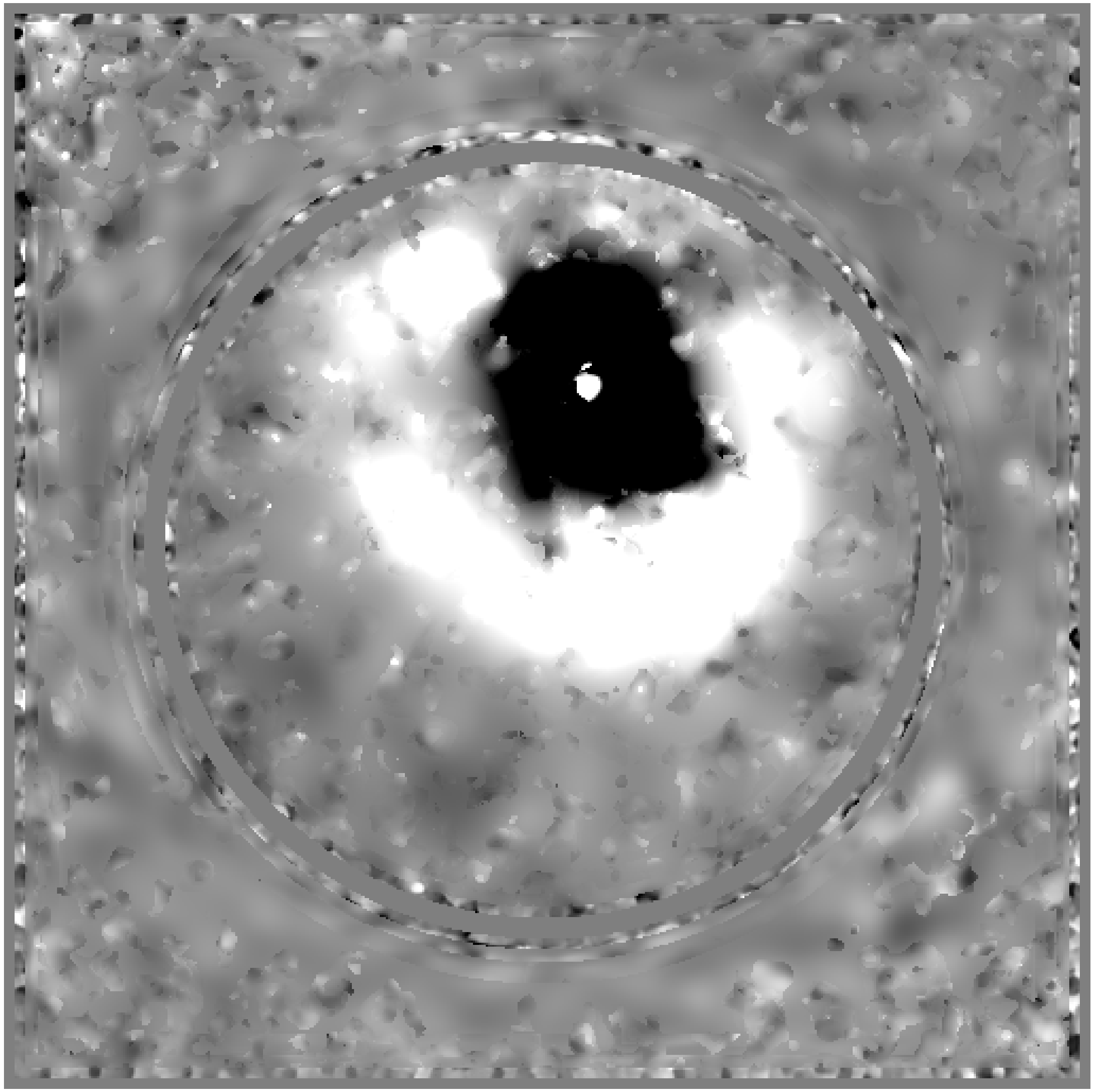


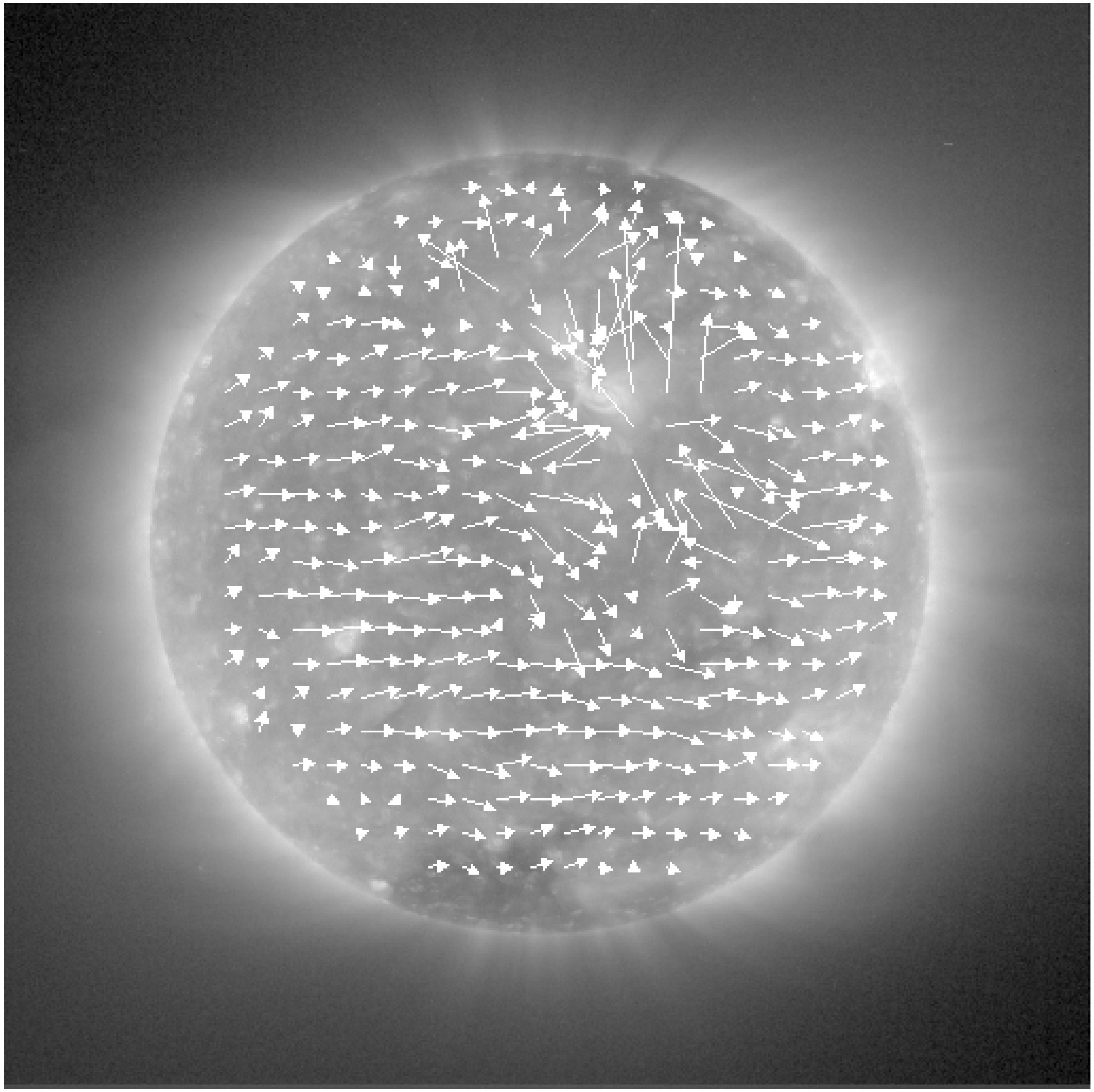
No intensity variation estimation





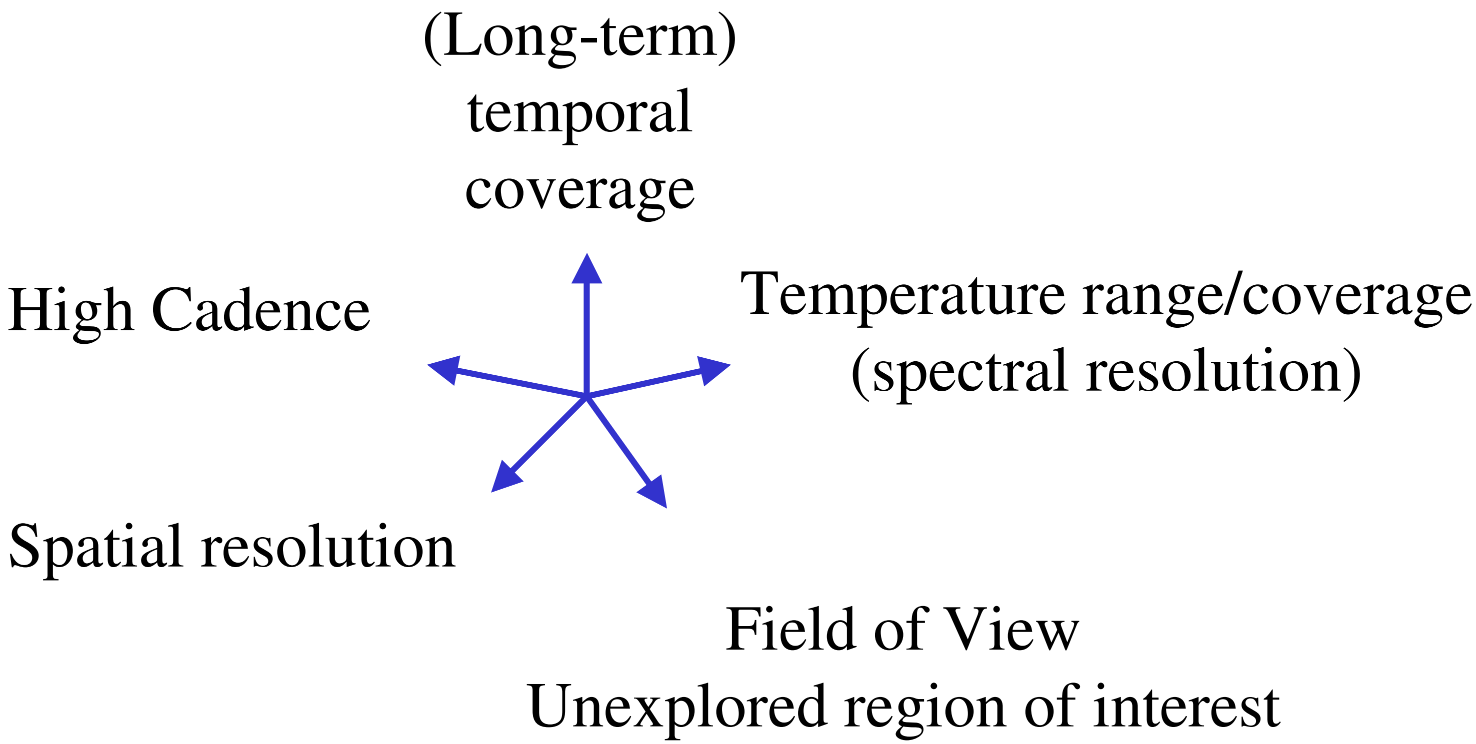







I was expecting to hear more about **Boudine** and **haecceity**
…the latter only if **really** needed.
Yes
Indeed
Eh oui

Where to go to continue solar research after SoHO-EIT?



Physics of the Sun Atmosphere today

research fields & keywords

1. Coronal heating :
   - Energy transport from convection zone to upper atmosphere, loop models, MHD & kinetic modeling, physics of the TR, moss, variability… Nanoflare / DC –based heating, MHD wave / AC –based heating, AR vs QS heating
2. Magnetic field, structure(s), activity :
   - Topology, handling complexity (*eg*. SOC), coupling of scales, modelling, MHD extrapolations, physics of the reconnection, of MHD waves, coronal seismology, variability (why), helicity…
   - Phenomenology, all atmospheric structures: CH, prominences, plumes, BP, blinkers, explosive events, and all small-scale transients, (macro-) spicules, chromospheric network, mag. carpet, interconnecting and transequatorial loops, canopy, AR↔CH …
3. Large transients :
   - CMEs, Flares, Eruptive prominences, Moreton & EIT waves - Their formation, trigger(s), timing, precursors, numerous scenarii, non-equilibria, helicity…
   - Validity of operational SpW nowcasting and forecasting
4. Emission mechanisms, irradiance, and abundances :
   - Ly-alpha (H&He), FIP effect, atomic processes, ionization balance, DEM analysis, radiative transfer/loss, plasma properties, diagnostics, irradiance budgets, impact on Earth thermosphere and ionosphere, variability (how)…
5. Solar cycle studies, atmospheric signatures of the dynamo :
   - SOHO follow-up in cycle 24, All long-term studies, differential rotation of tracers, 1.3-year periodicity in the Corona, new proxies, helicity (shedding), active longitudes…
6. Heliospheric studies, solar wind, Space Weather :
   - Fast & slow wind acceleration, large-scale transients, AR expansion, CH, streamers, H & He distribution, Doppler dimming, inflows, blobs, plasmoids, geoeffectiveness, SpW Forecast, Climate Global Change…

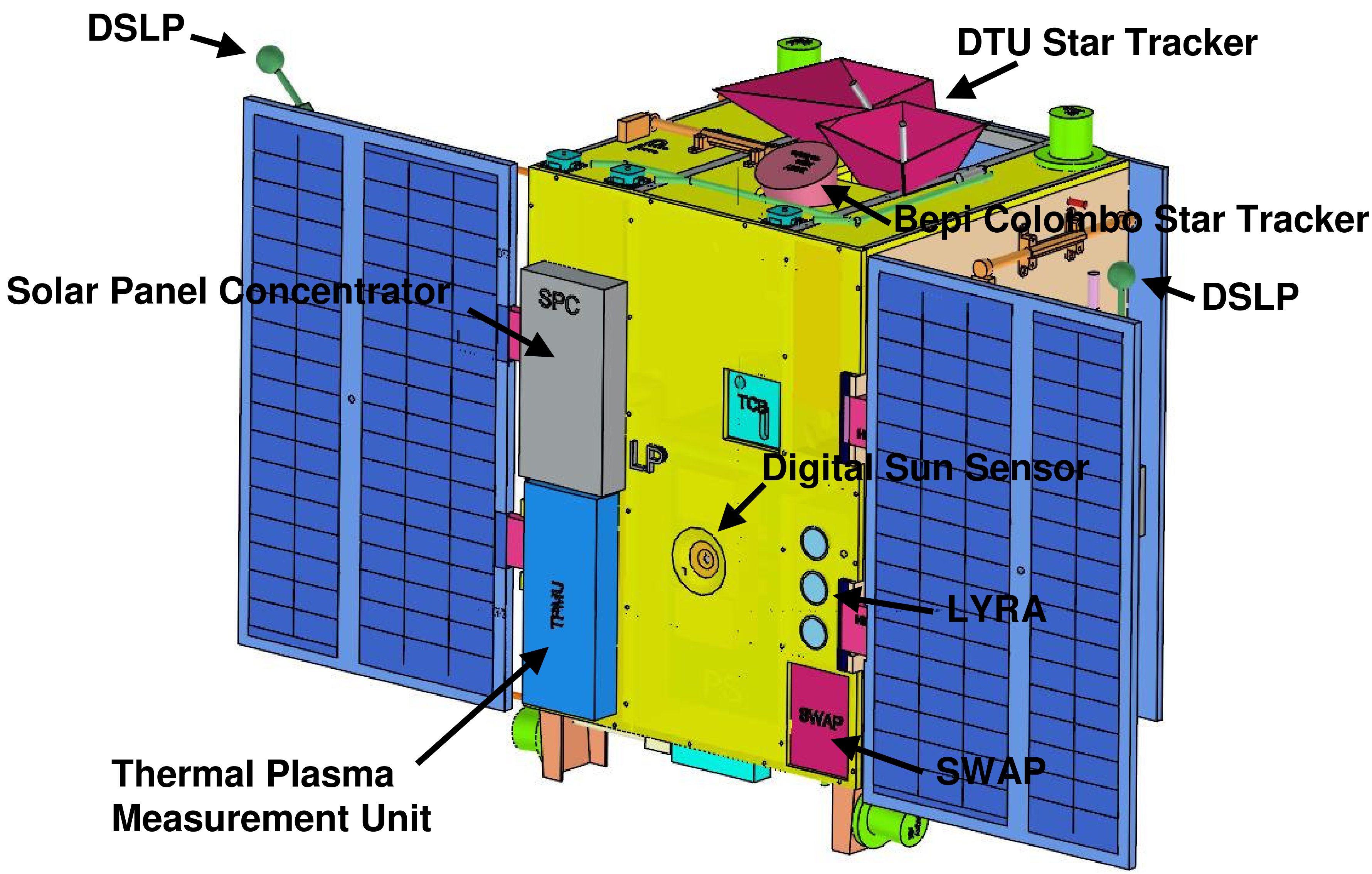
Large cross-talk between goals and techniques

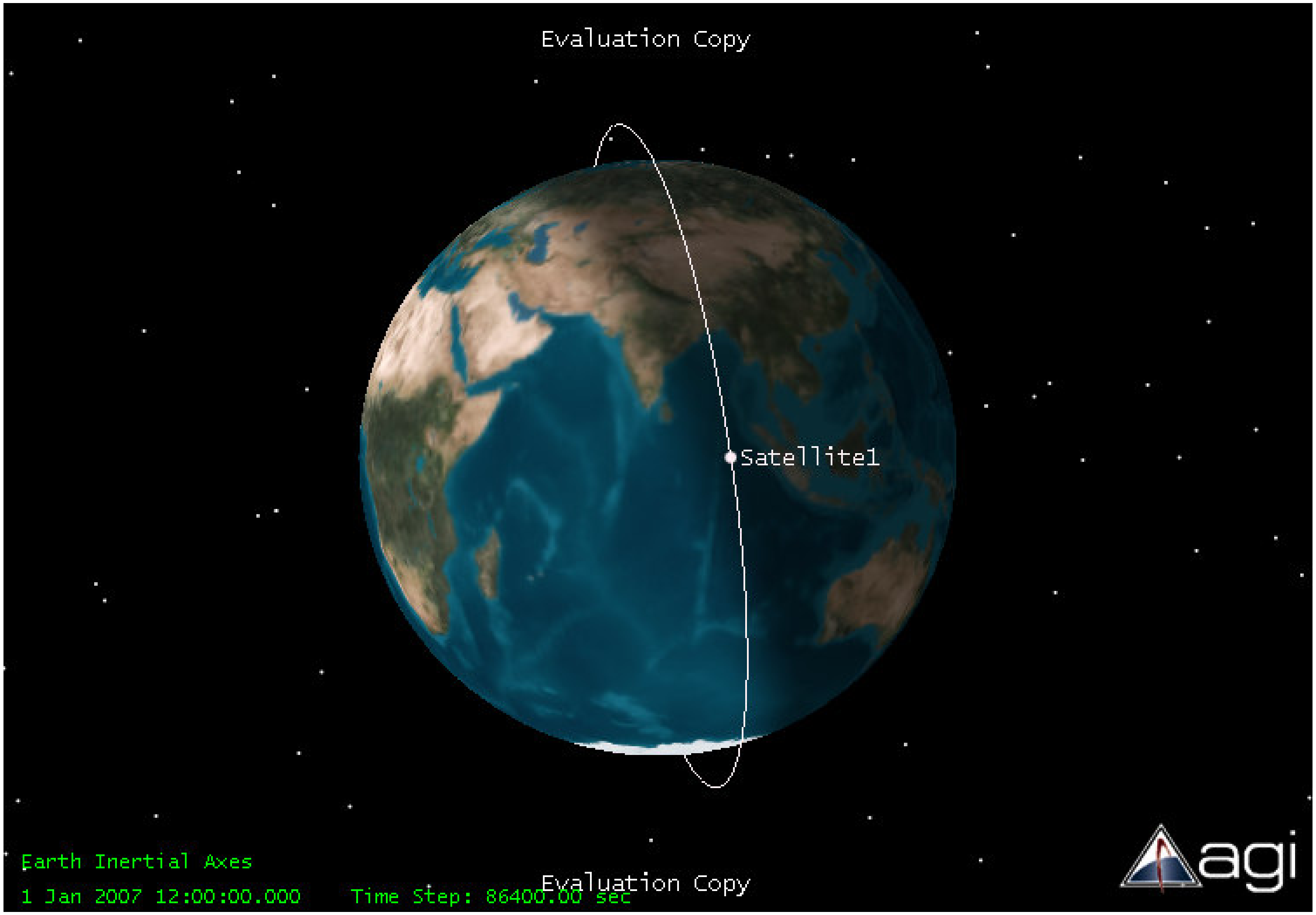
illustrative examples

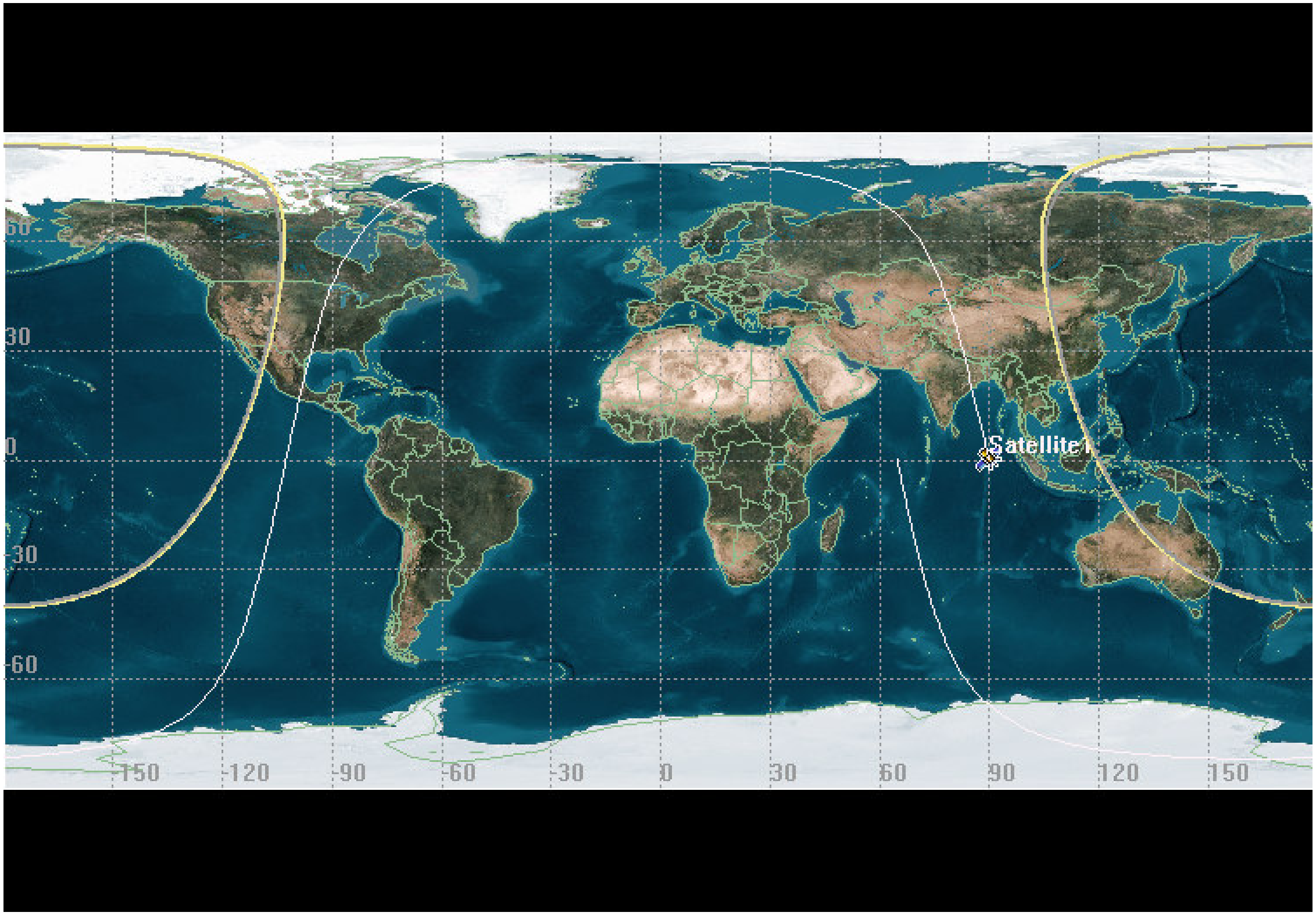
	Heating	Atmospheric structures	Large-scale Transients	Irradiance + Basic processes	Cycle & dynamo	Heliosphere Wind & SpW
DEM	Loop modelling	All!	Perhaps	Prerequisite?	Yes	Yes
MHD extrapolation	Current sheet sites	Prominences	Precursors		Helicity removal	Yes
Coronal seismology	Estimate viscosity	MHD Waves	EIT waves	Perhaps		?
Joint studies	EIS - S.O.	HMI	STEREO XRT	EVE	SOHO	All in-situ
Calibrations	DEM	flat-fielding	energetics	Radiometry	Long-term In-flight	Ly-a
Image processing	Brightenings extraction	Scaling laws (eg. Loops)	Nowcast	Irradiance budget	Huge archive	Nowcast
Statistics	Yes	Compensation of DEM limits	Yes	Yes	Yes	Forecast validation

Several techniques often combined to reach a result

Sun side view

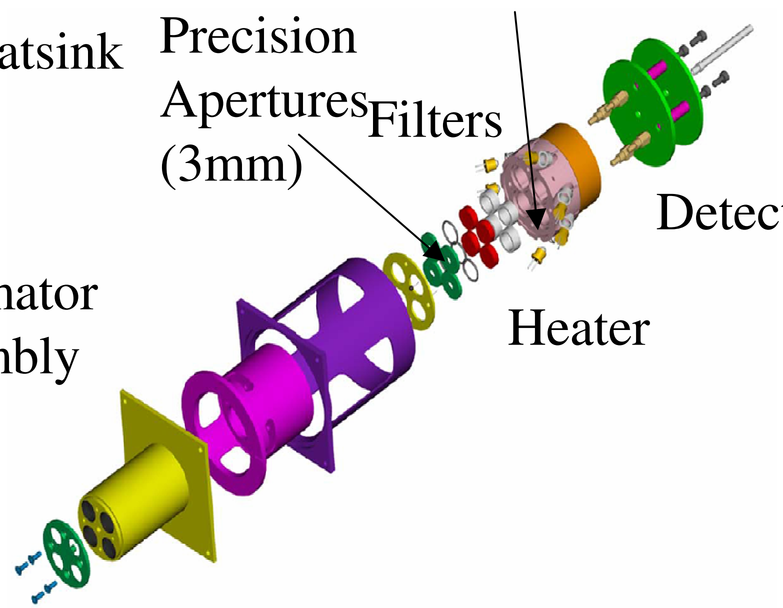


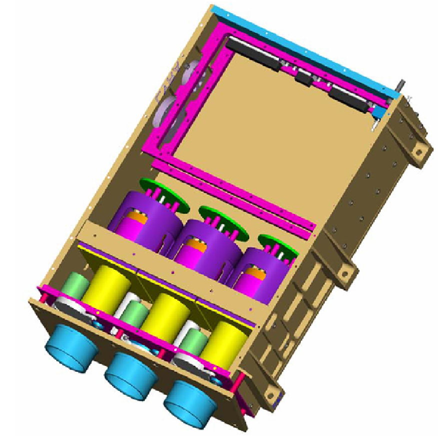

Evaluation Copy
Satellite1
Earth Inertial Axes
1 Jan 2007 12:00:00.000
Time Step: 86400.00 sec
Evaluation Copy
agi



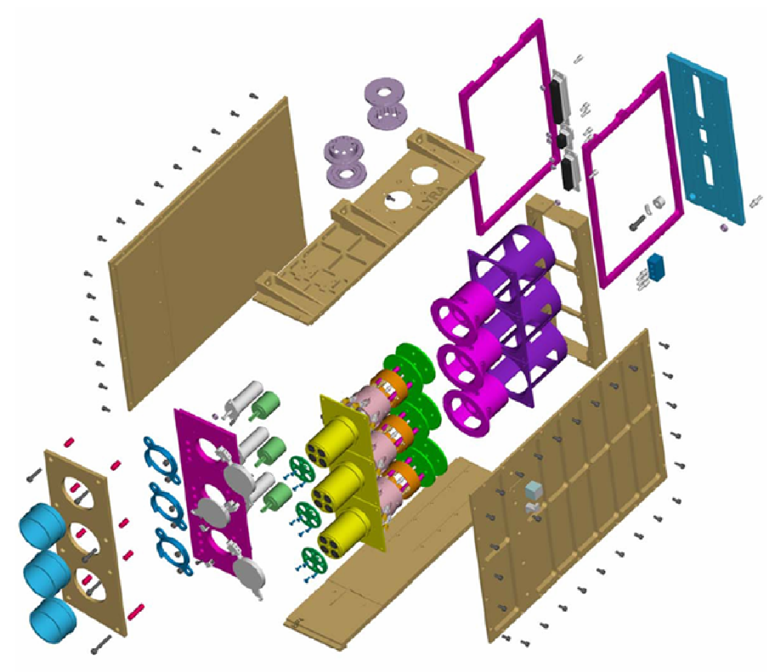
60
30
0
-30
-60
-150
-120
-90
-60
-30
0
30
60
90
120
150
Satellite1

Inside LYRA



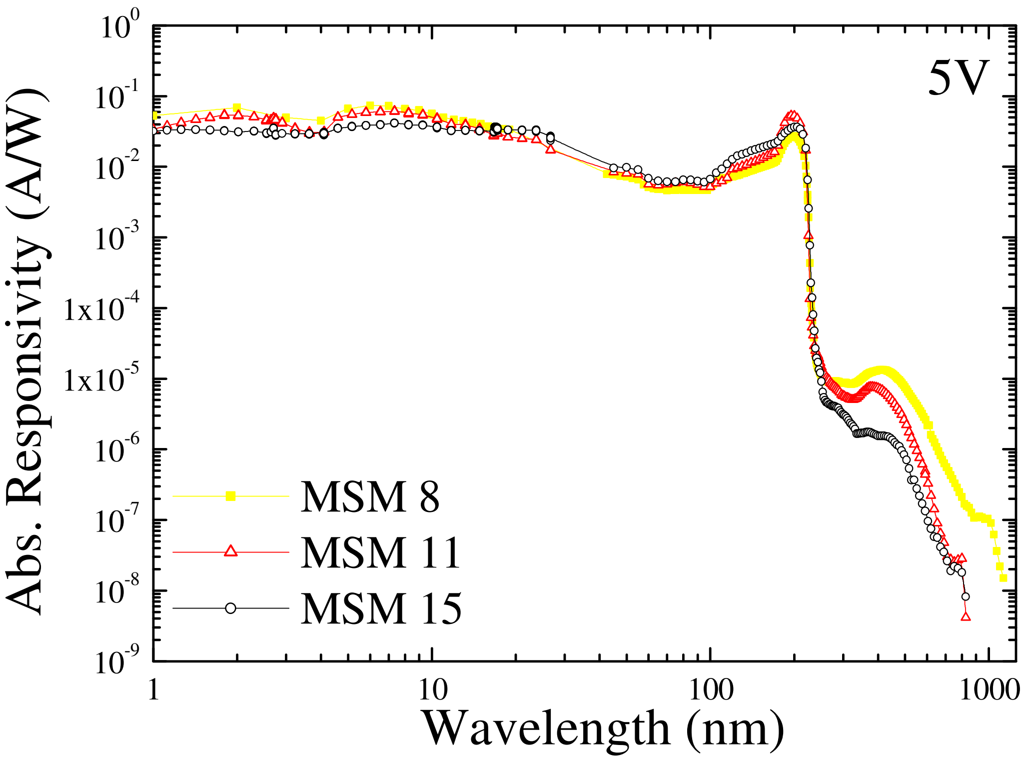


3 units
12 detectors
24 LEDs
…

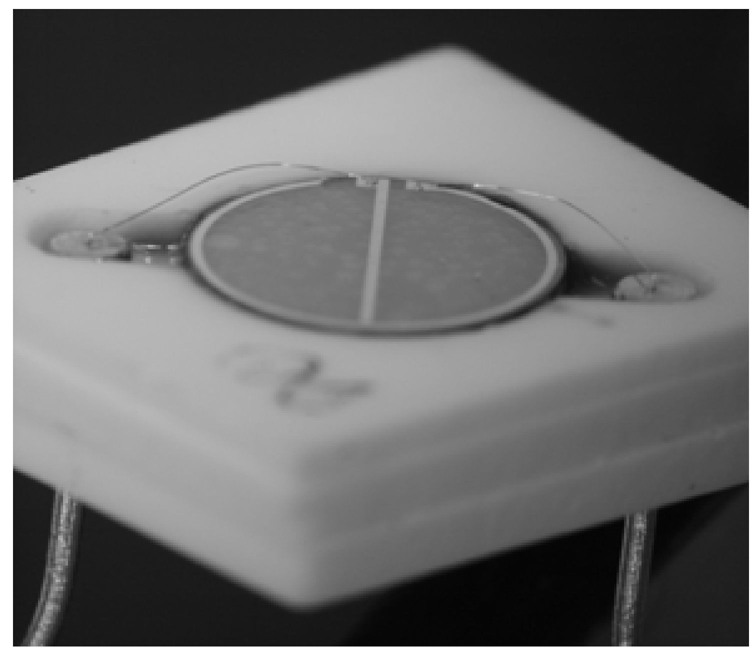


315.0 x 92.5 x 222.0 mm
~A4 size

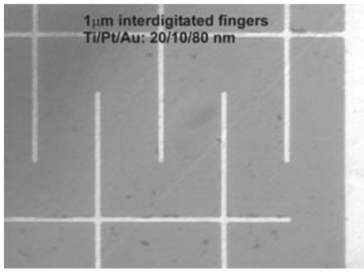
5.0 kg

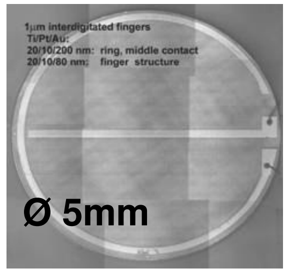


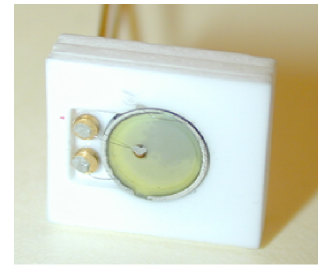
5V
Abs. Responsivity (A/W)
Wavelength (nm)
MSM 8
MSM 11
MSM 15

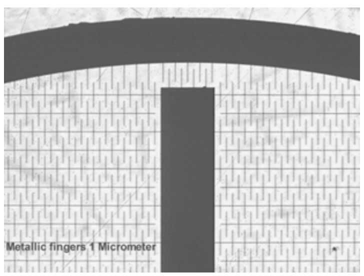


Solar blind diamond detectors









Ti/Pt/Au contacts – diamond MSM structures

diamond PiN sensor

Images: courtesy IMOMEC

IMOMEC, Belgium with the collaboration of the **National Institute for Materials Science** (NIMS), Japan.

MSM structures and PiN junctions, depending on the LYRA channel.

The collaboration between ROB and IMOMEC originates with the **BOLD** program (http://bold.oma.be) submitted to ESA.

LYRA contributes to demonstrating the feasibility of a technology that will be highly beneficial in the context of the **Solar Orbiter** ESA mission.

SWAP, off-axis EUV imager

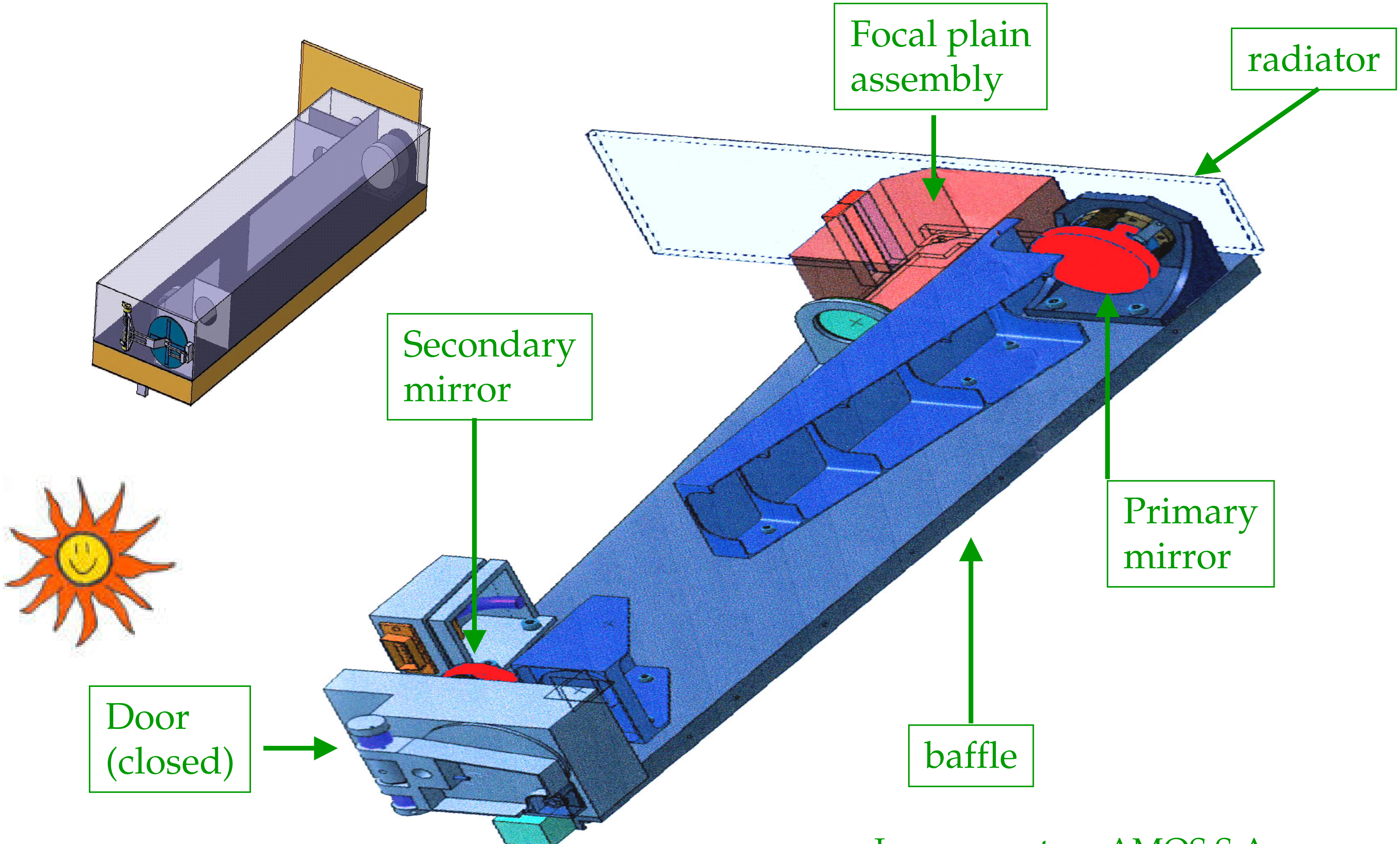
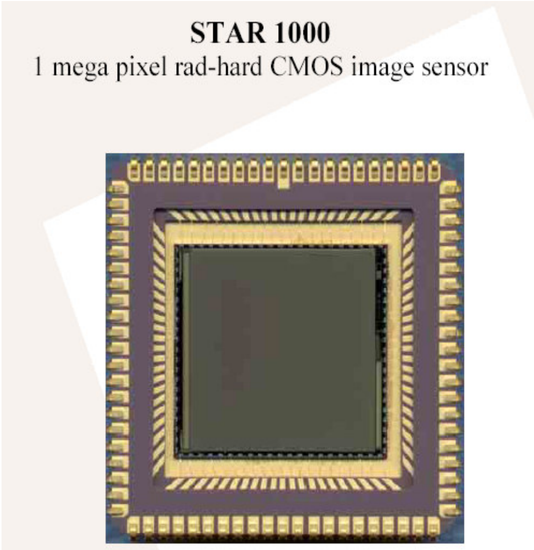


Image courtesy AMOS S.A.

Scintillator-coated APS detectors

Detection at 17.5 nm is critical
SWAP orbit is submitted to radiations (4 krad EOL)



- 12-bit readout
- 1 Mpixels 15 µm
- tolerant to > 230 krad
- QE x FF ~20 % (VIS)

APS CMOS from FillFactory (B)
with scintillator coating (EUV sensitivity)
and passive cooling (< -10°C)

Tests are conducted at PTB, BESSY with MPS to assess the performance at 17.5 nm of different scintillator coatings

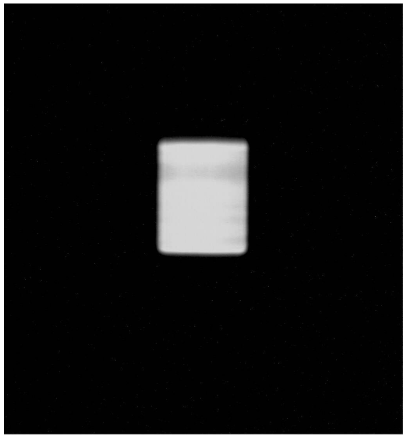
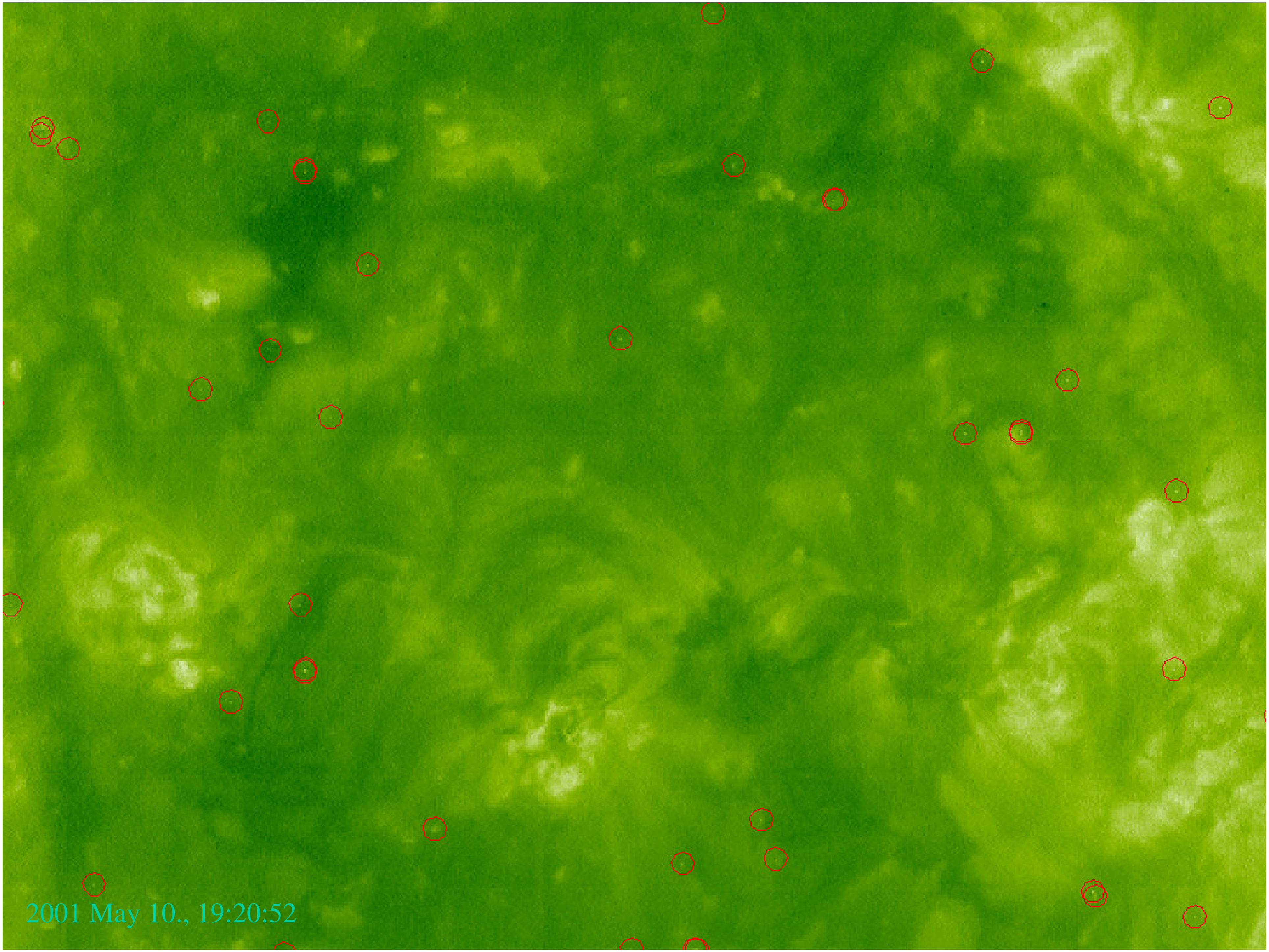
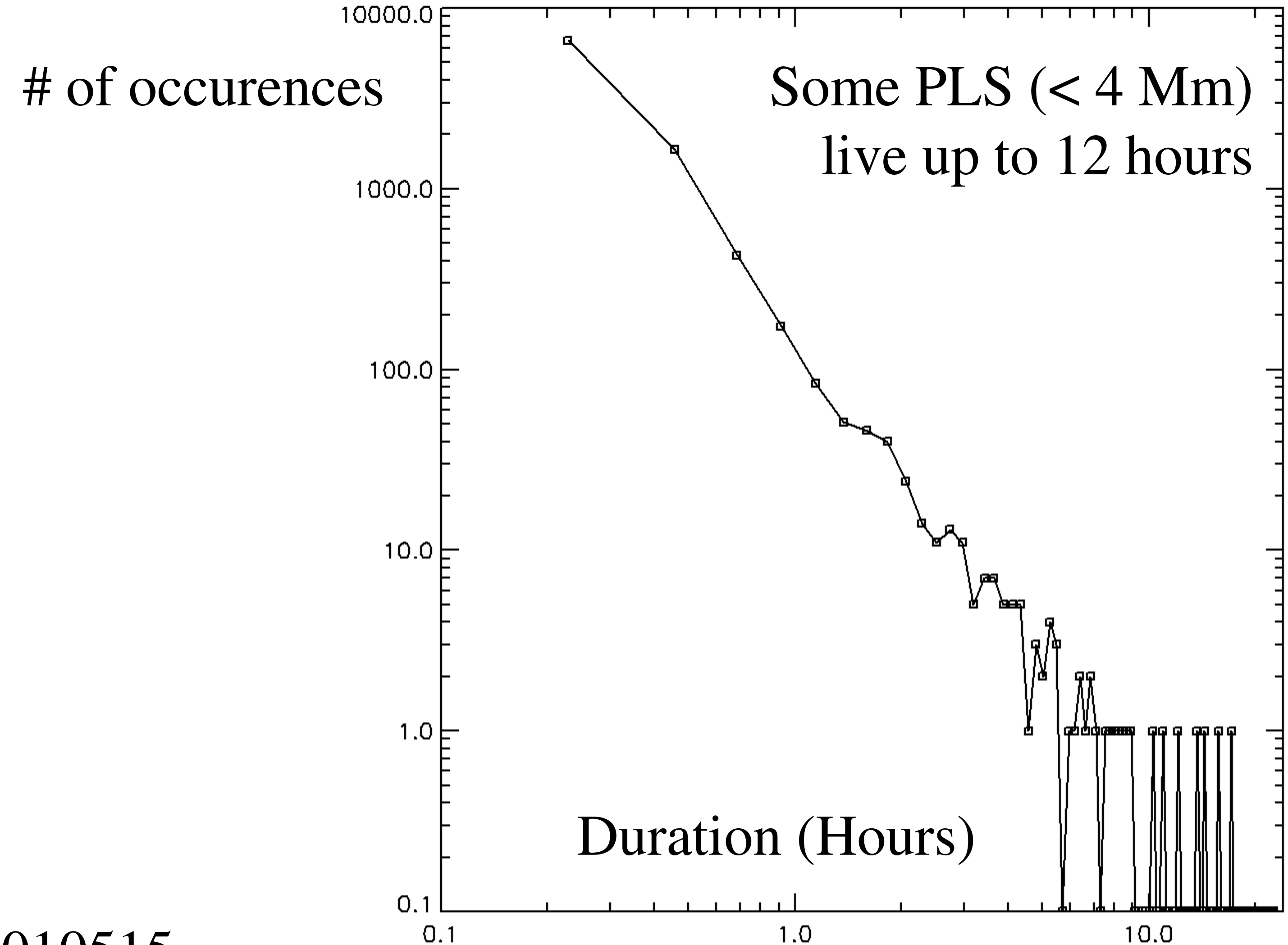


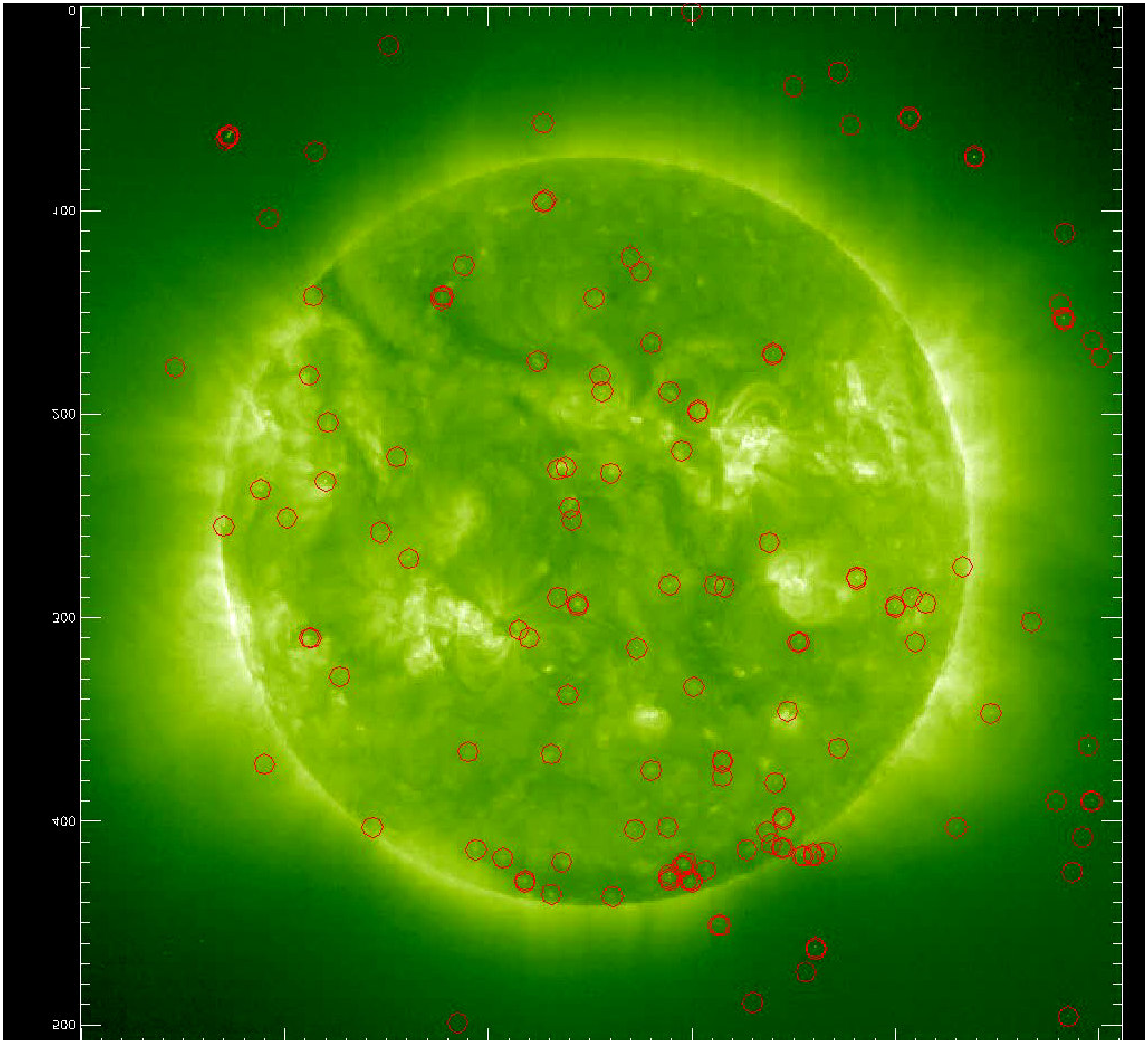
Image at 19.5 nm
in the collimated beam
at the PTB synchrotron
(Berlin)

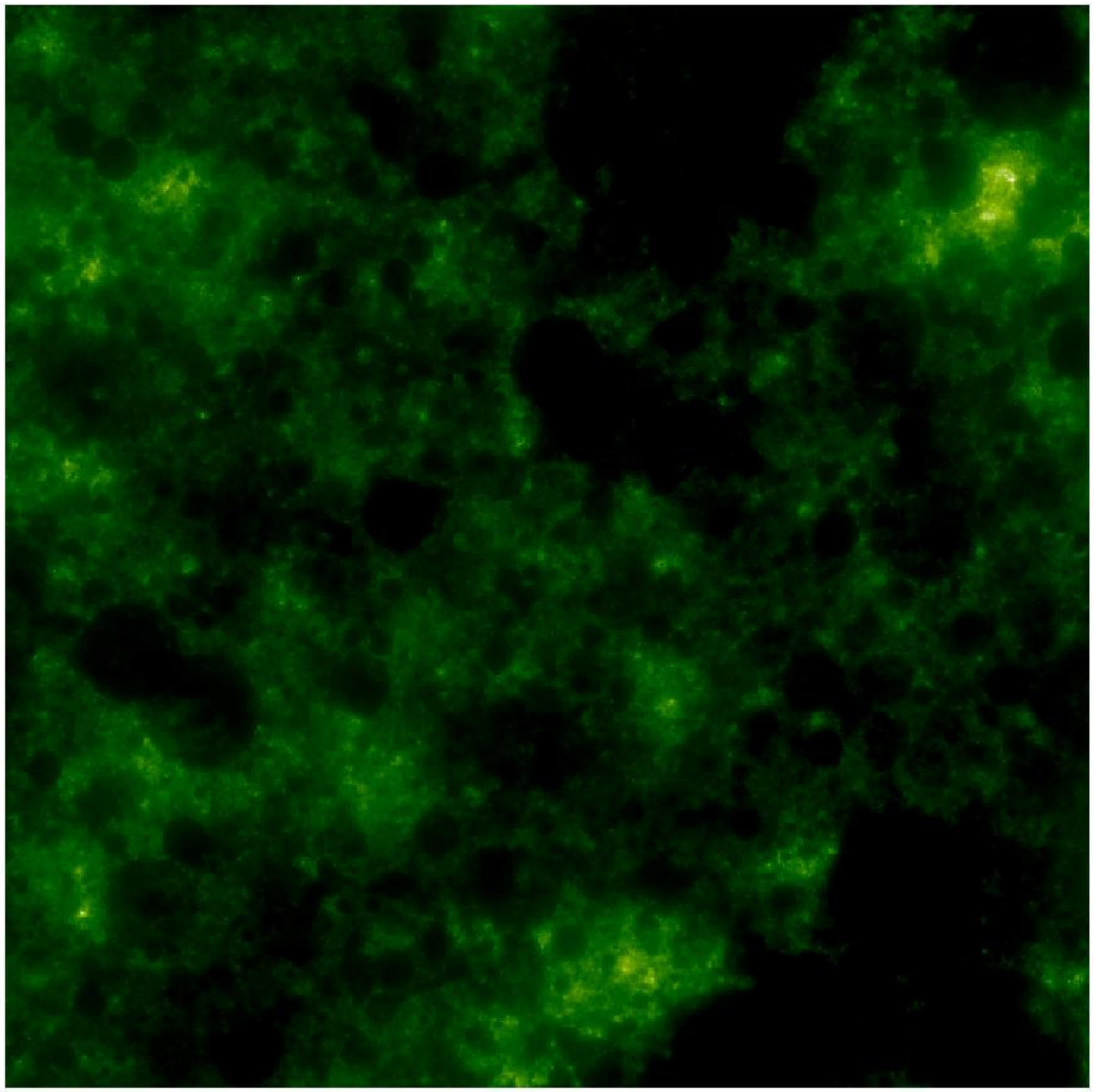

2001 May 10., 19:20:52

Lifetime distribution



20010515


0
100
200
300
400
500



Haecceity

ˌhaksēətēˌ

- ORIGIN mid 17th cent.: from medieval Latin ***haecceitas***, from Latin ***haec***, feminine of ***hic*** ***'this.'***

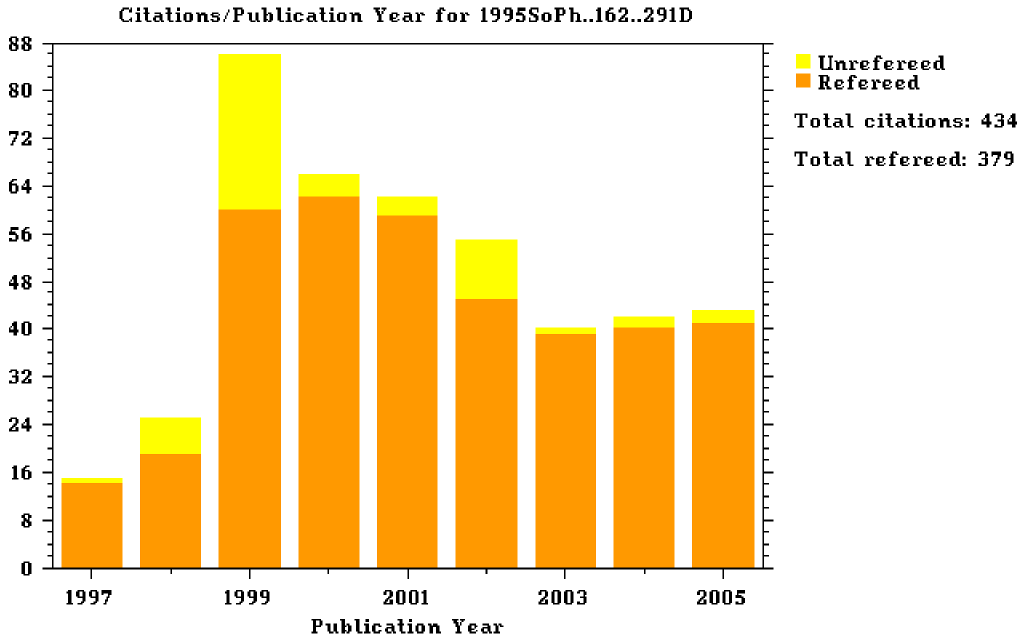
- that property or quality of a thing by virtue of which it is unique or describable as "this (one)."
- the property of being a unique and individual thing.
- Idiosyncrasy, nitty-gritty
- Quiddity
  - which also means hair-splitting…

Deleuze and Guattari's positive ontology *A Thousand Plateaus*

- It is the entire assemblage in its individuated aggregate that is a haecceity; it is this assemblage that is defined by a longitude and a latitude, by speeds and affects, independently of forms and subjects, which belong to another plane. It is the wolf, itself, and the horse, and the child, that cease to be subjects to become events.
- You will yield nothing to haecceities unless you realize that that is what you are, and nothing else. ... You are longitude and latitude, a set of speeds and slownesses between unformed particles, a set of non-subjectified affects.
- A haecceity has neither beginning nor end, origin nor destination; it is always in the middle. It is not made of points, only of lines. It is a rhizome…

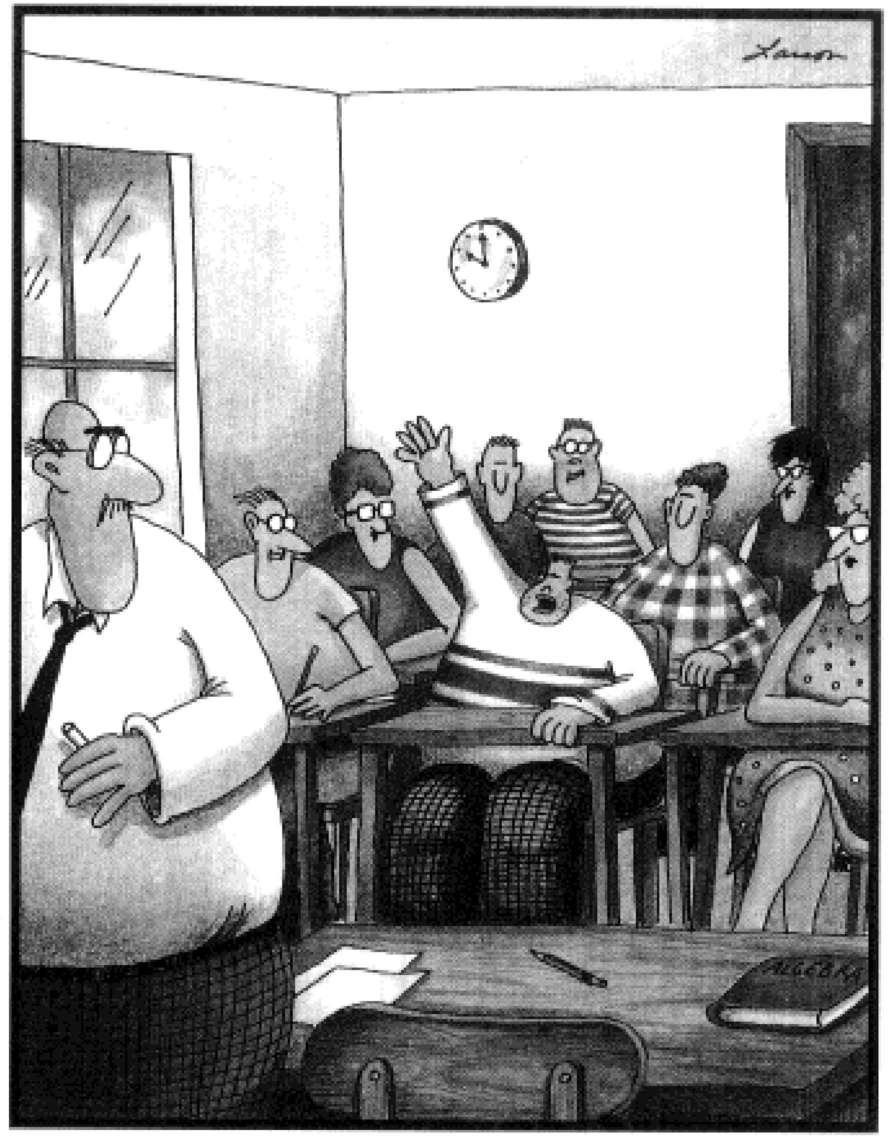
Haecceity of EIT

- EIT is a TIE in the Solar community
  - And Boudine is a bedoin
- EIT is a highly cited instrument



Boudine's idiosyncrasy

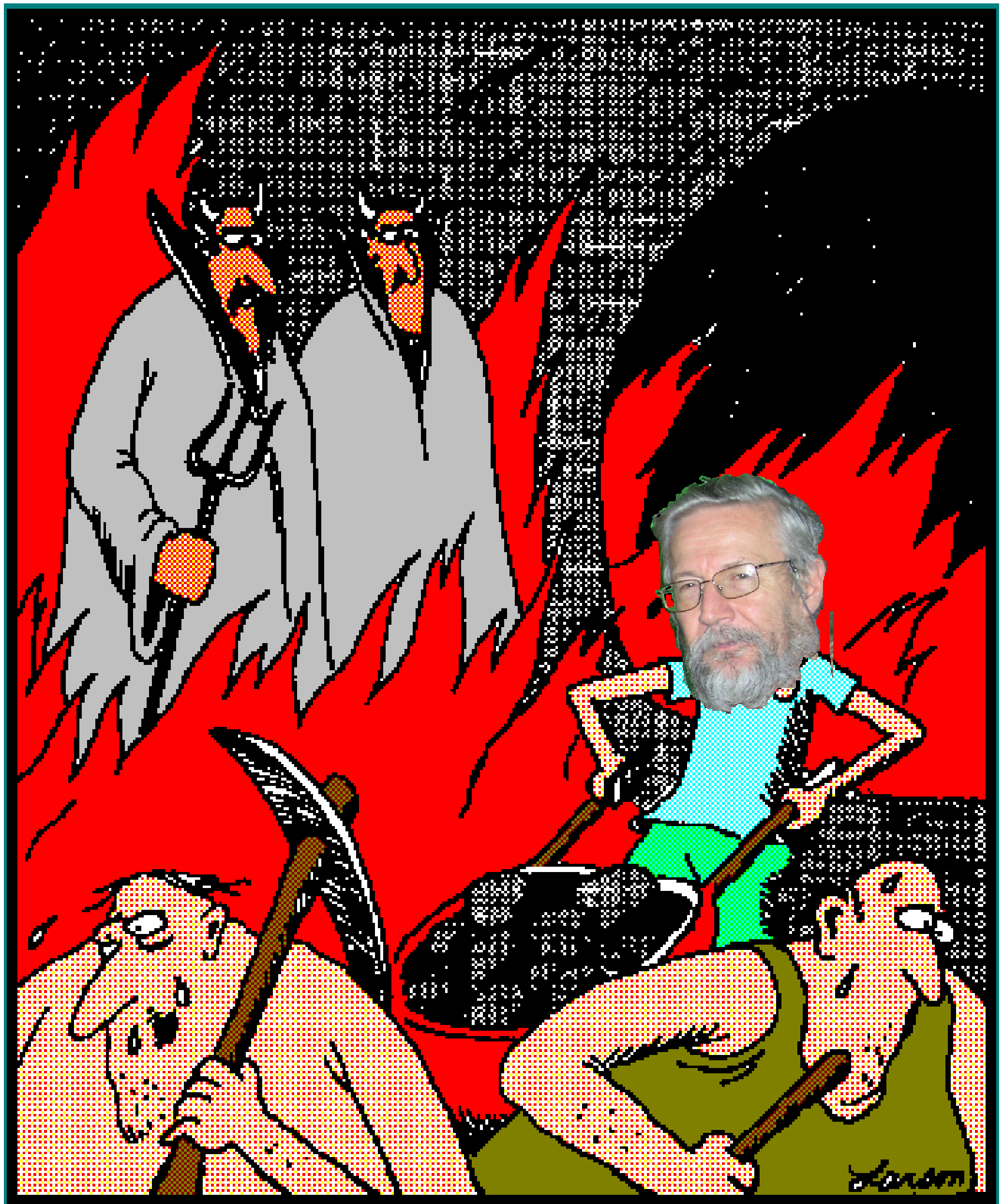
Serendipitous



"Mr. Osborne, may I be excused? My brain is full."

Boudine's idiosyncrasy

Bravery & tenacity

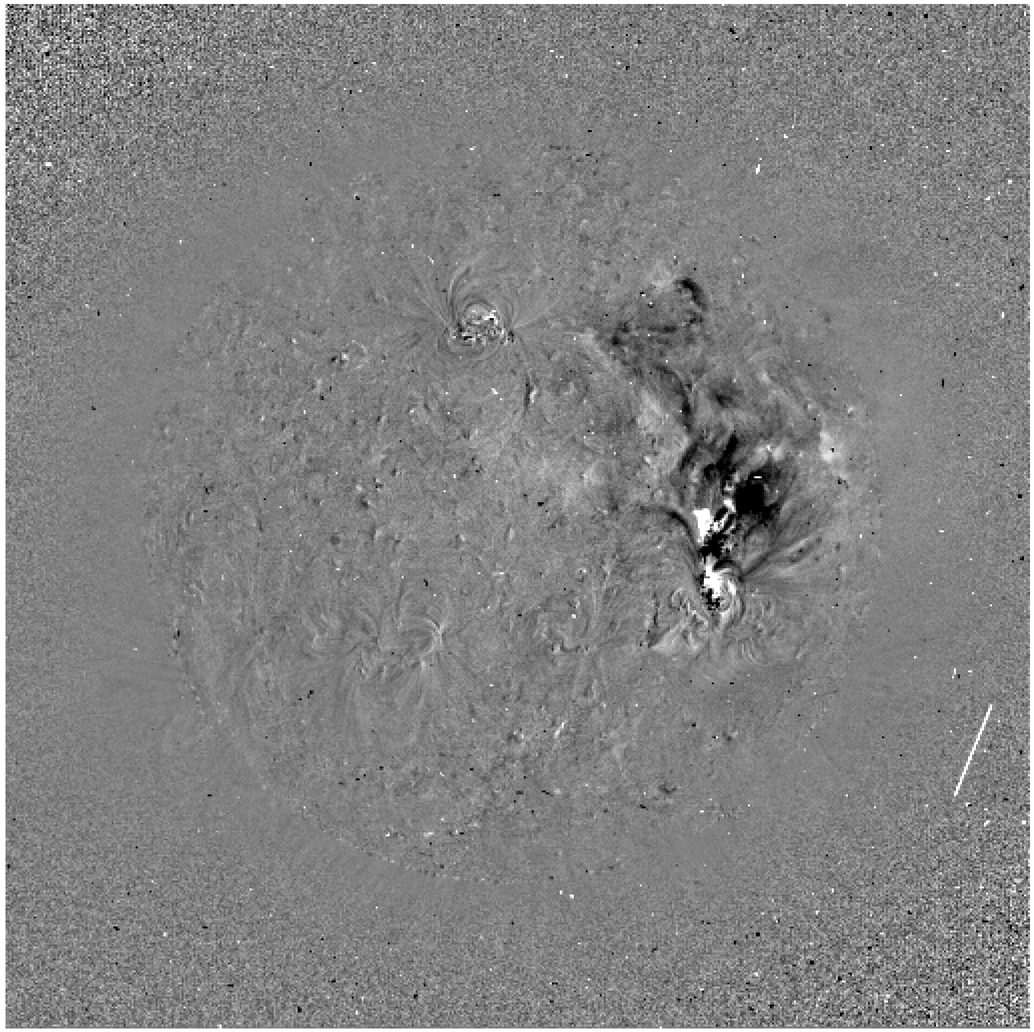


"You know we're just not reaching that guy."

Thank you Jean-Pierre

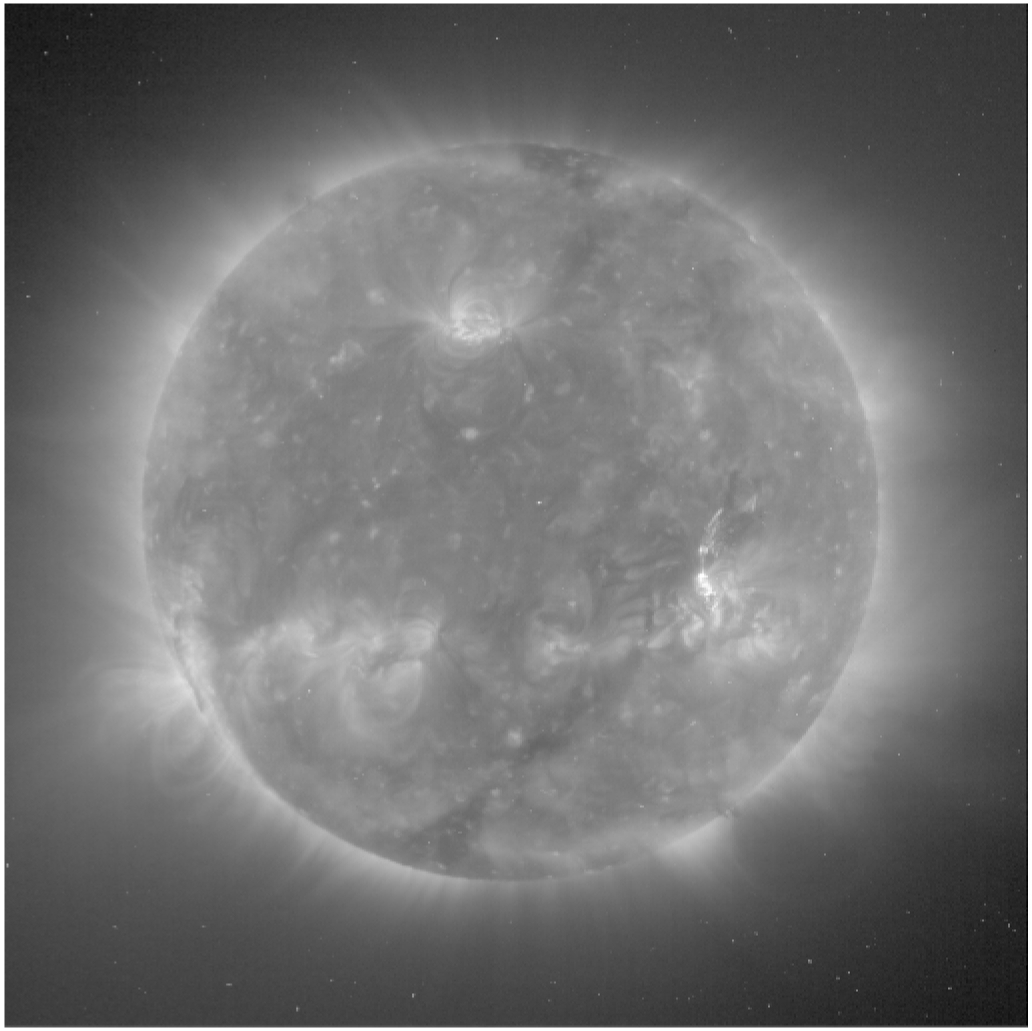
Gesundh.eit & tak.eit. Easy !

Difference image



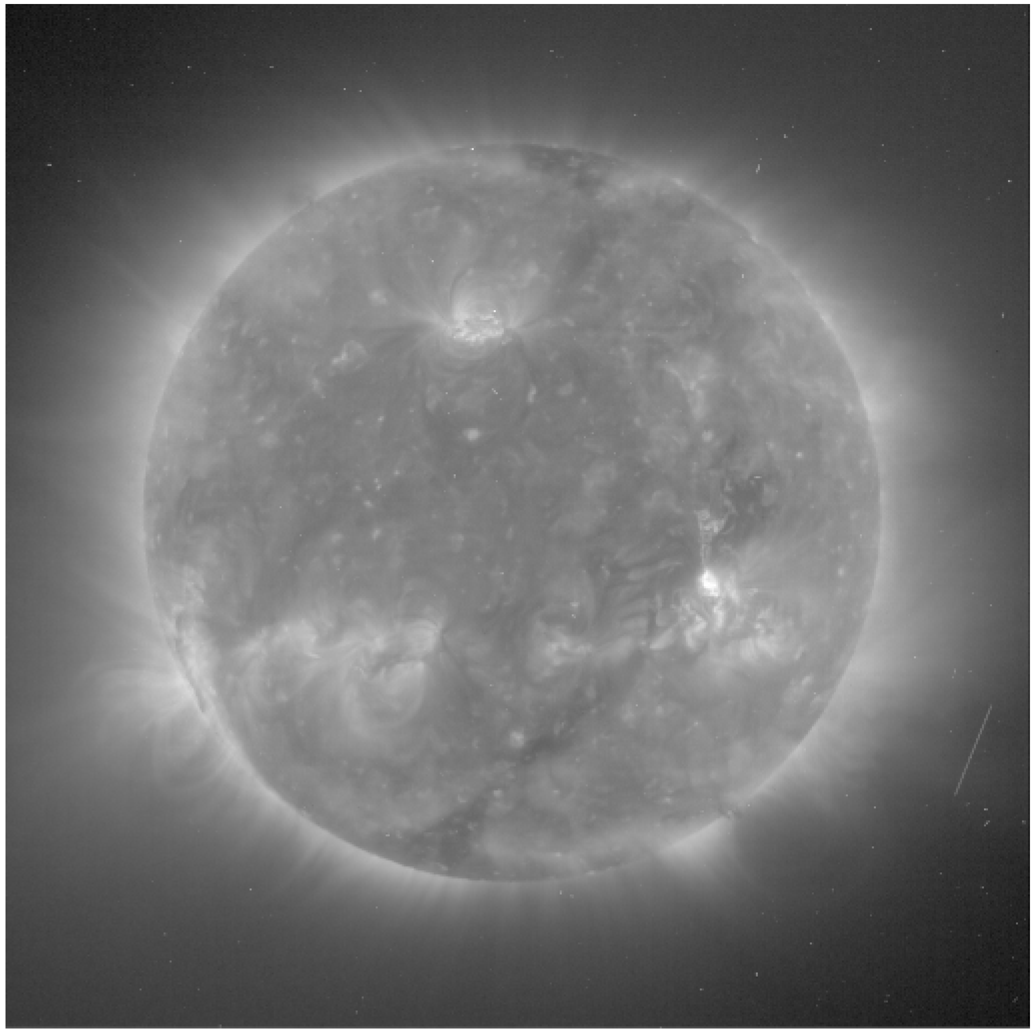
3 May 1998

EIT image #3



1998-05-03 21:22:37 (512x512 rebinned)

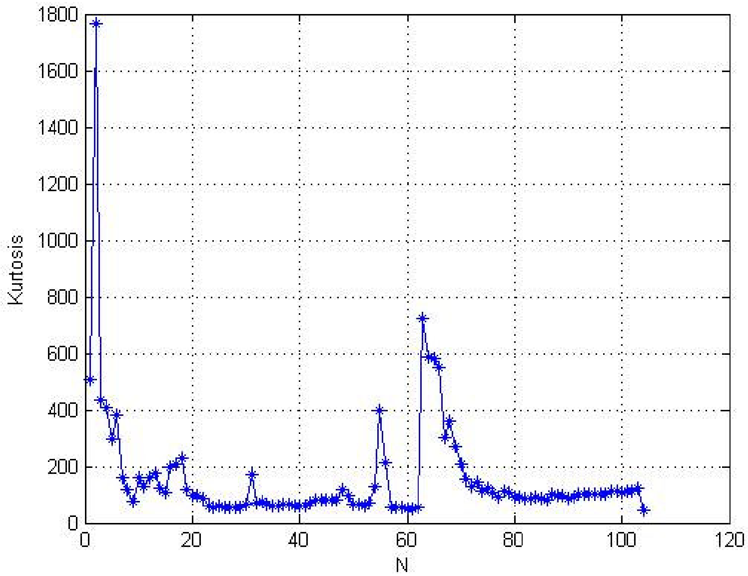
EIT image #2



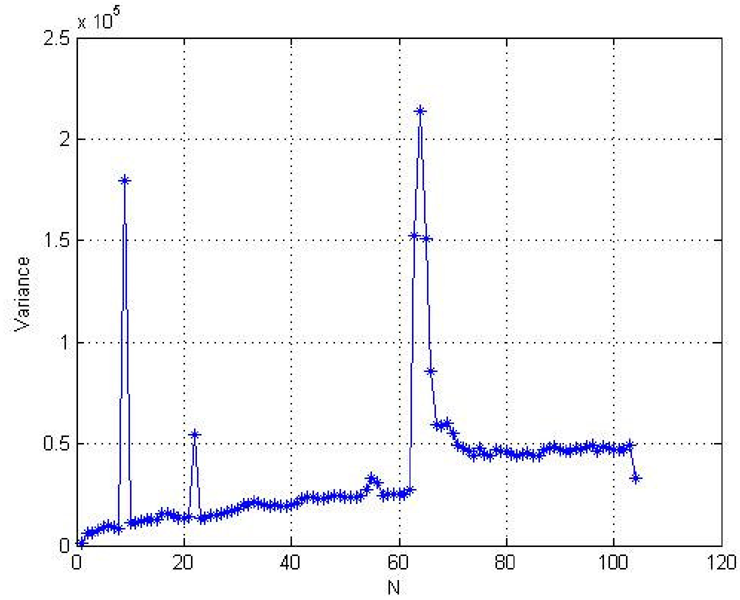
14 minutes later

12 May, 1997

PDF Kurtosis



PDF Variance



Courtesy of Podladchikova & Berghmans