Leibniz-Institut für Astrophysik Potsdam

AIP

High-Resolution Imaging Spectroscopy of Micro-Pores in a Small Emerging Flux Region

1st SOLARNET Spring School: Introduction to Solar Physics

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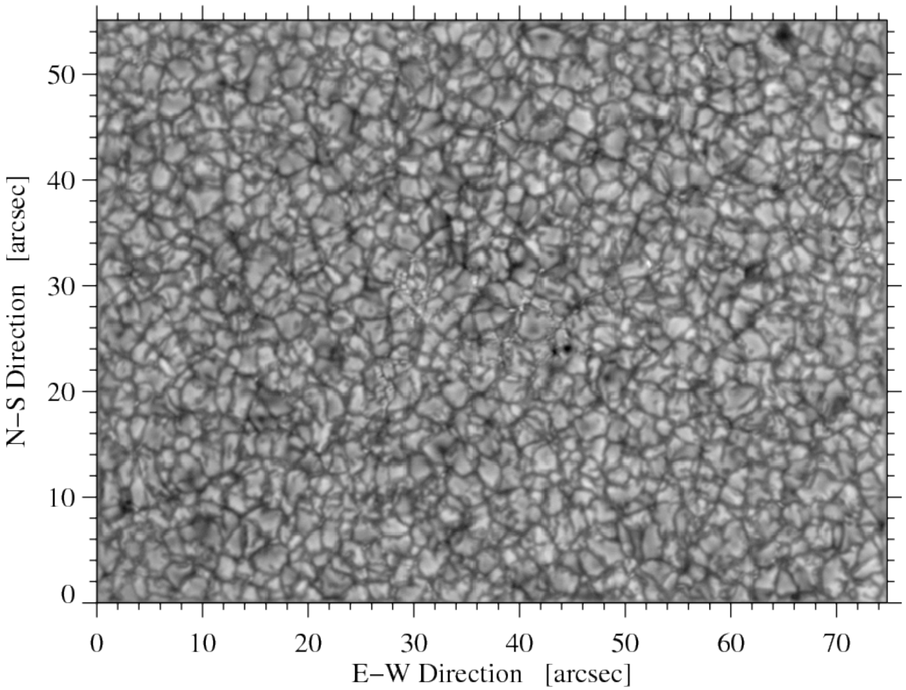
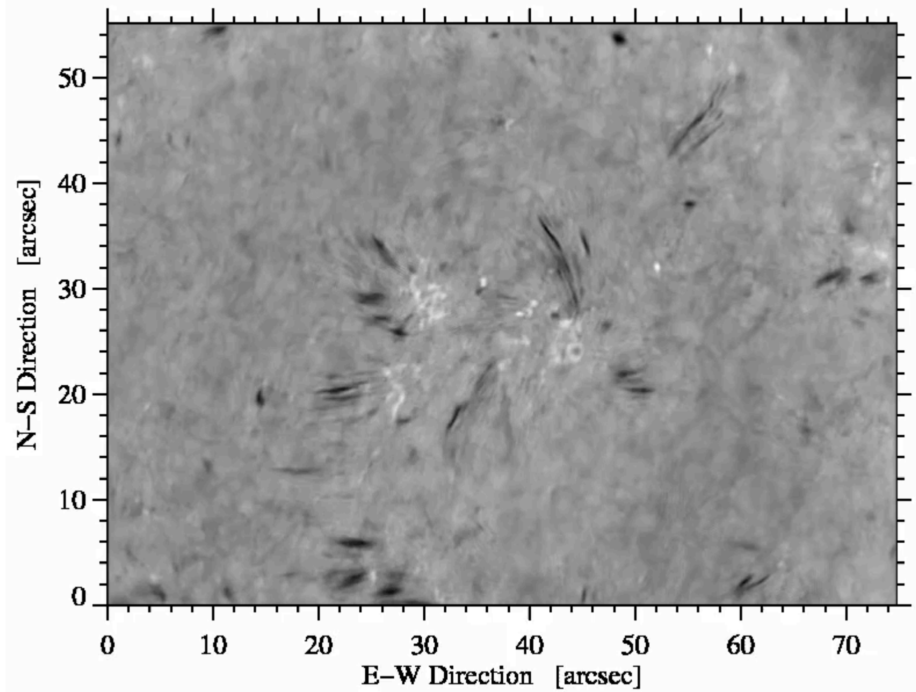
Contents

- Observations.
- Temporal evolution of the micro-pores.
- Horizontal flow field around the micro-pores.
- Cloud model inversions.

Observations

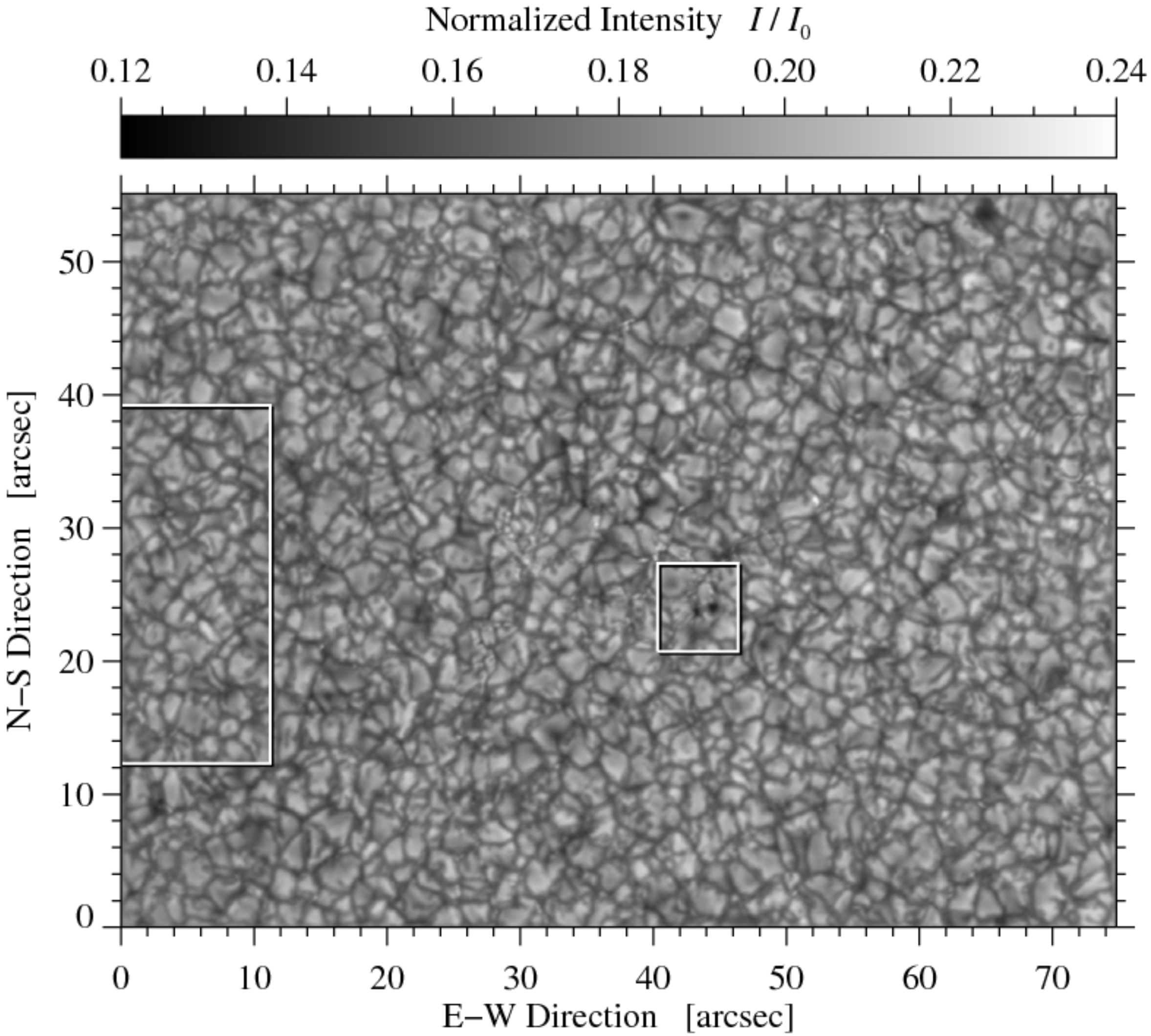




- Heliographic Coordinates: E21.7º, S1.1º.
- Chromospheric Hα λ656.28 nm line (669 x 493 pixels).
- Göttingen Fabry-Pérot Interferometer (GFPI).

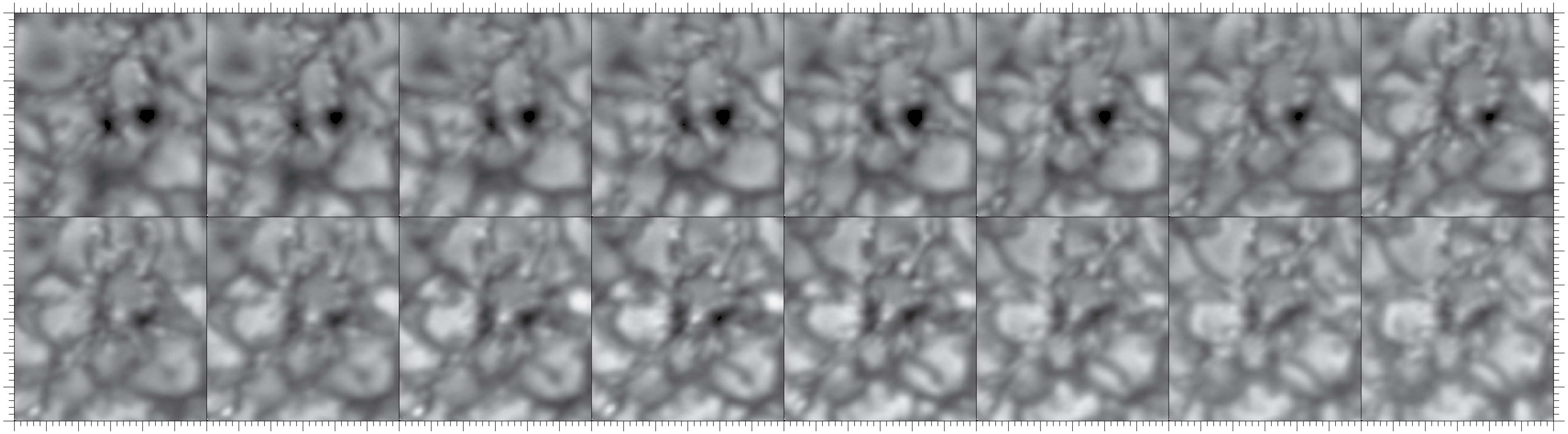
- Vacuum Tower Telescope (VTT).
- Image restoration using MOMFBD.
- Restored broad-band image (~ λ600 nm).

Temporal Evolution of the Micro-Pores



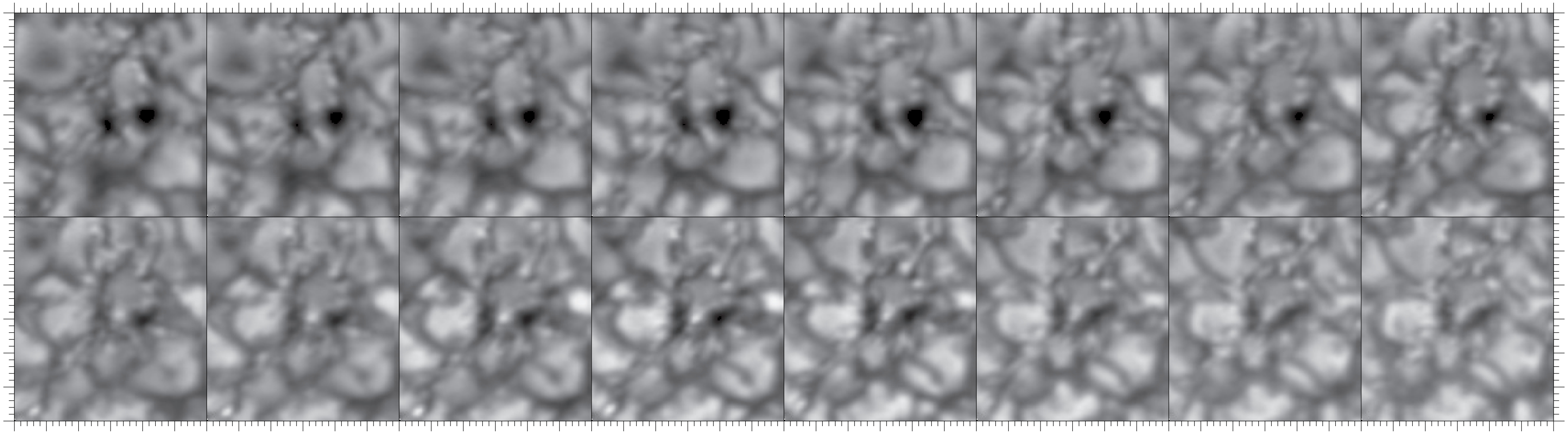
- Two micro-pores within the quiet Sun.
- Emerging flux region close to disk center.
- ROI of 6”×6” centered at the micro-pores.
- Initially micro-pores have diameters of less than 1”.

Temporal Evolution of the Micro-Pores



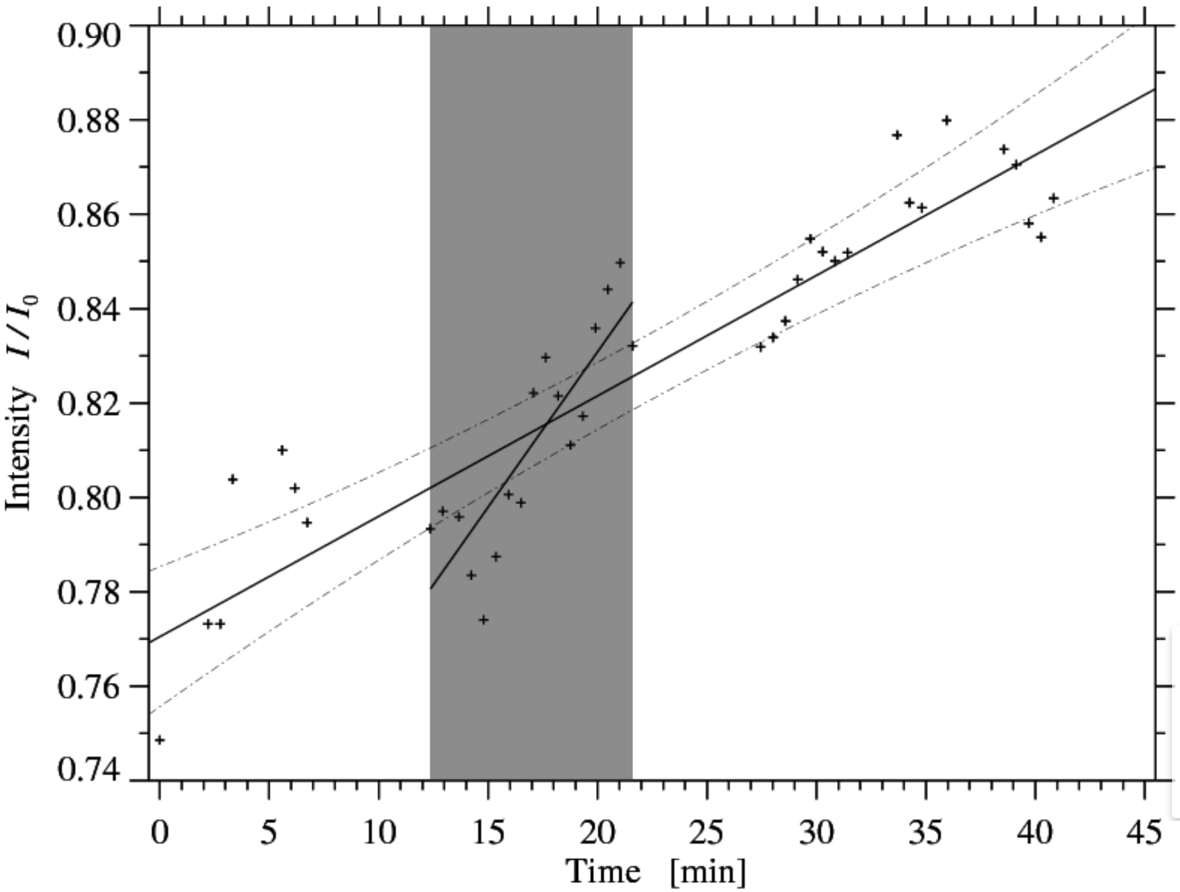
- Time sequence start at 08:07 UT.
- Cadence of 34 s.
- Total duration ~10 min.
- Both micro-pores evolve with time in intensity, size, and shape.
- Intensity increase.
- Area decrease.
- Both micro-pores approach each other (without merging).

Temporal Evolution of the Micro-Pores



- Right micro-pore is large and circular.
- Left micro-pore exhibits some starlike extrusions.
- Besides the term "micro-pore" *Rouppe van der Voort et al.* (2005) introduce the nomenclature "ribbon" and "flower".
- Ribbon → elongated
- Flower → more circular magnetic structures

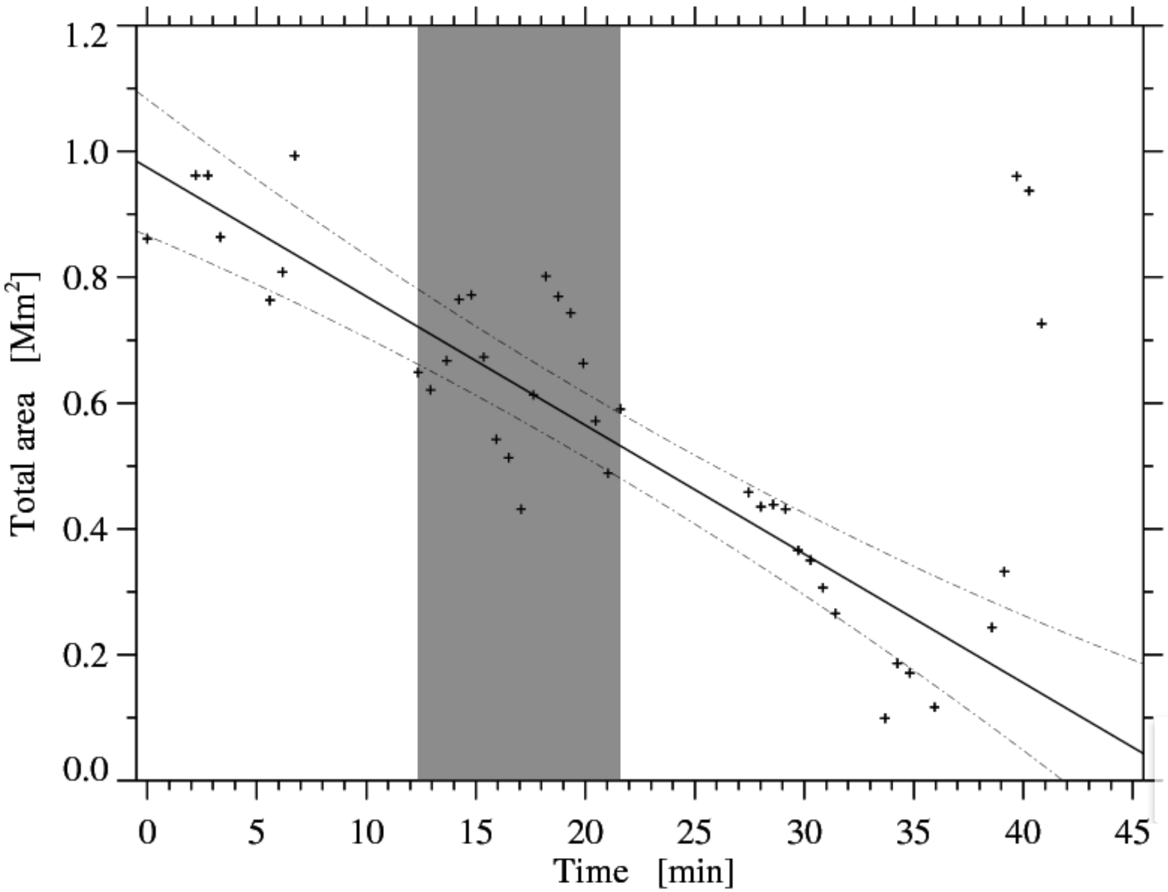
Temporal Evolution of the Micro-Pores



- Chronological sequence of parameters describing the decay process.
- Smoothing using anisotropic diffusion.
- Intensity thresholding < $0.9 I_0$.
- Blob Analysis.
- Starting at 07:54 UT.
- Average Intensity I_{mp} / I_0.
- Total Area A_{mp}.
- Center-to-center distance d_{mp}

$$\frac{dI_{\rm mp}}{dt} = 0.042 \; I_0 \; s^{-1}$$

Temporal Evolution of the Micro-Pores



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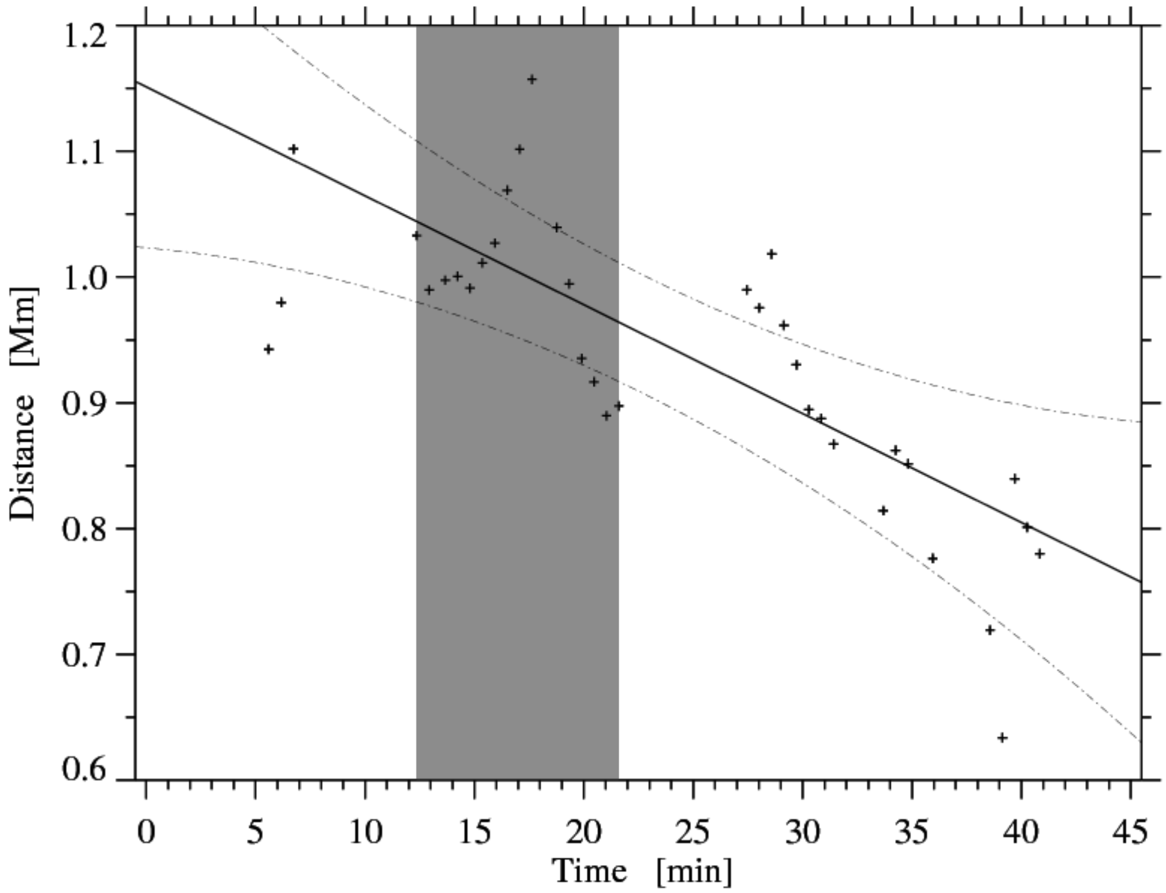
$$\frac{dA_{\mathrm{mp}}}{dt} = -0.34\ \mathrm{km}^2\ \mathrm{s}^{-1}$$

Temporal Evolution of the Micro-Pores



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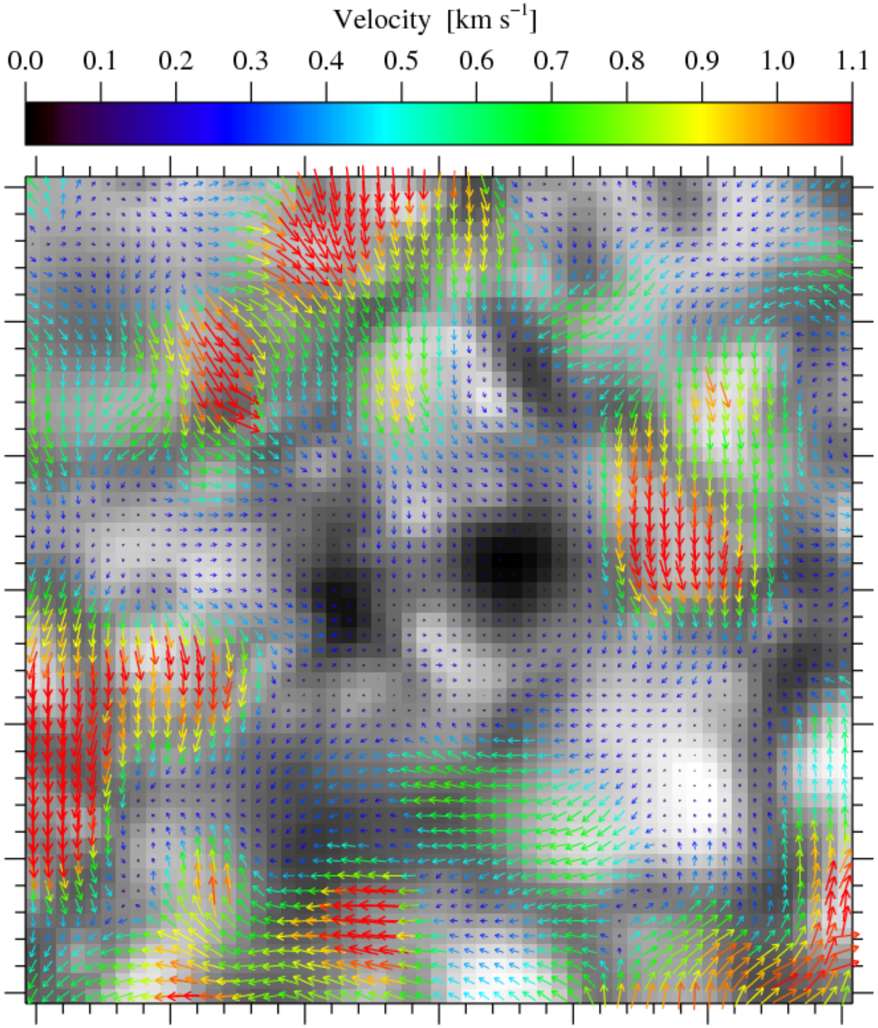
$$\frac{dd_{\mathrm{mp}}}{dt} = -0.14 \text{ km s}^{-1}$$

Horizontal Flows Around the Micro-Pores



Horizontal proper motion were derived from the time series of 17 broad-band images using local correlation tracking (LCT) as described in *Verma & Denker* (2011). LCT input parameter: cadence of

Δt = 34 s and an averaging time of $\Delta T \approx 10$ min.

Mean flow speed:

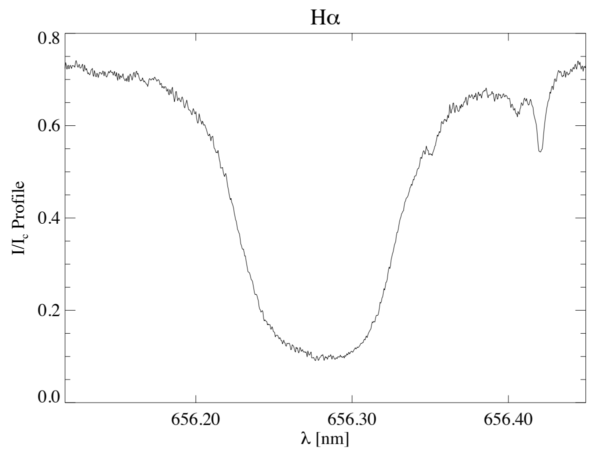
FOV: $\bar{v} = 0.60 \pm 0.41\ \mathrm{km\ s^{-1}}$

ROI: $\bar{v} = 0.51 \pm 0.31\ \mathrm{km\ s^{-1}}$

Cloud Model Inversions

$$C(\lambda) = \frac{I(\lambda) - I_0(\lambda)}{I_0(\lambda)}$$ Intensity contrast profile

$C(\lambda) =$



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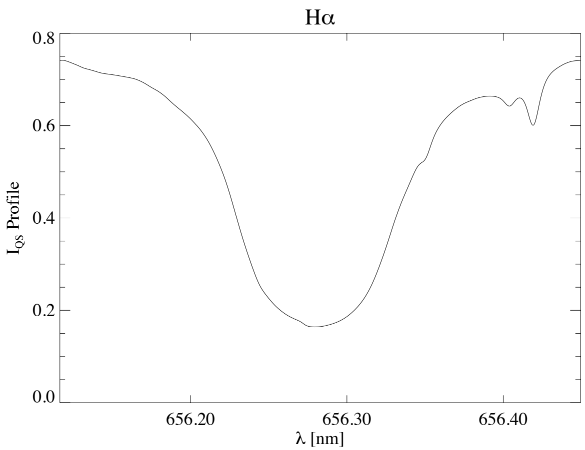

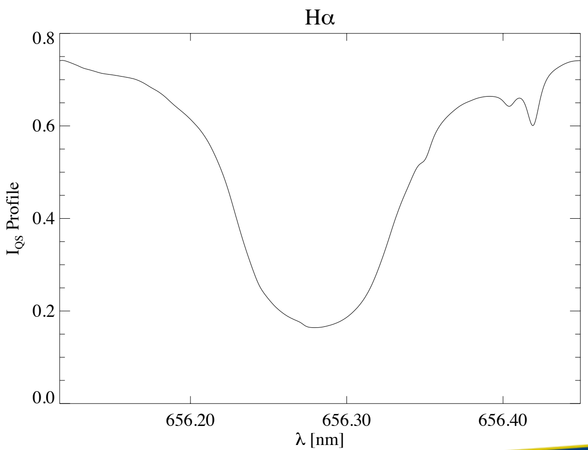

Cloud Model Inversions

$$C(\lambda) = \frac{I(\lambda) - I_0(\lambda)}{I_0(\lambda)}$$

Intensity contrast profile

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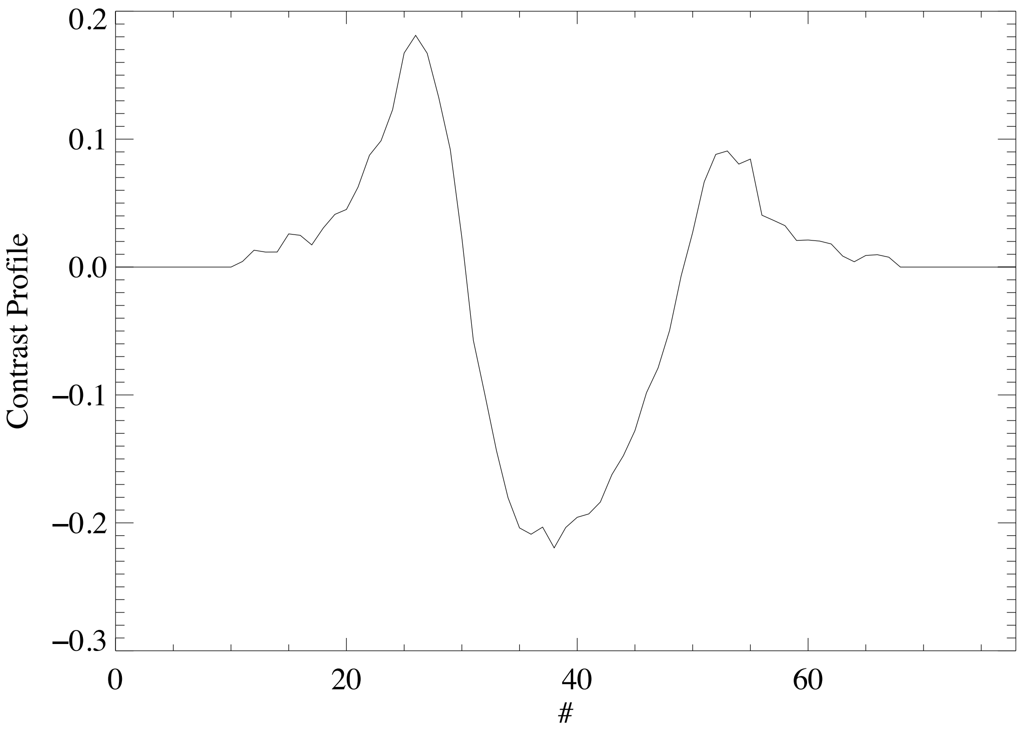


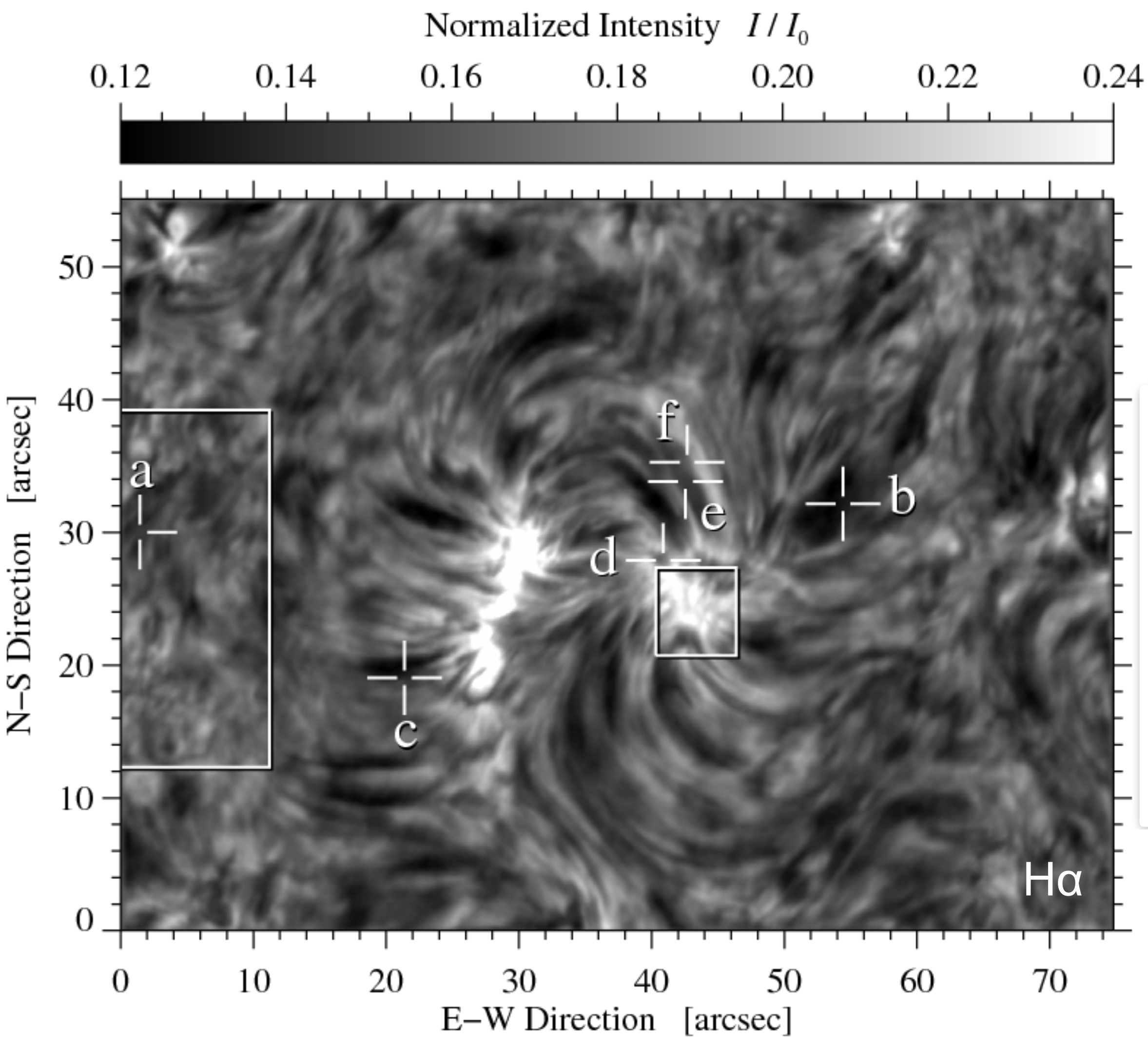
Cloud Model Inversions

- The Cloud Model (CM, *Beckers*, 1964) assumes a cool plasma cloud of absorbing material suspended by the magnetic field above the photosphere.
- Relationship between the $C(\lambda)$ and the central wavelength of the absorption profile λ_c (v_{LOS}), the Doppler width of the absorption profile $\Delta\lambda_D$, the optical thickness τ_0 of the cloud at the central wavelength, and the source function S.

$$C(\lambda) = \left[\frac{S}{I_0(\lambda)} - 1\right]\left(1 - \exp[-\tau(\lambda)]\right) \quad \text{with}$$

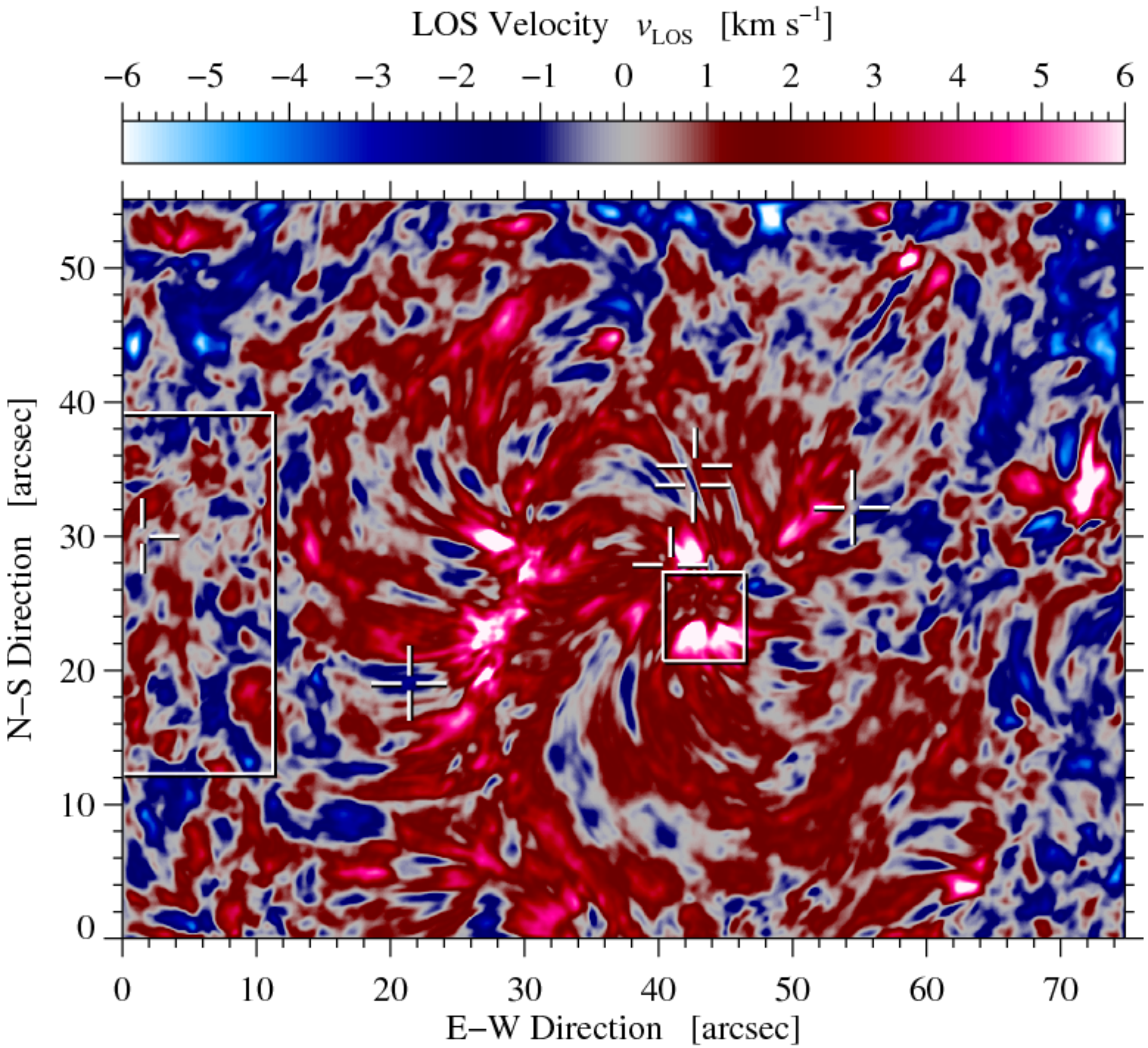
$$\tau(\lambda) = \tau_0 \exp\left[-\left(\frac{\lambda-\lambda_c}{\Delta\lambda_D}\right)^2\right]$$

Cloud Model Inversions



- ❑ Crosses and alphabetic labels mark the locations of six contrast profiles.
- ❑ Two bright areas called footpoints.
- ❑ Arch filament system.
- ❑ Chromospheric Doppler velocity map derived with center-of-gravity method.
- ❑ Red and blue colours represent down- and upflows, respectively.

Cloud Model Inversions



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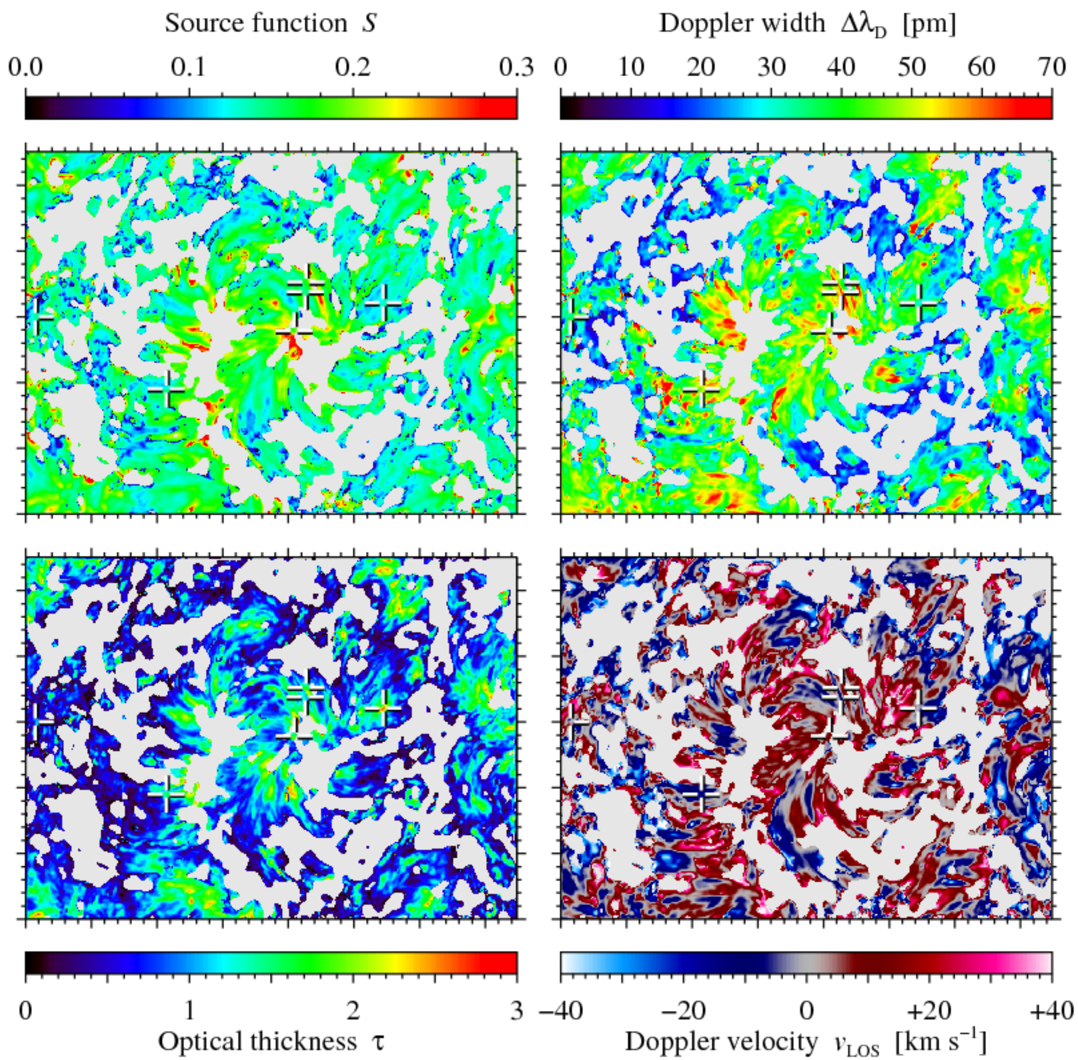
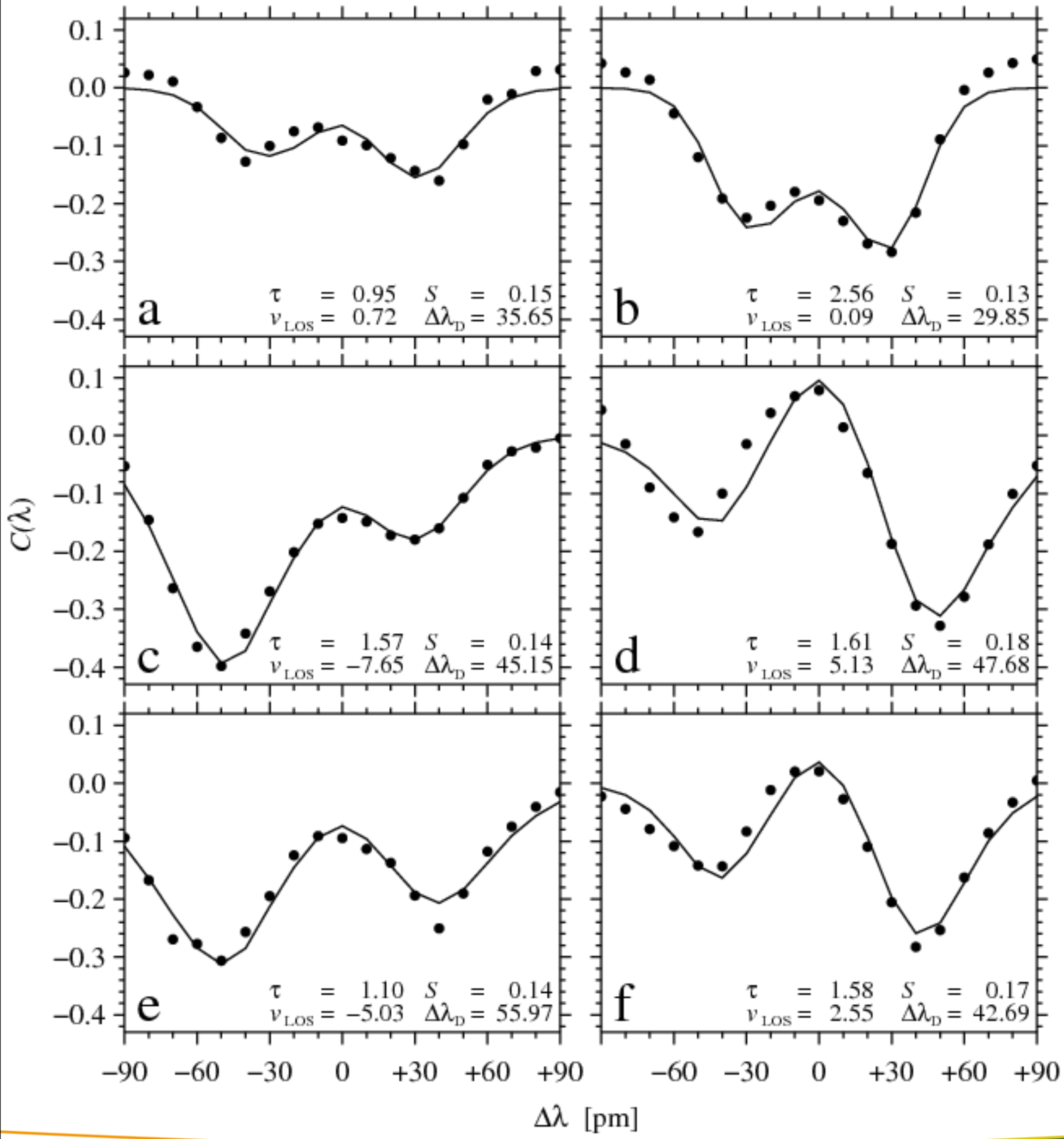


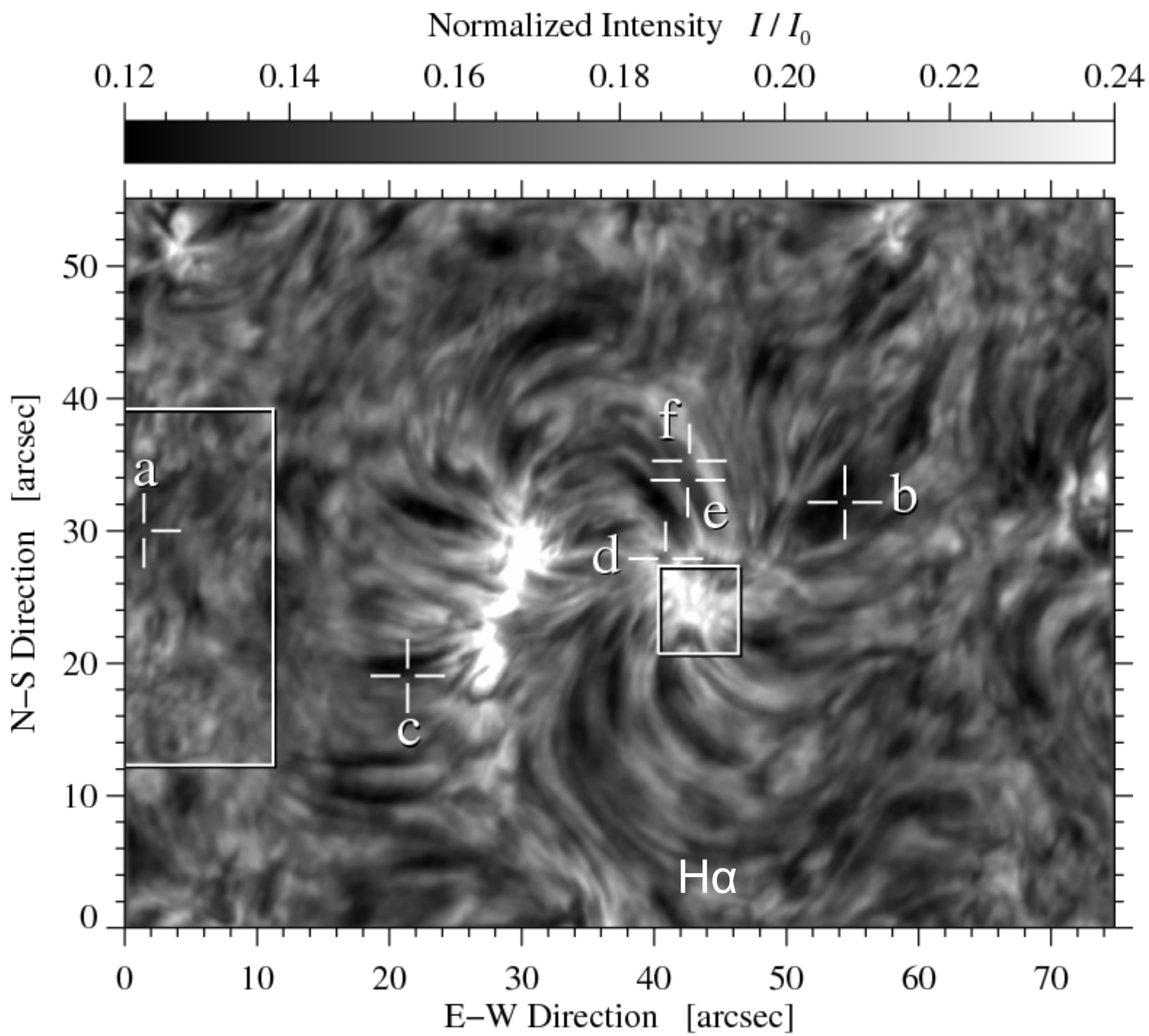
- ❑ Maps of the CM parameters for the inverted Hα contrast profiles.
- ❑ Two steps are required in the CM inversion.
- ❑ Create data base with 50000 synthetic contrast profiles.
- ❑ Each observed profile is then compared with the synthetic profiles and the CM parameters of the closest match are saved.
- ❑ Mediocre and failed fits are indicated as light gray areas.

Cloud Model Inversions

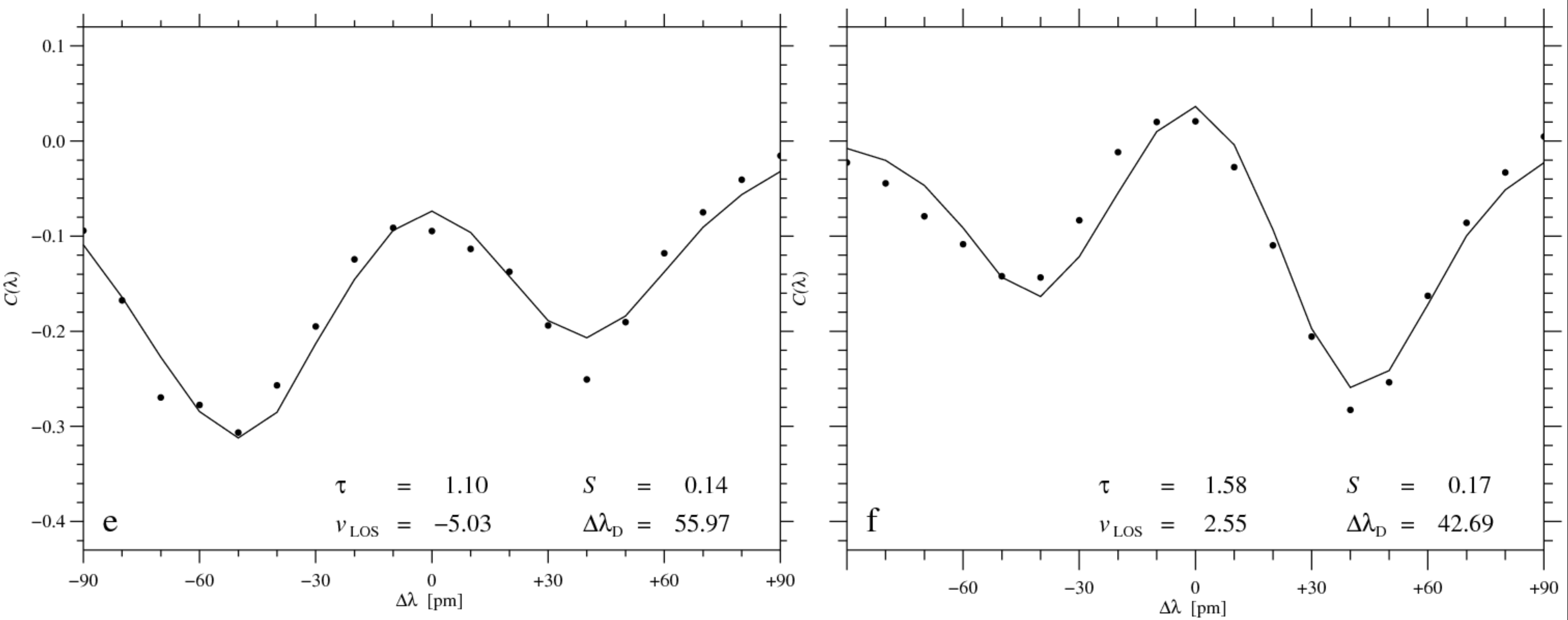


- Observed (dots) and fitted (solid) contrast profiles *C*(*λ*) using CM inversions.
- The CM parameters of the fits are given in the lower right corner of each panel.
- Alphabetical labels correspond to the location marked in the figure of the Hα line core intensity image.

Cloud Model Inversions

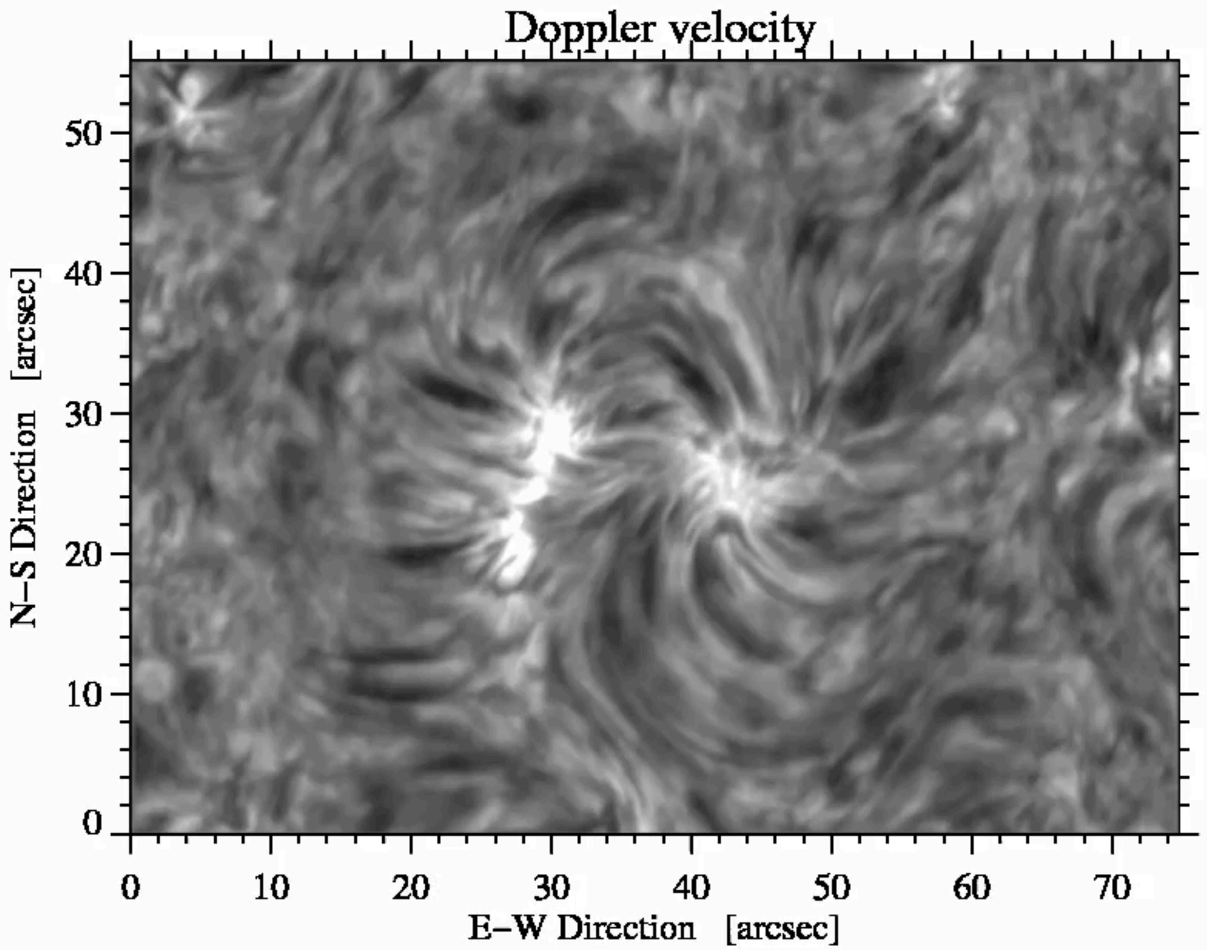


Cloud Model Inversions



e and **f** represent two contrast profiles within the same arch filament. Upflows occur in the left side of the filament and downflows in the right side.

Cloud Model Inversions



- *Zuccarello et al.* (2009):
  (1) Upward motions in the entire loop.
  (2) Downward motion of plasma in the legs of the loop.

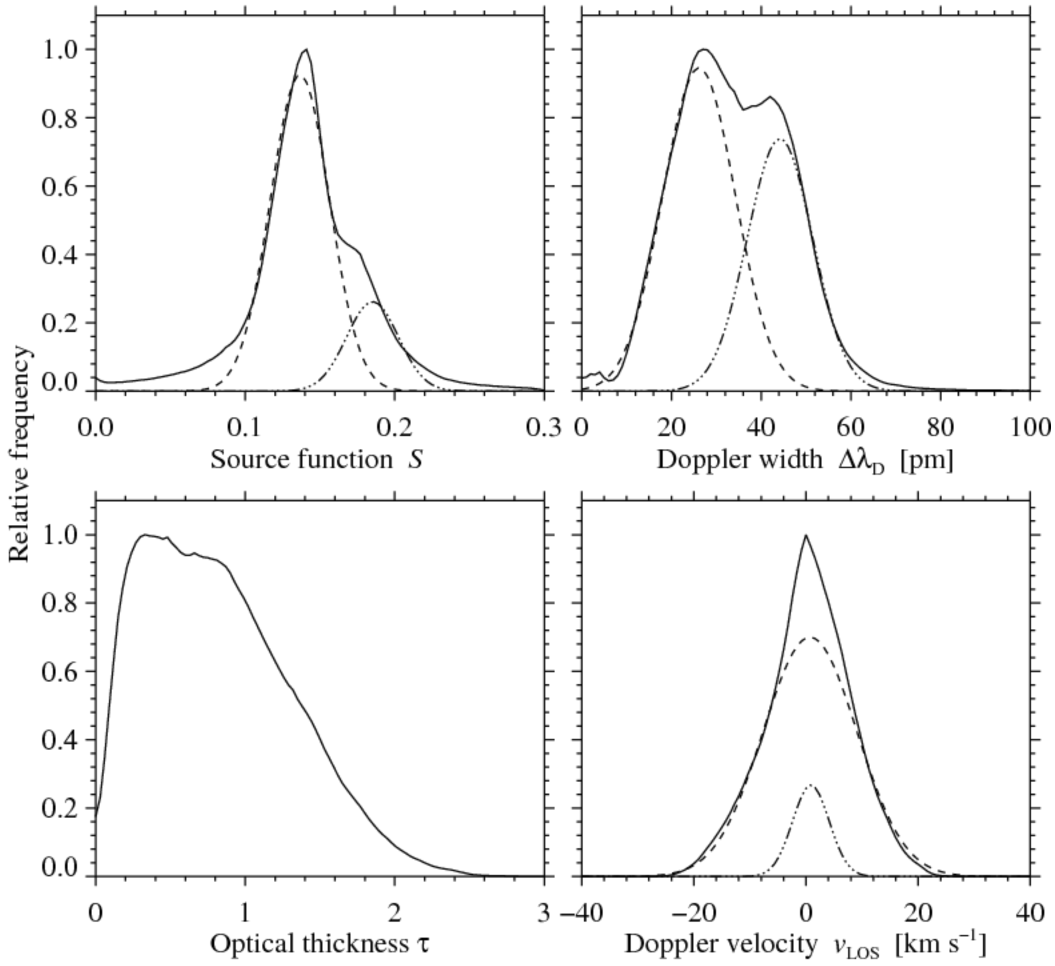
- Down- and upward motions in the leg of the arch filament.

Conclusions

- The small magnetic flux system of micro-pores is decaying.
- The horizontal flow speed is significantly reduced in the immediate neighbourhood of the micro-pores. Strong magnetic fields tend to suppress convective motions.
- CM inversions describe the cool plasma contained in the arch filament system, which is suspended by the magnetic field above the emerging flux region.
- Down- and upflows in the same arch filament.

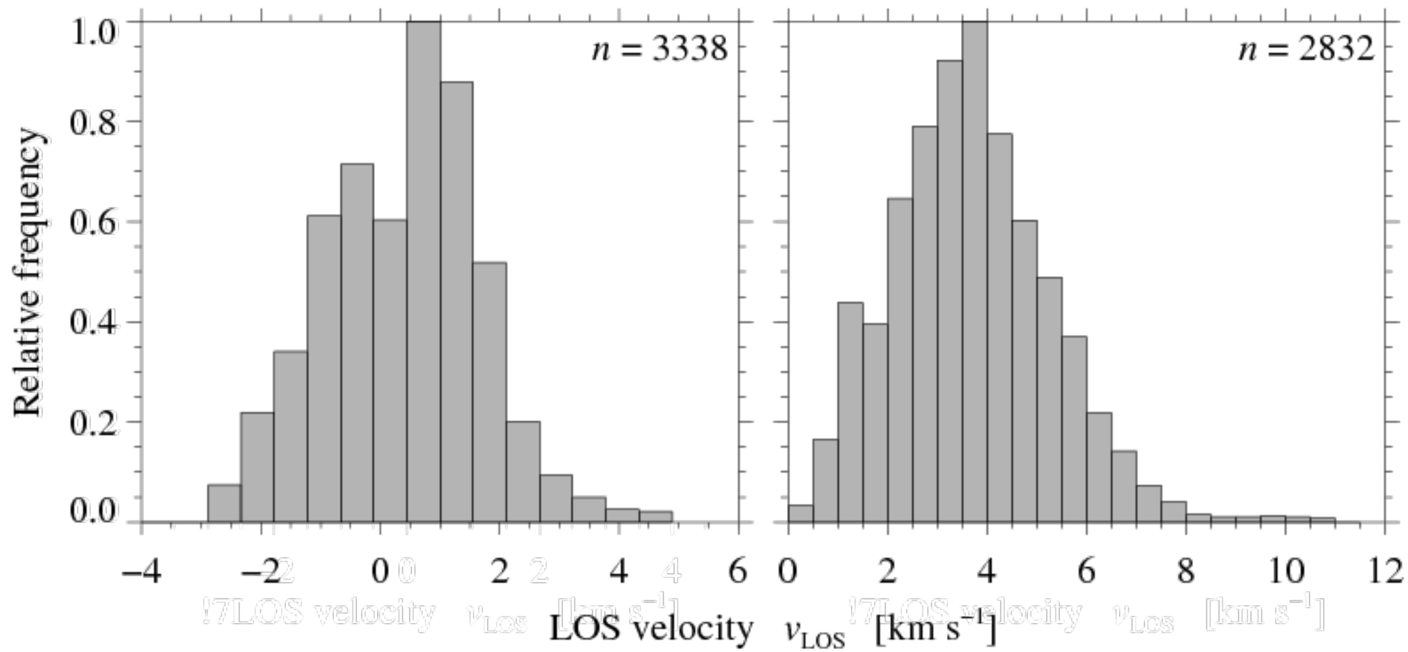
Questions?

Cloud Model Inversions



- Normalized frequency distributions of the CM parameters.
- The dashed and dash-dotted curves are two-component Gaussian fits to the distributions.

Cloud Model Inversions



Normalized frequency distributions of the chromospheric Doppler velocity v_{LOS} for dark filamentary features (left) and bright footprints (right) of the small arch filament system. Variable n indicates the number of Hα line profiles on which the distribution are based.