Temporal Evolution of the Convection in Sunspots Penumbrae

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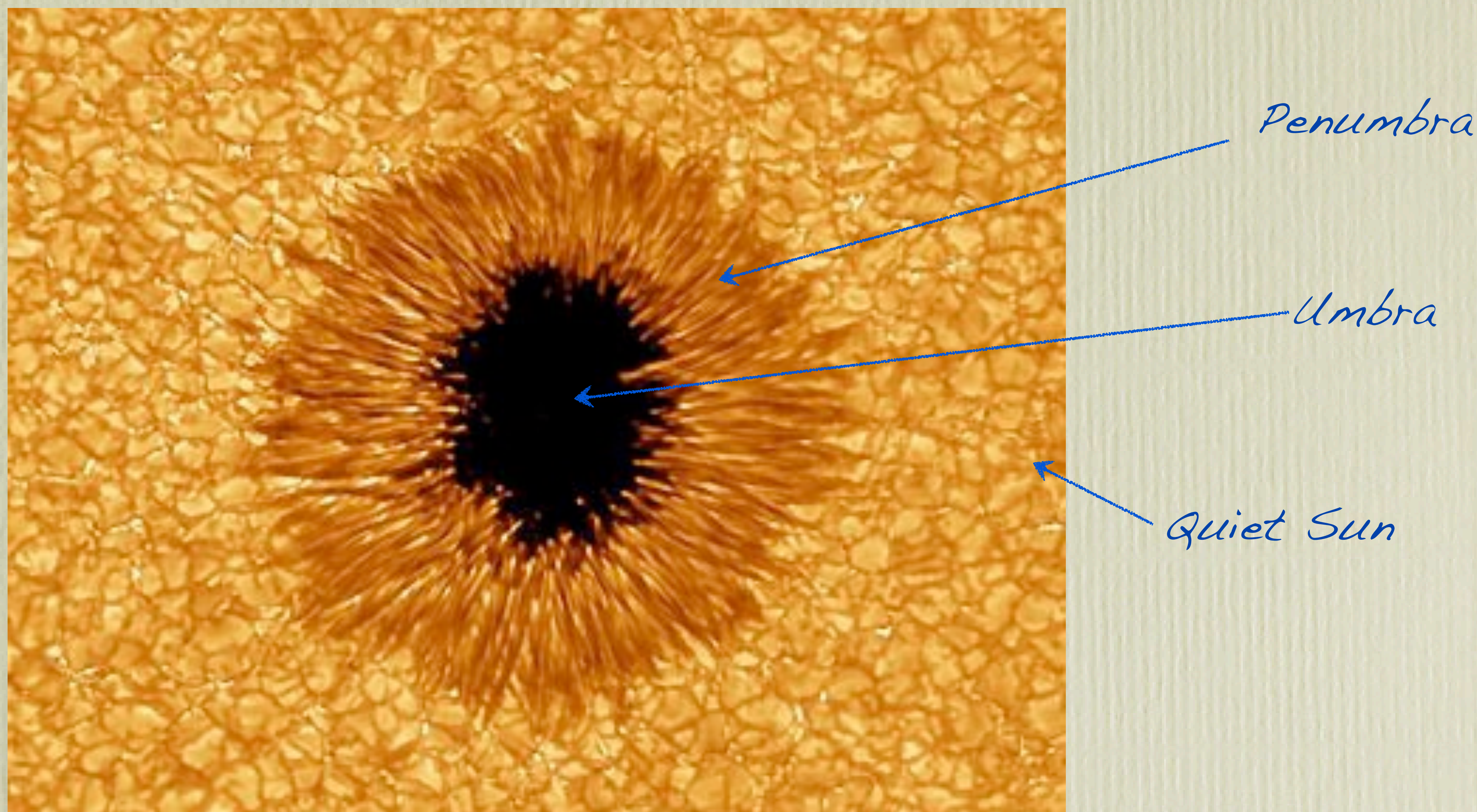
What am I going to talk about?

- Sunspots and the problem of the penumbral heating
- Observations
- Analysis
- Results

Sunspots and the problem of the penumbral heating

Sunspots are the most observable manifestation of the solar magnetic field.

Magnetic flux tubes rise through the convective zone and appear at the solar surface.



Observatory of Big Bear.

Sunspots and the problem of the penumbral heating

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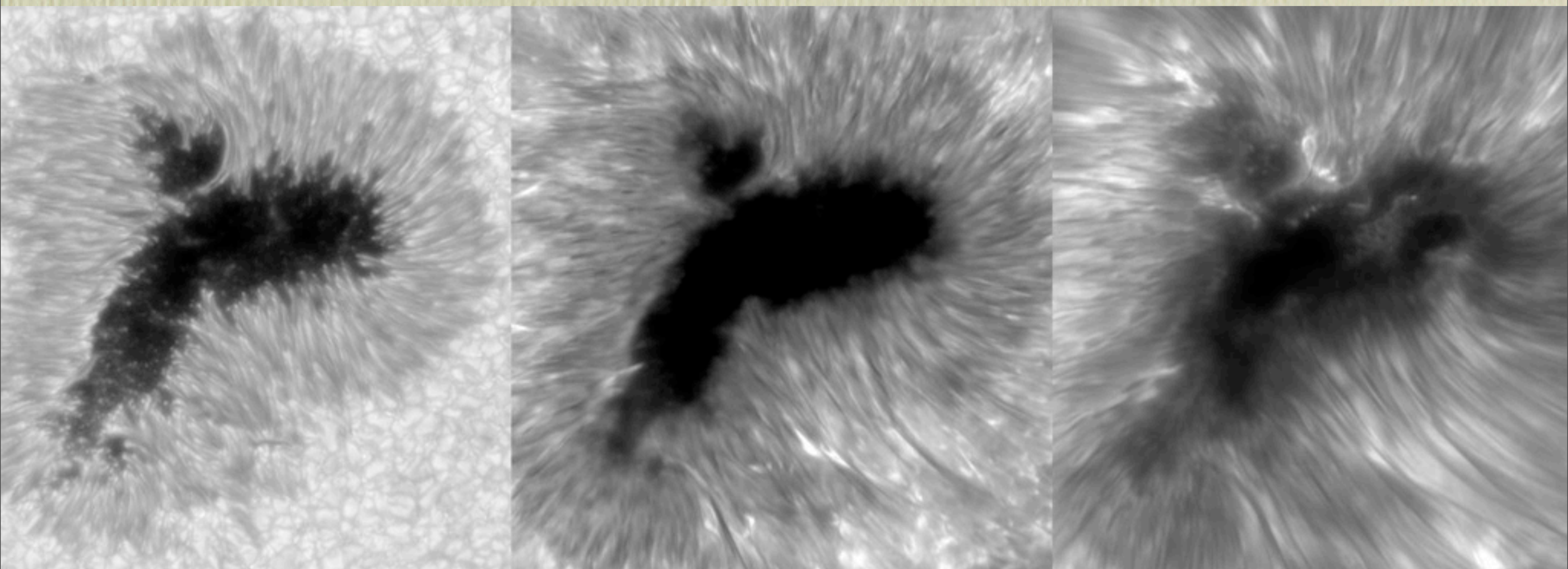
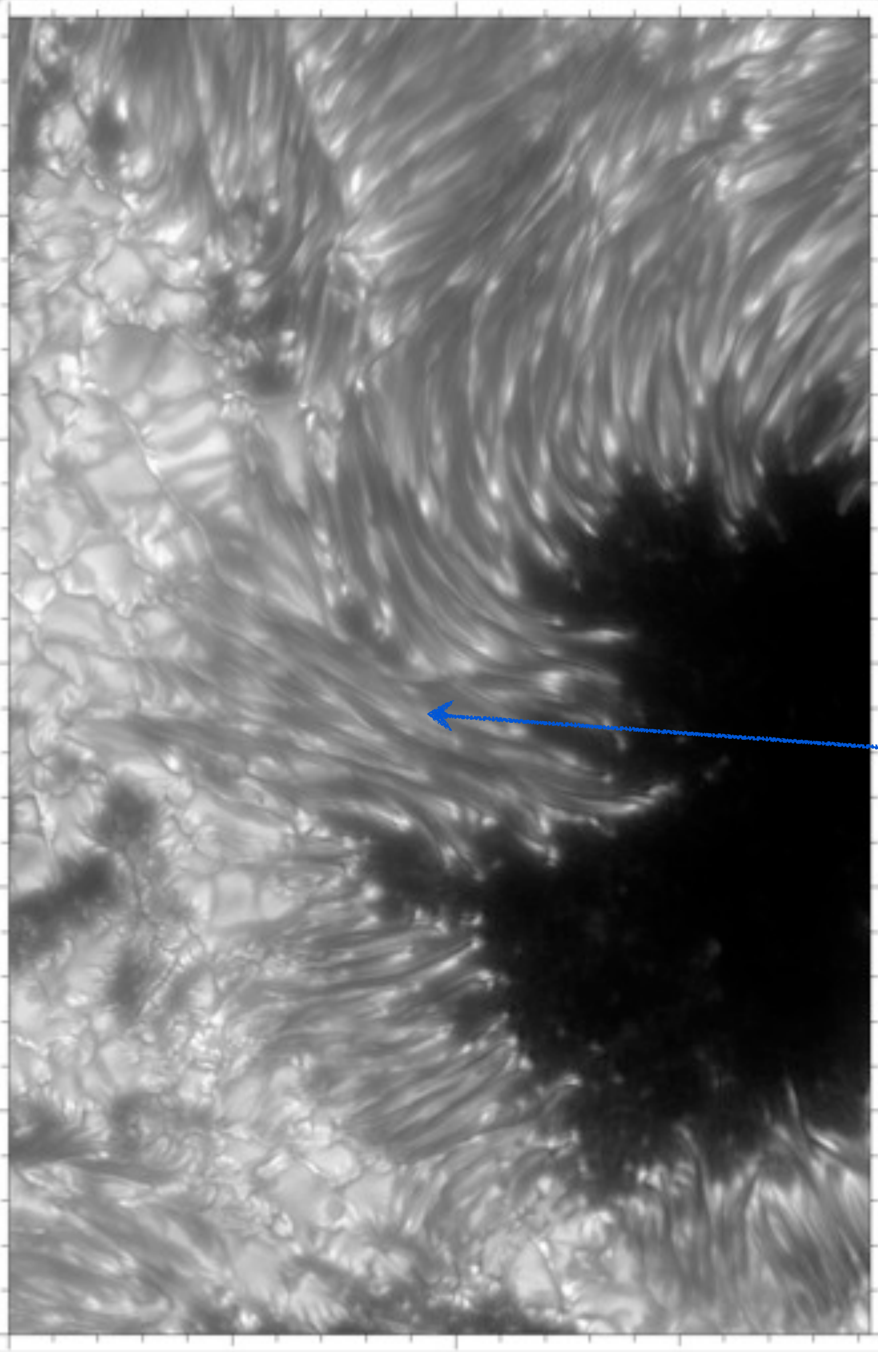


Photosphere
Fe I 6173Å

Upper Photosphere
H-alpha 6563Å

Chromosphere
Ca II 8542Å

Sunspots and the problem of the penumbral heating



Scharmer et al. (2002)

Penumbra: Radial distribution of bright and dark filaments.
Length: 3000-4000 km
Width: 150 km
Duration: 1 or 2 hours

Penumbral filaments

Bright edges + Dark core = Penumbral filament

According to the penumbral magnetic field, **convection should be limited... but the brightness of the penumbra is as much as 75 % of quiet Sun brightness.**

Sunspots and the problem of the penumbral heating

Evershed (1909)

Redshifts in the **limb-side**.
Blueshifts in the **center-side**.

"...an accelerating movement from center to the sunspot outwards. At the outer limit it suddenly dissapear."

Could the **Evershed flow** be associated with the **enhanced brightness** of the penumbra?

Sunspots and the problem of the penumbral heating

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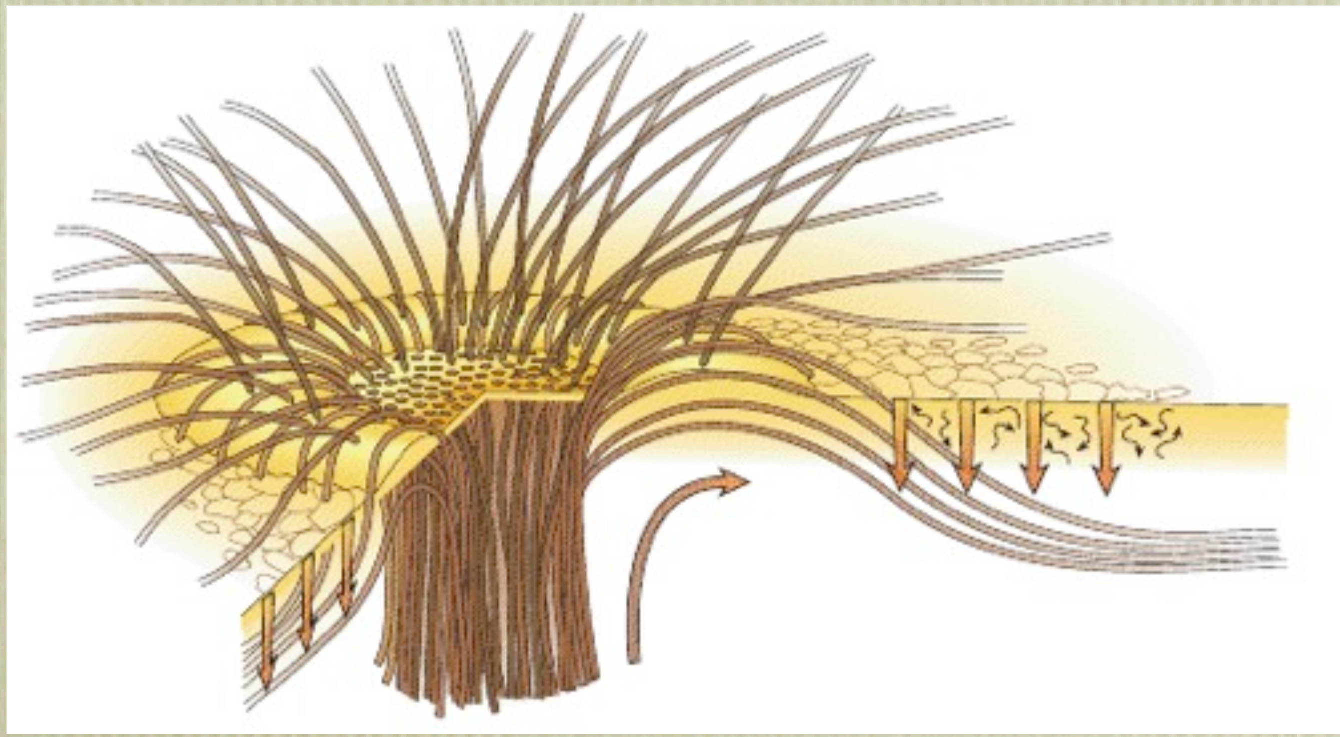
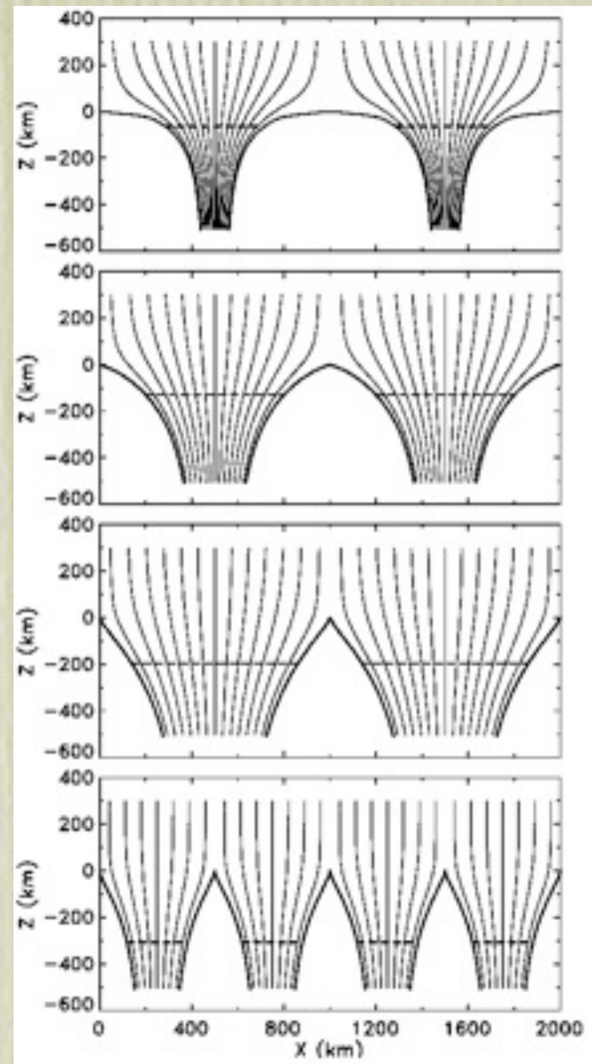
Theoretical **Models**...

Flux-tube Models...



Gappy Penumbra Model...



Sunspots and the problem of the penumbral heating

Theoretical **Models**, 3-D **Simulations** MHD, **Observational** Effects... **What is happening??**

Sunspots and the problem of the penumbral heating

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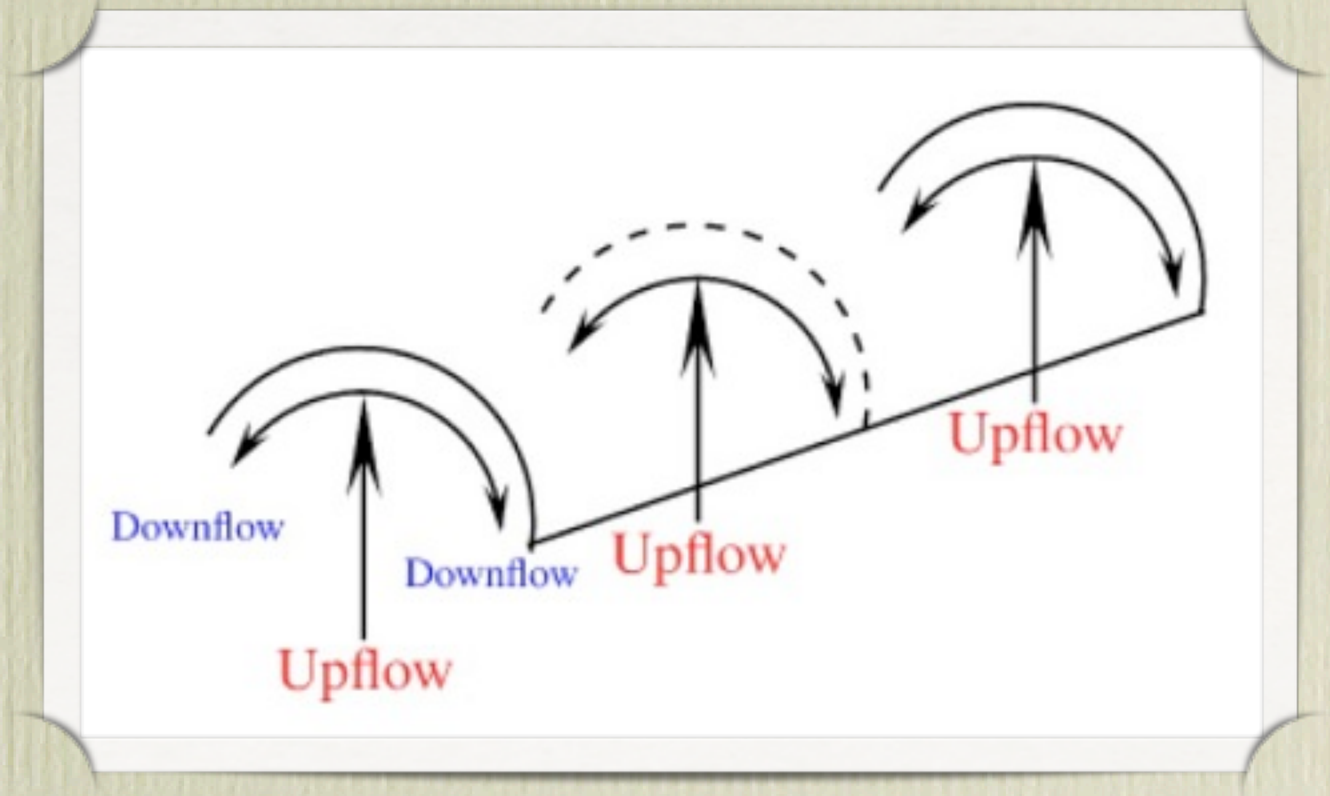
CONVECTIVE MOTIONS!

- Upflow and Final Downflow
(e.g., Bellot Rubio et al. 2004, 2010, Franz & Schlichenmaier 2009...)

- Lateral Downflows??
(Scharmer et al. 2011, Joshi et al. 2011...)



Borrero & Ichimoto (2011)

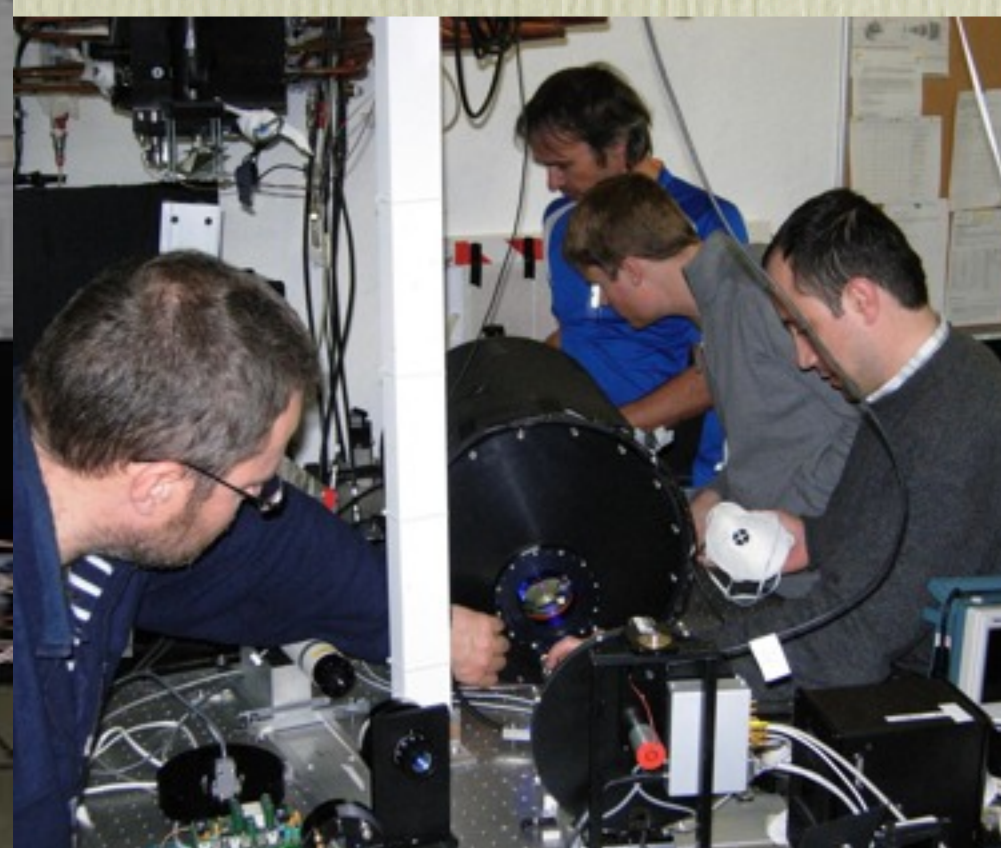
- ***What is the Behaviour of the Lateral Downflows?***
- ***New!!: Using Temporal Sequences of High-Resolution Spectropolarimetric Data.***

- ***How is their Velocity Field??***
- ***How can we Interpret them??***

Observations

CRISP spectropolarimeter at the **Swedish Solar Telescope (SST)**

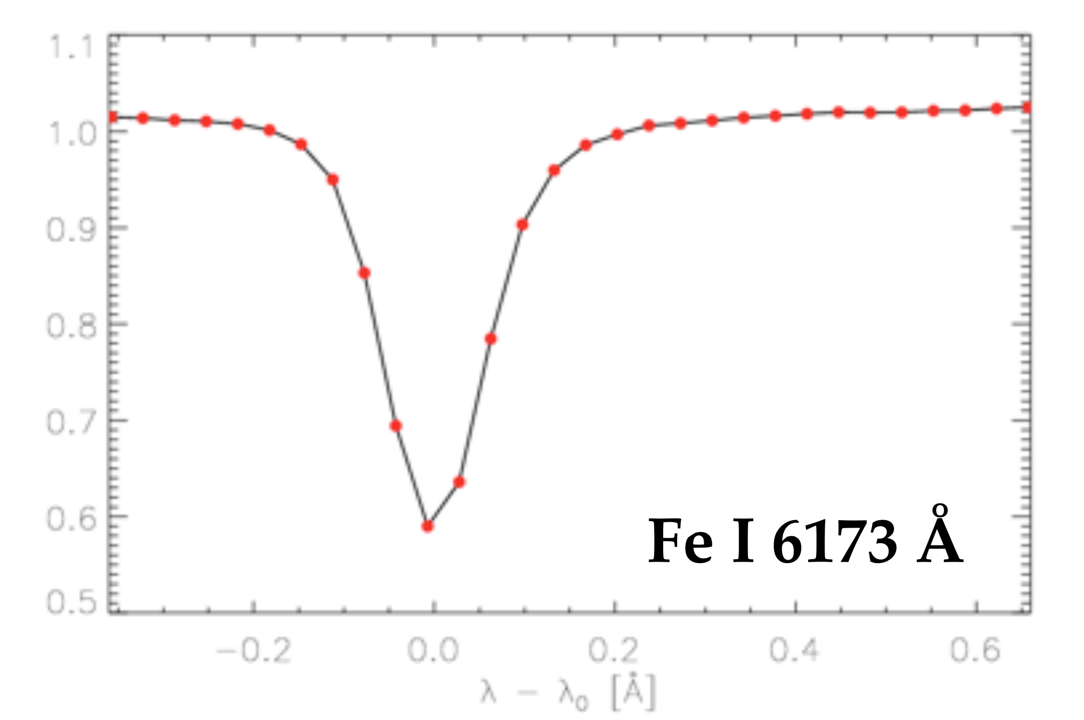
The SST offers the best spatial resolution observations (0.1″ ~ 71 km) from ground.

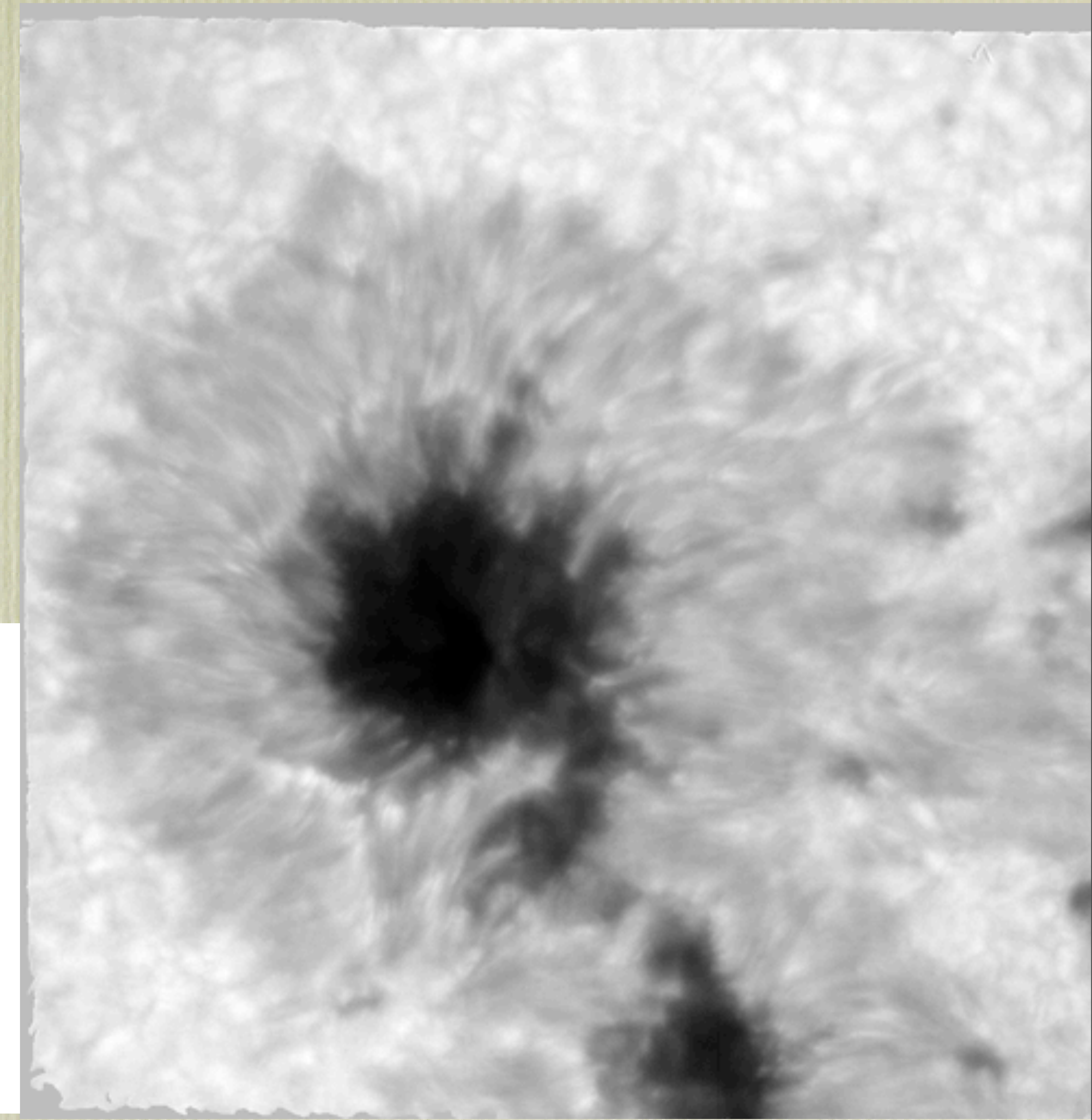


Observations

Date: 2011.09.28
Hour: 09:18:00
Active Region: AR 11302

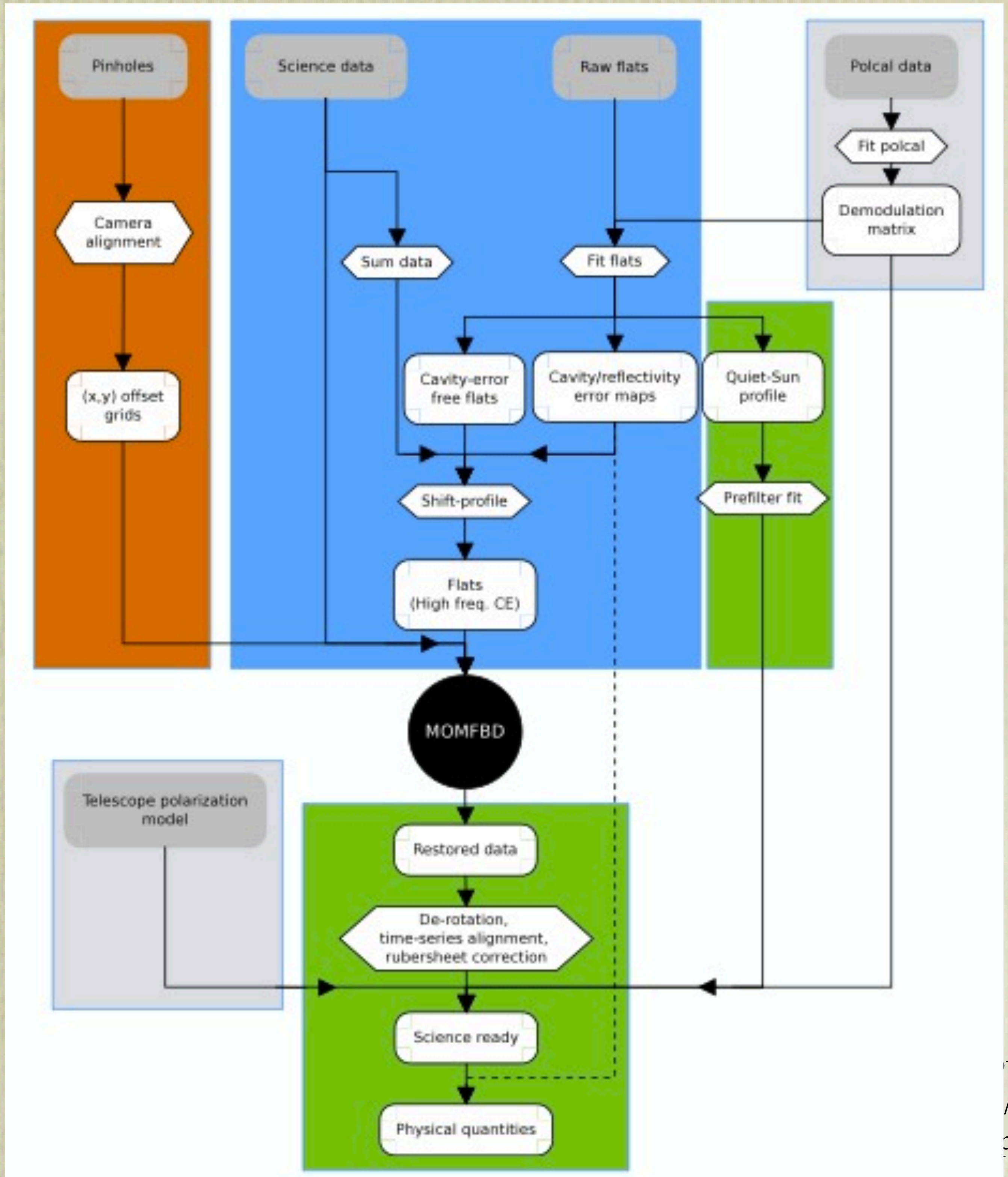
Heliocentric Angle: ~ 7º
Field of view: 58″ x 57″
Cadence: 32 s





Observations

MOMFBD Reconstruction Technique
(new **CRISPRED** pipeline)



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Observations

MOMFBD Reconstruction Technique (new **CRISPRED** pipeline)

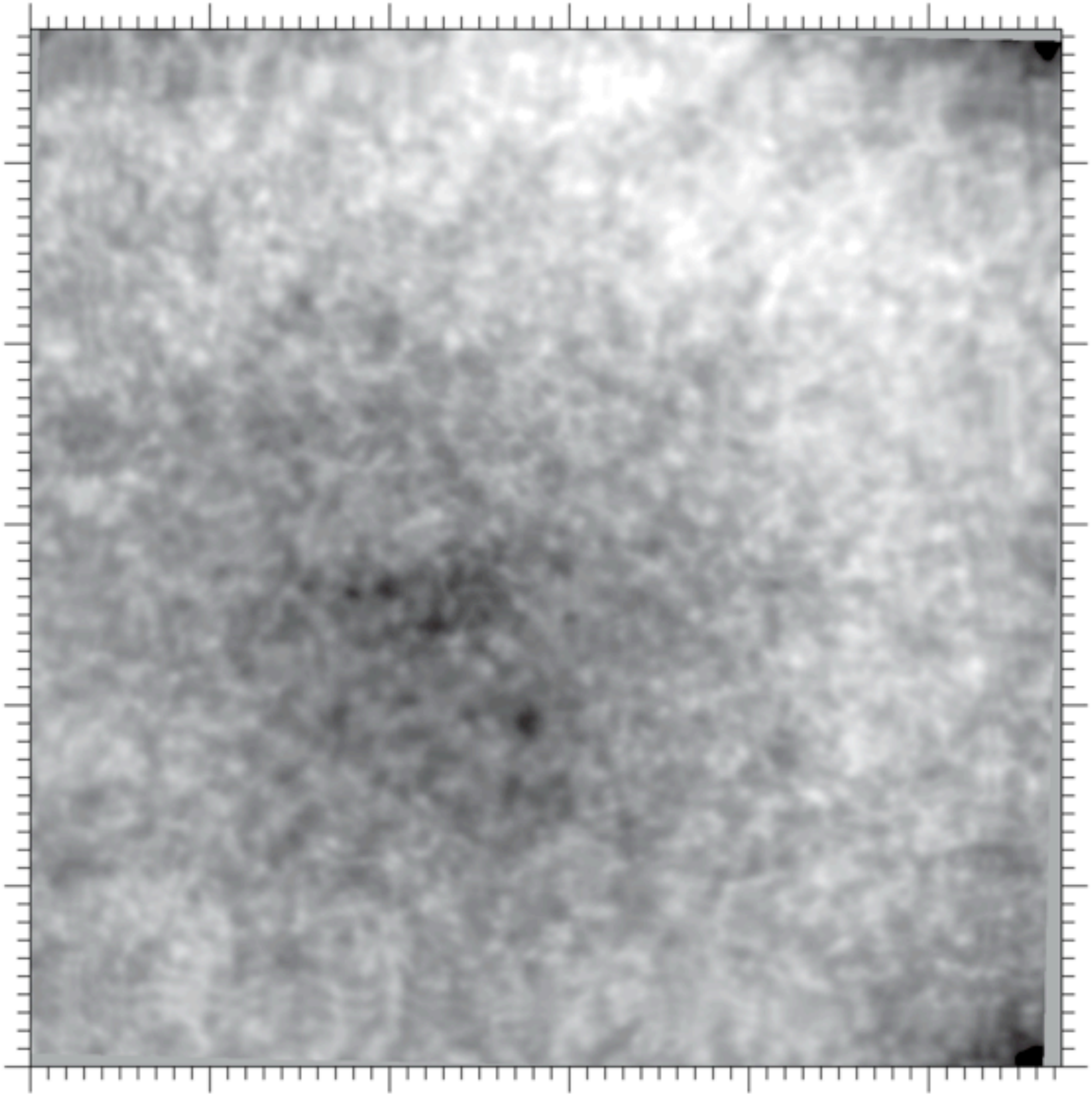
CRISP's Telecentric Configuration

↓

Imperfections at the surface of the etalons: Wavelength's shifts

↓

Cavity Errors



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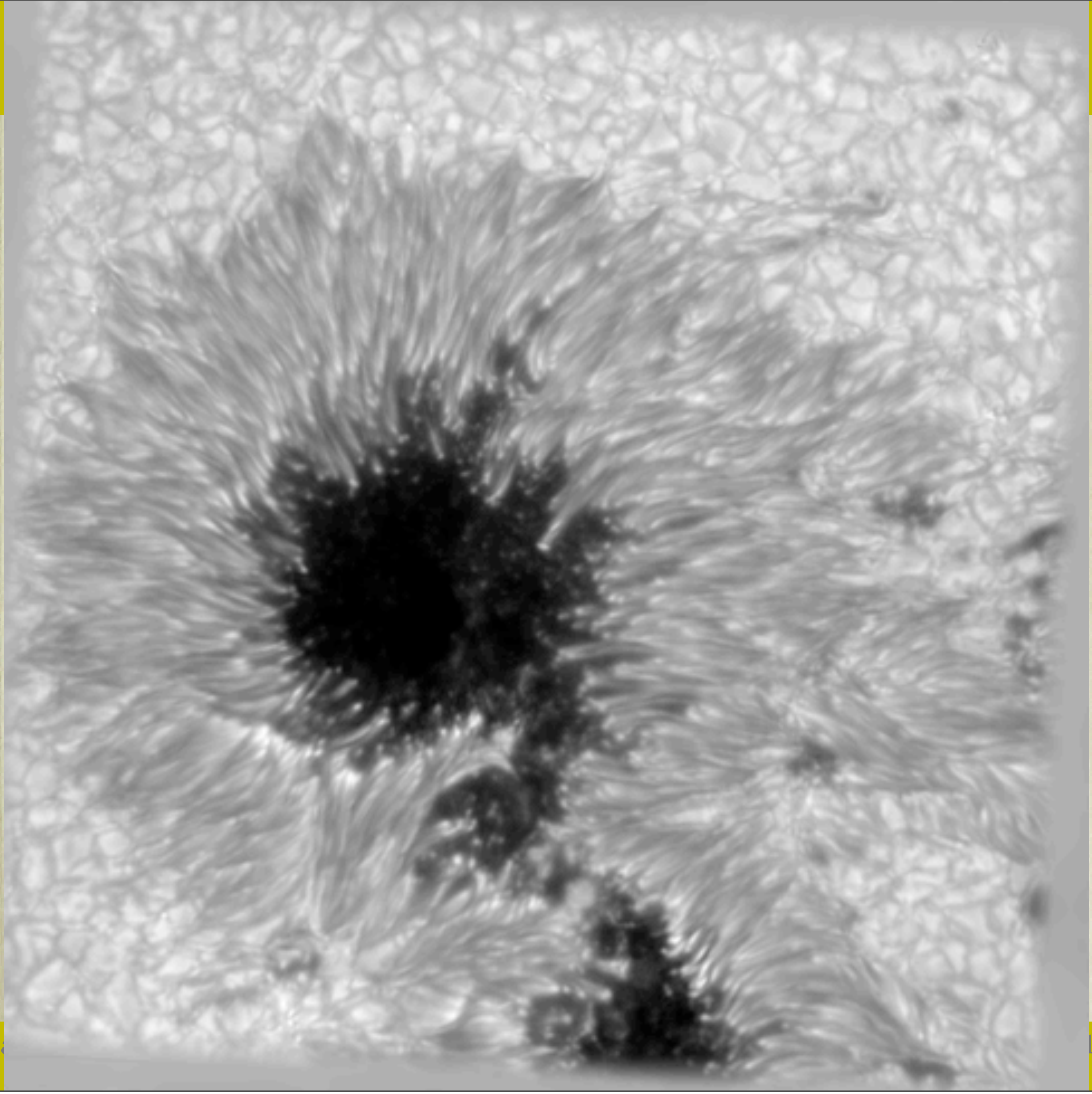
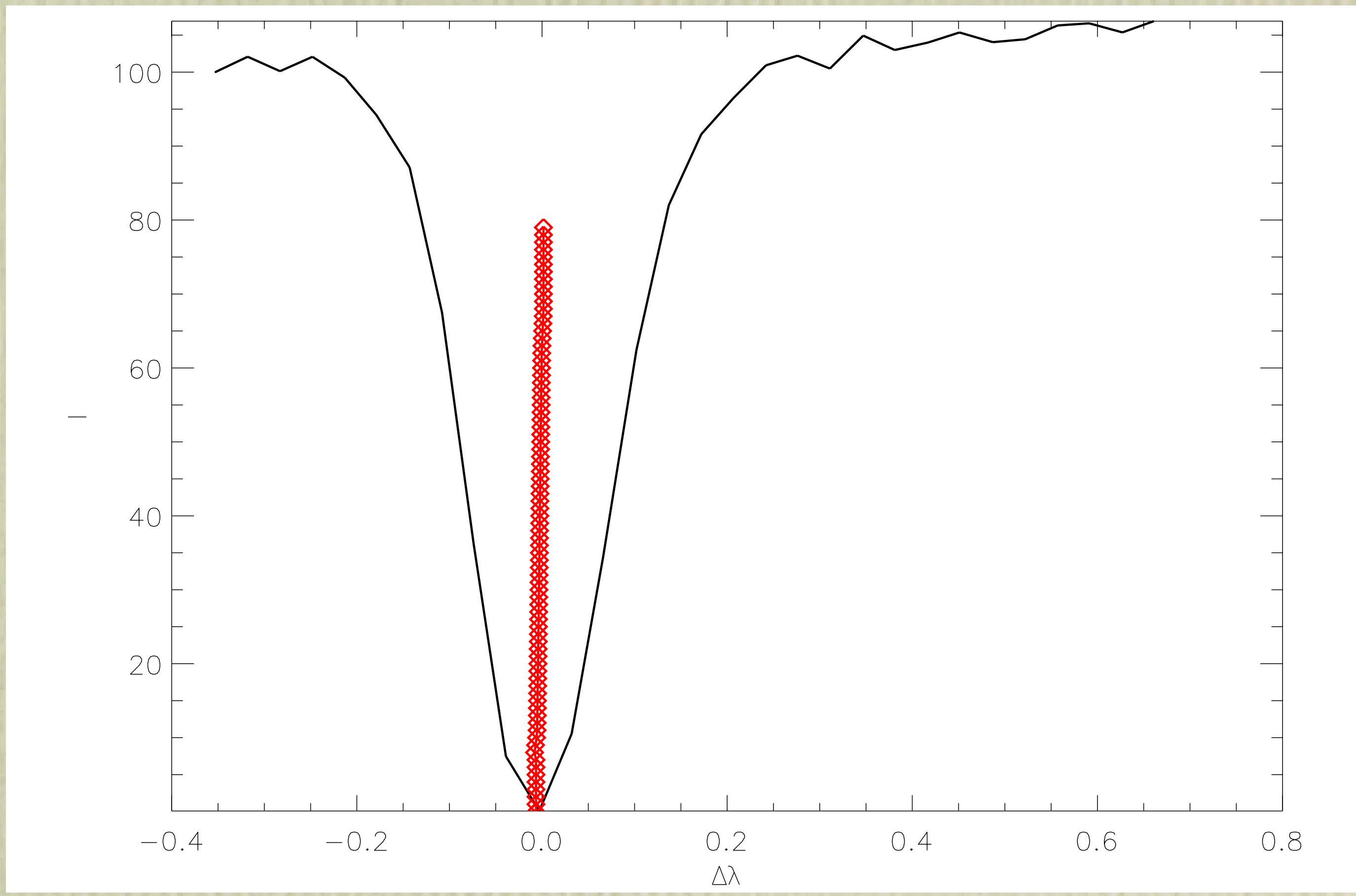


Analysis

LOS velocity calculated following the Bisector technique (linear interpolation)



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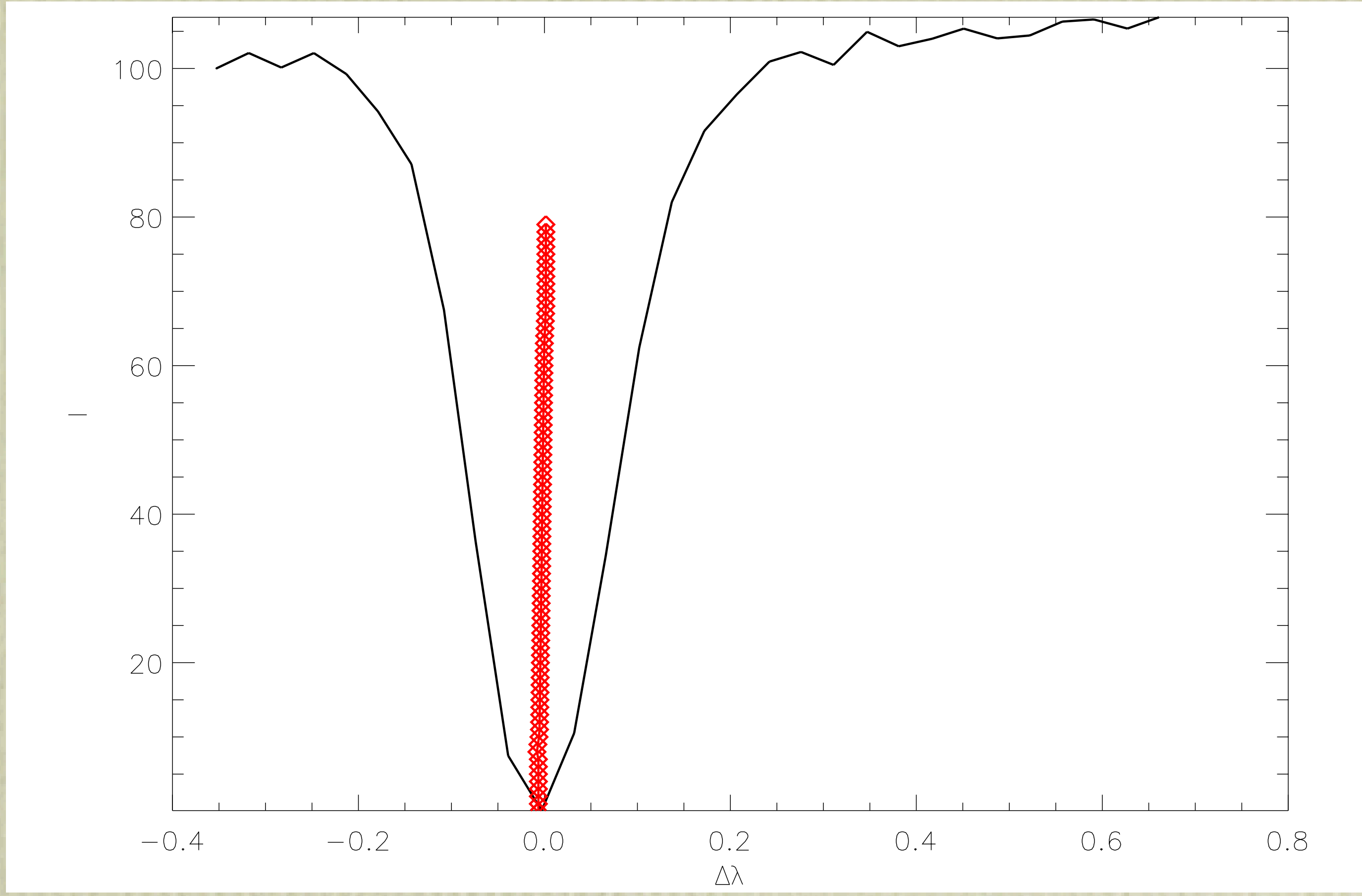

Subsonic oscillations are filtered

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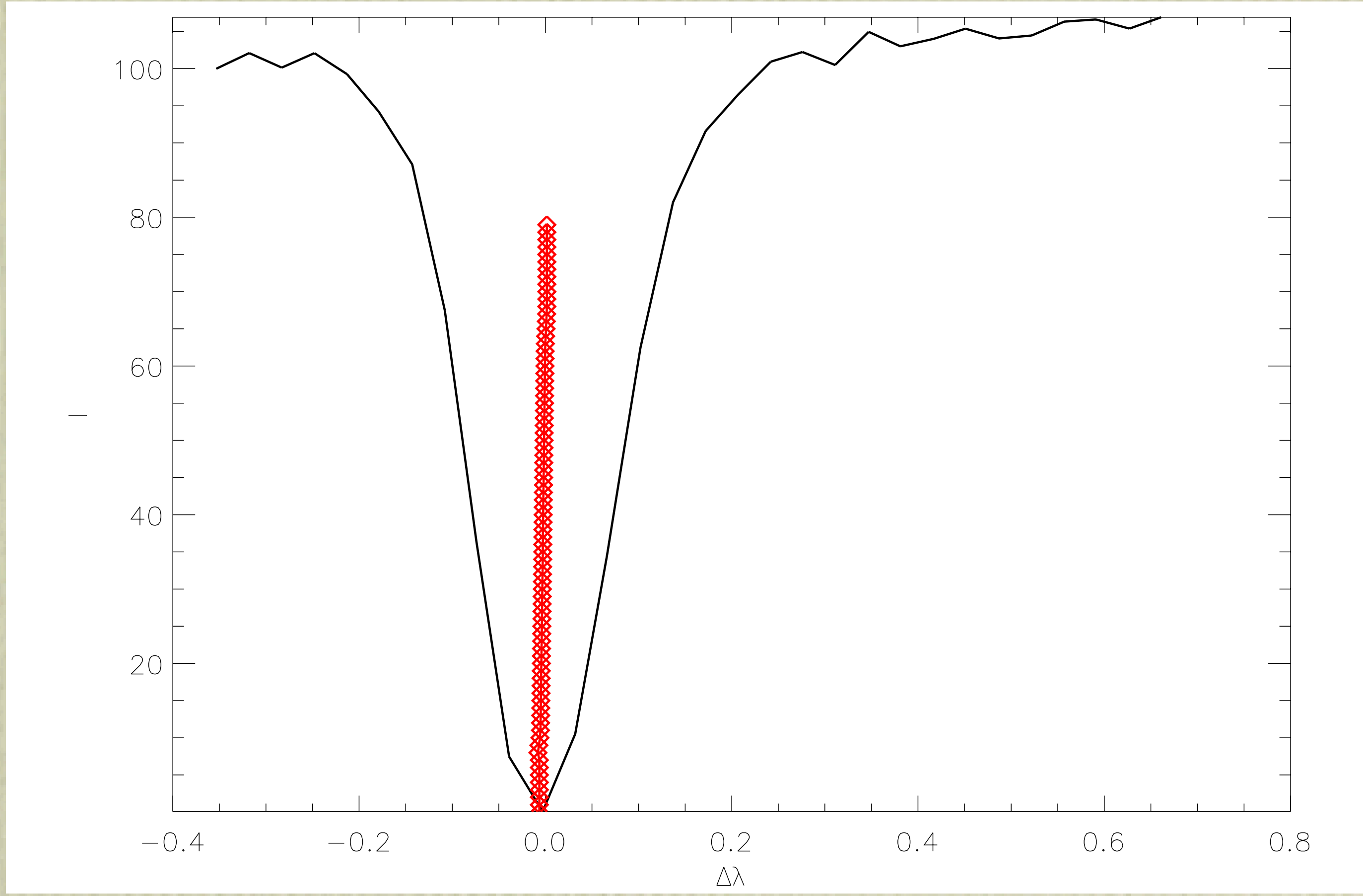
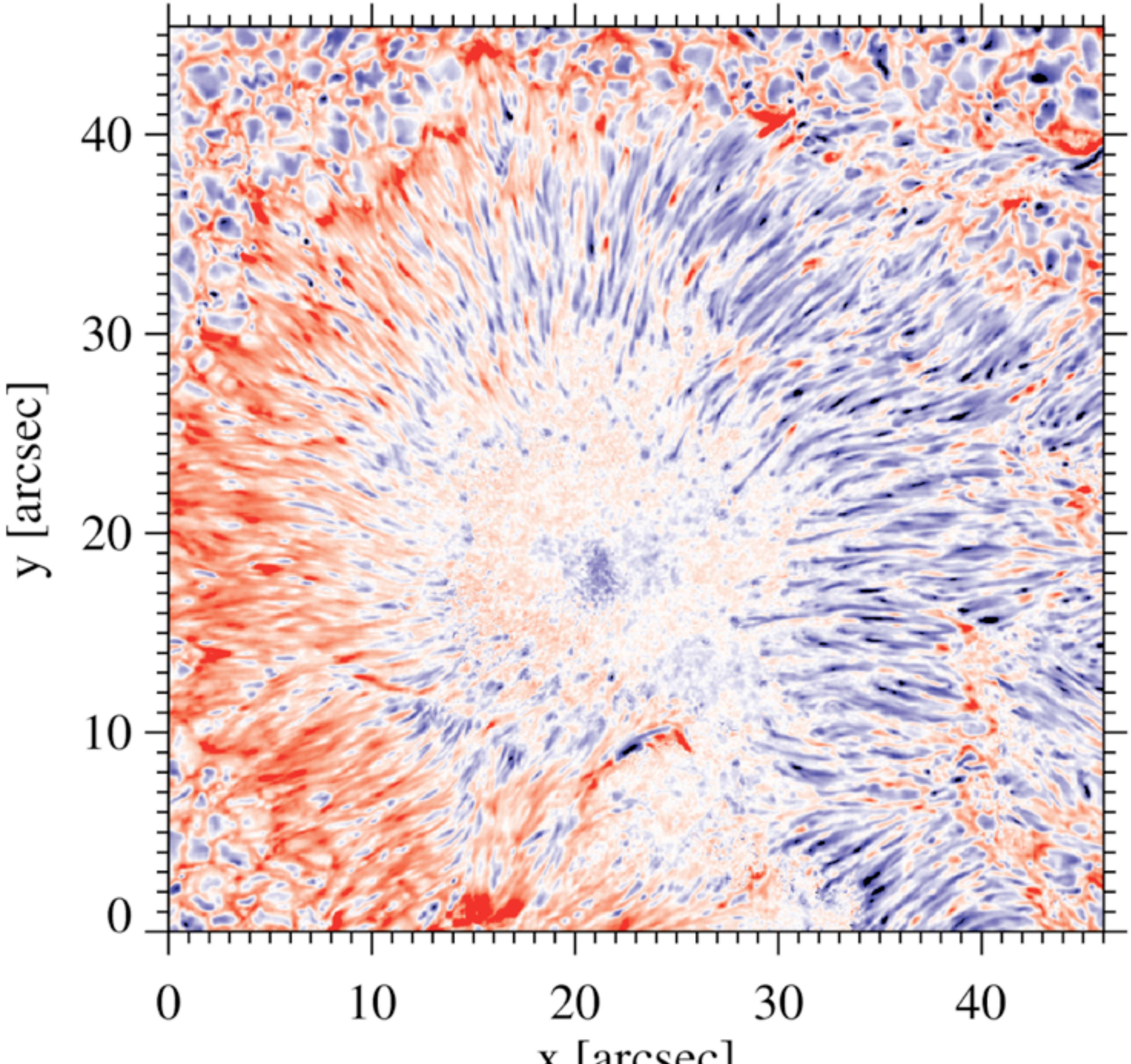


Subsonic oscillations are filtered

Calibration of the LOS velocity: Asymmetry of the peaks of Stokes V



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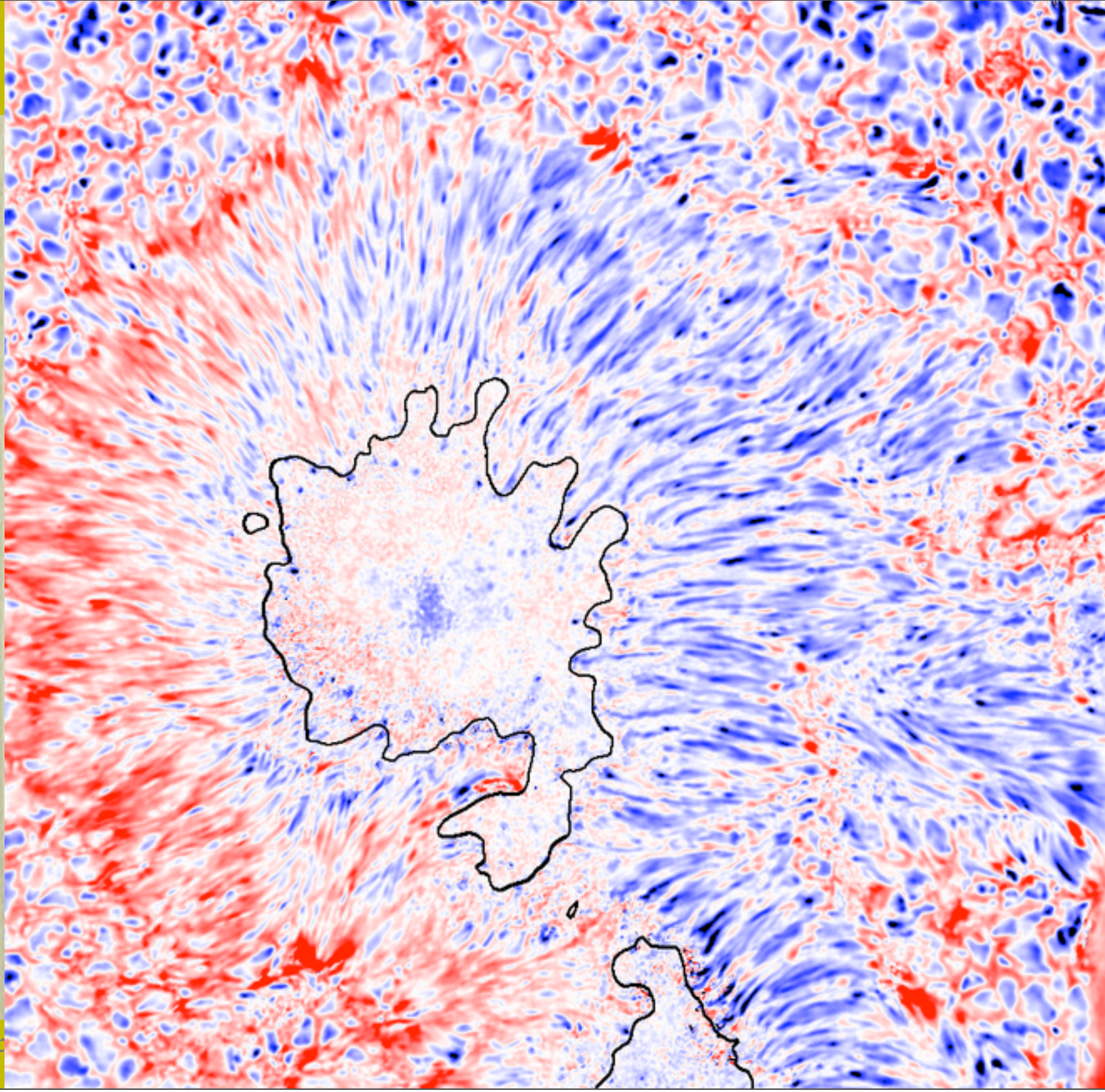

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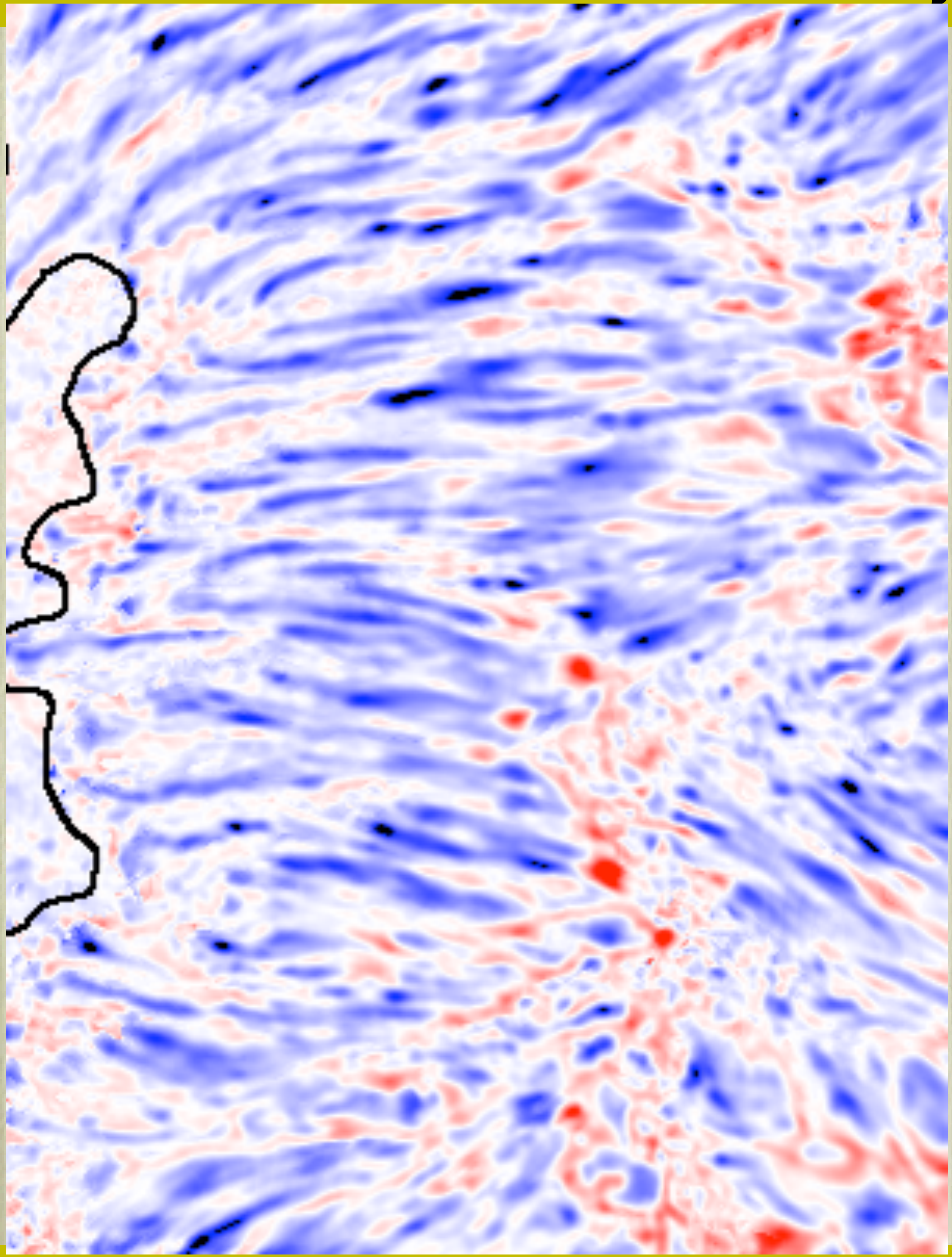
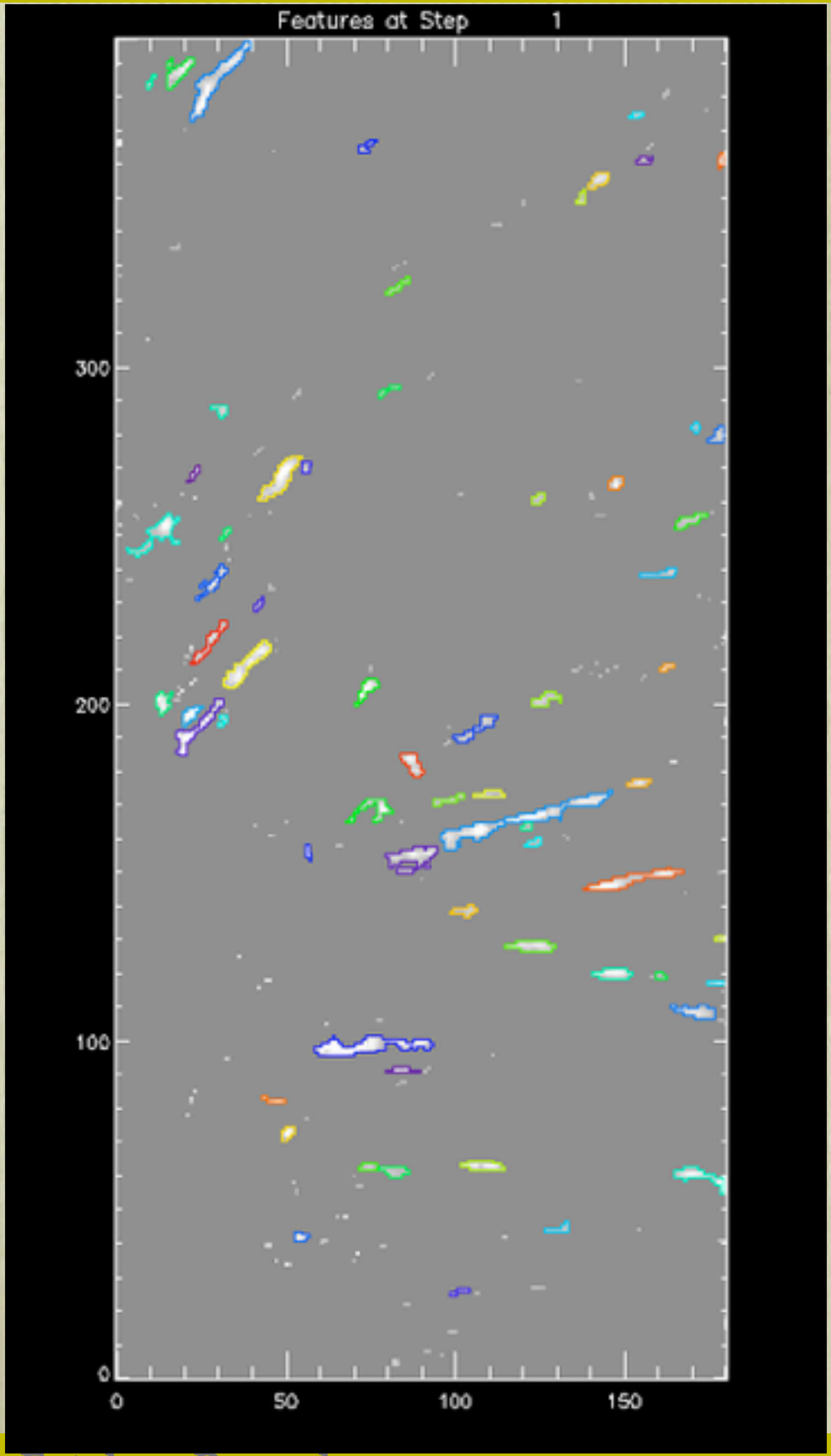
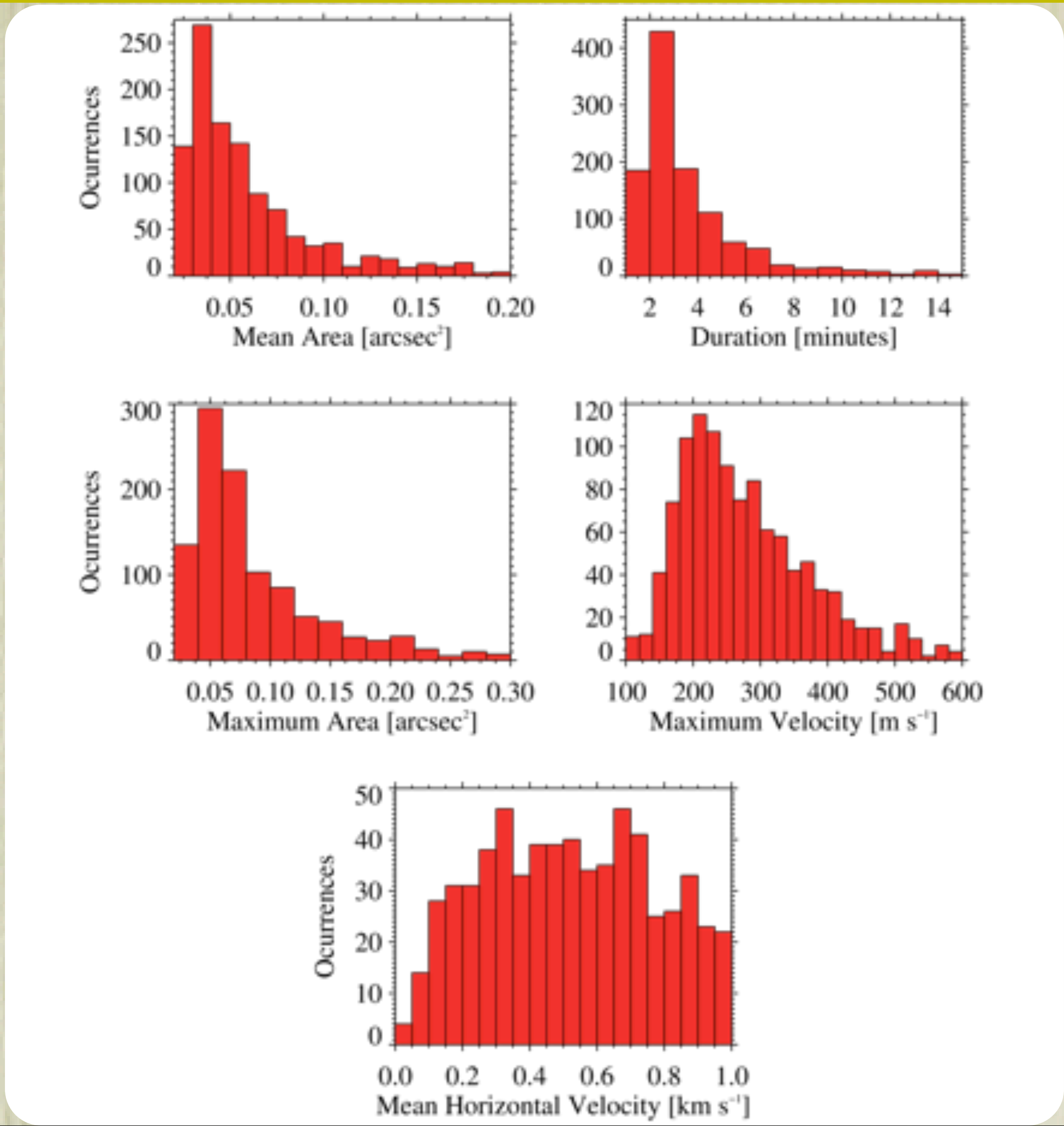


- Patchy and Weak Redshifts between Blueshifts
- Different Sizes
- Practically Ubiquitous
- Appearing and Disappearing
- Short or Large Lifetime?
- Becoming Elongated Redshifts

Analysis





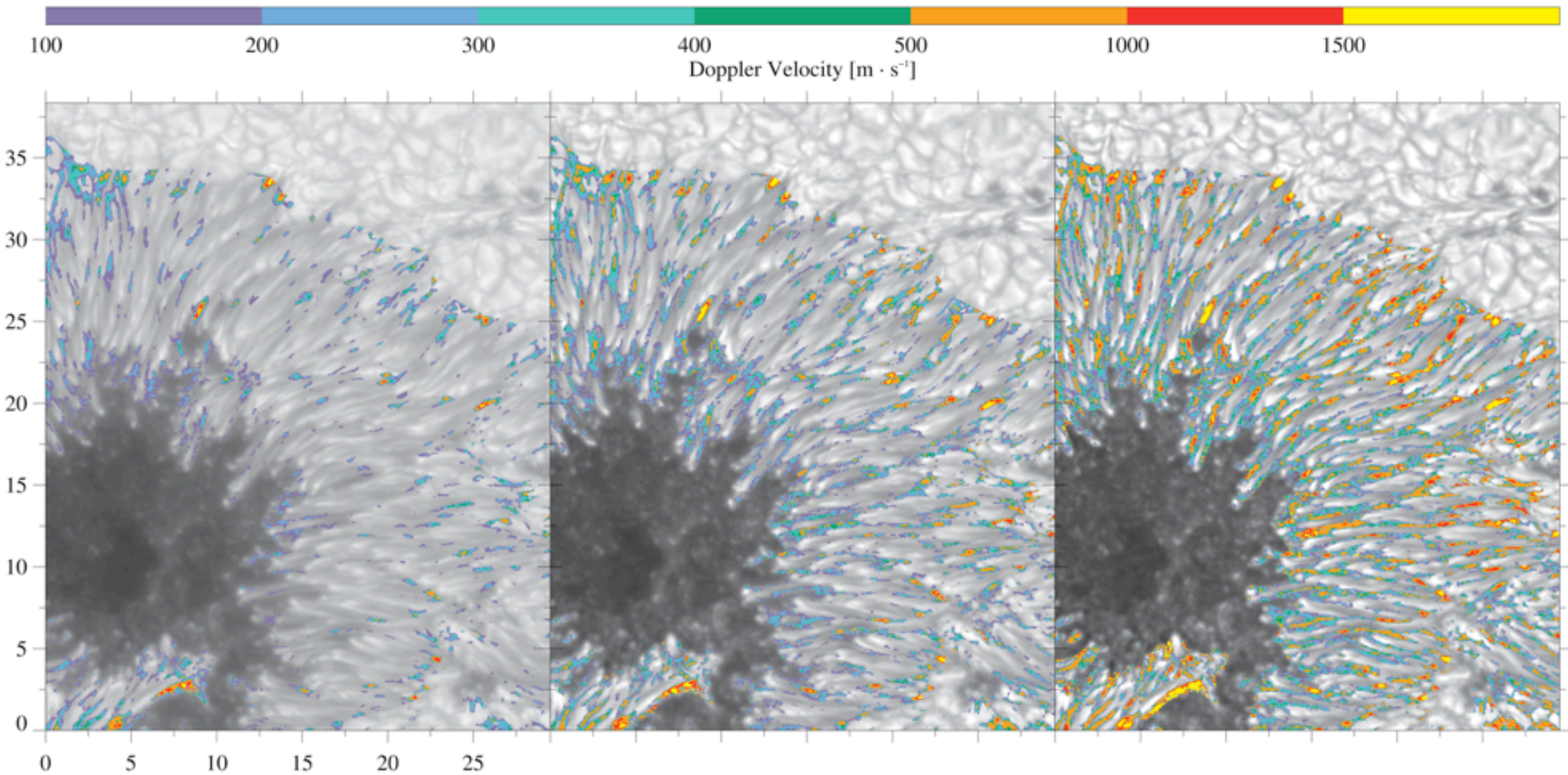
Mean Size	0.06 arcsec^2
Mean Duration	6 minutes
Mean LOS Velocity	220 m·s^{-1}
Mean Horizontal Velocity	0.7 km·s^{-1}

Analysis

Just to test... Let's deconvolve!

$$I_o = (1 - \alpha) \cdot I_t + (\alpha \cdot I_t) * P$$

(Scharmer et al. 2011, Scharmer & Henriques 2011, Scharmer et al. 2013)



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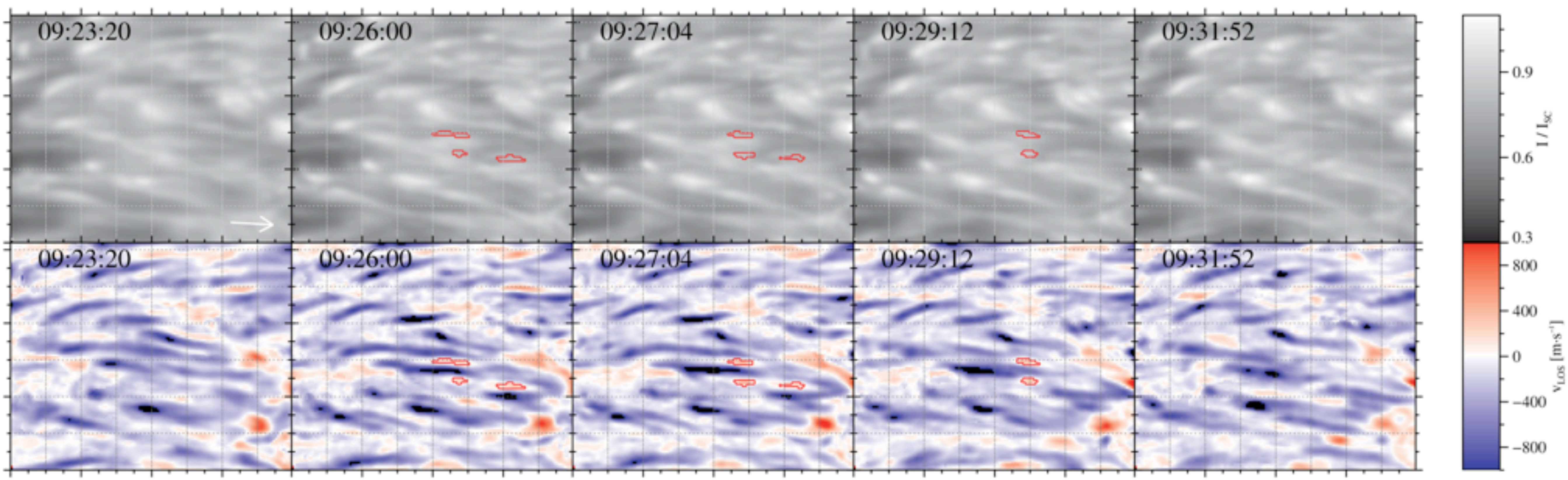
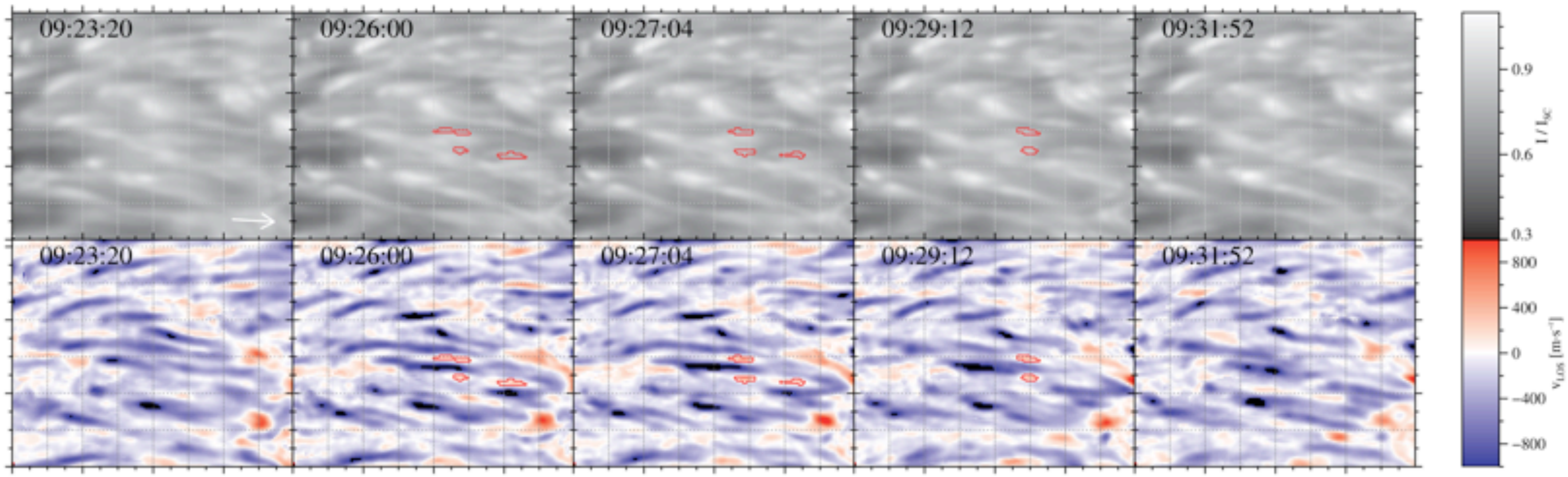
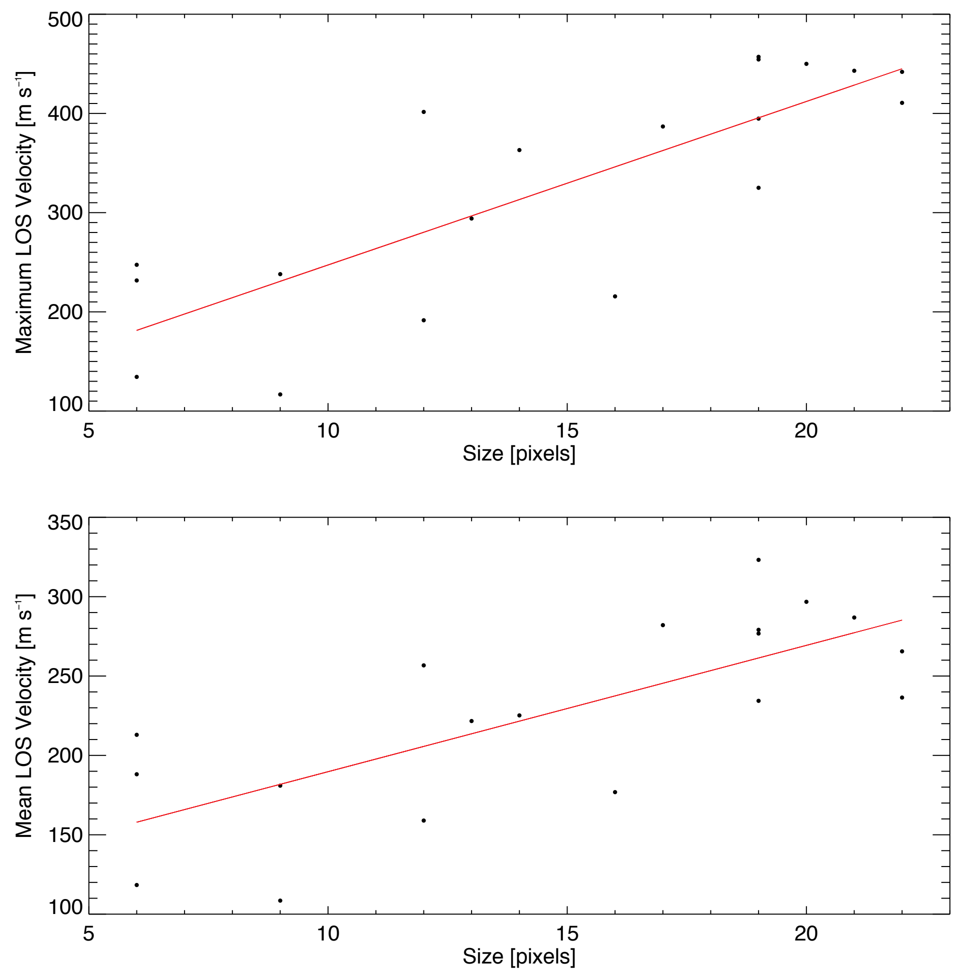


09:23:20
09:26:00
09:27:04
09:29:12
09:31:52
09:23:20
09:26:00
09:27:04
09:29:12
09:31:52
0.9
0.6
0.3
I / I$_{SC}$
800
400
0
−400
−800
v$_{LOS}$ [m·s^{-1}]

Analysis





Relation between LOS velocity and Size!

LOS velocity's enhancement from the appearing to the most visible moment of their lifetime. Then, it starts to extinguish as it gets smaller

Results

Results

Lateral downflows are patchy and weak redshifts located between blueshifted filaments. If some patches appear together, they form an elongated downflow. They appear almost in all angular positions and radii, being practically ubiquitous. Therefore, they are not due to a projection effect.

Some general properties can be established:

★ Their mean lifetime is approx. 6 minutes. Some of them only live 2 or 3 minutes, but others stay almost 15 minutes. It could be said that they have an intermitent life!
★ The mean size is 0.06 $arcsec^2$. They can appear as roundish or elongated structures.
★ Their LOS velocities are ranged between 100 and 450 $m{\cdot}s^{-1}$, with a mean of 220 $m{\cdot}s^{-1}$ for the 70% bisector level. LOS velocity increases as deeper layers are inspected.
★ At the inner and middle penumbra, they seem to move outwards with a mean horizontal velocity of 0.7 $km{\cdot}s^{-1}$.

How they appear and move seem to depend on what blueshifted filaments do. They move following the same wiggle as filaments. They are not always located at both edges of a filament. In this sense, penumbra looks like quiet Sun!

Results

Results

All downflows detected in original data are also found in straylight compensated data. Almost these downflows are not due to a mathematical artifact.

It is not possible to establish a common behaviour, each one has its own. But, there is a relation between their sizes and their LOS velocity. As they grow up, the LOS velocity increases. Then, they extinguish as they get smaller.

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Upflows at filaments' heads, up-and-outwards flow channels along the filaments, a flow returning to the solar surface at their tails and also lateral downflows at their edges. It supports the **existence of an azimuthal component of the convection located at the filament's edges** (Scharmer et al. 2008). We suggest a scenario where these flow structures are produced by an **elongated convection: Very close convective cells have a predominant outwards plasma flow's direction and cool plasma is laterally falling down where is allowed by the up-and-outwards flows.**