# Hundred Gauss magnetic fields in spicules and coronal rain clumps

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europa inverteix en el teu futur

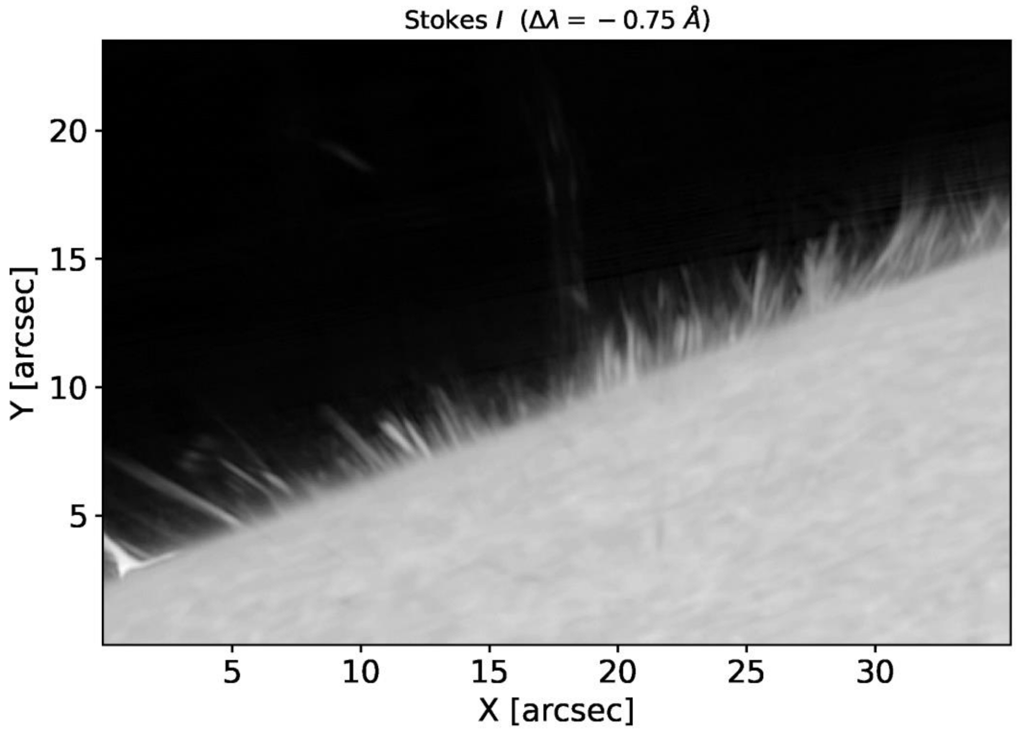
IAC3 Institute of Applied Computing & Community Code.

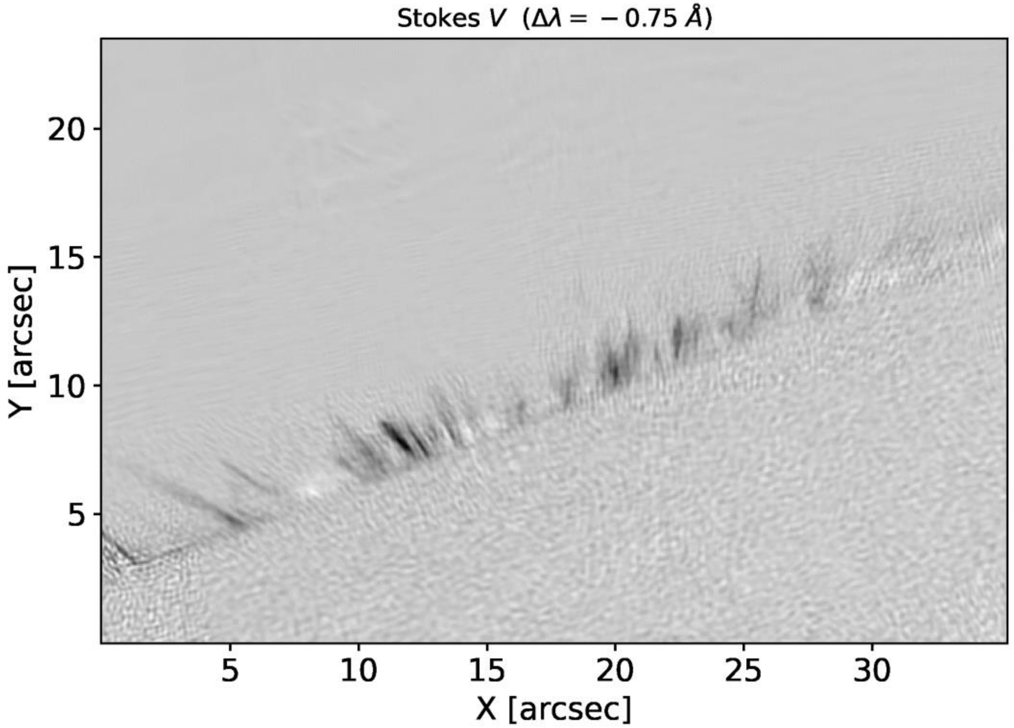
# Context of research and observations

The observations were obtained on 02, 03 and 09 June 2016 with the CRISP instrument at the SST, spanning the Ca II 8542 line with full Stokes spectropolarimetry. On-disk and off-limb spicules are visible along with coronal rain. The spatial resolution is around 40 km, and the cadence of the data is close to 30 s.

Previous inferences of magnetic fields in spicules were mainly done using the He I 1083 nm line (Centeno et al. 2010, Trujillo Bueno et al. 2005, Ramelli et al. 2006, etc). These works yielded values of $B_{LOS}$ of a few G, but they were limited by the spatial/temporal resolution of the observations.

For coronal rain clumps, Schad et al. (2016) also used the He I line to infer B of the order of 1000G at the heights corresponding to our observations.



# The Weak Field Approximation (WFA)

Its validity relies upon two conditions:

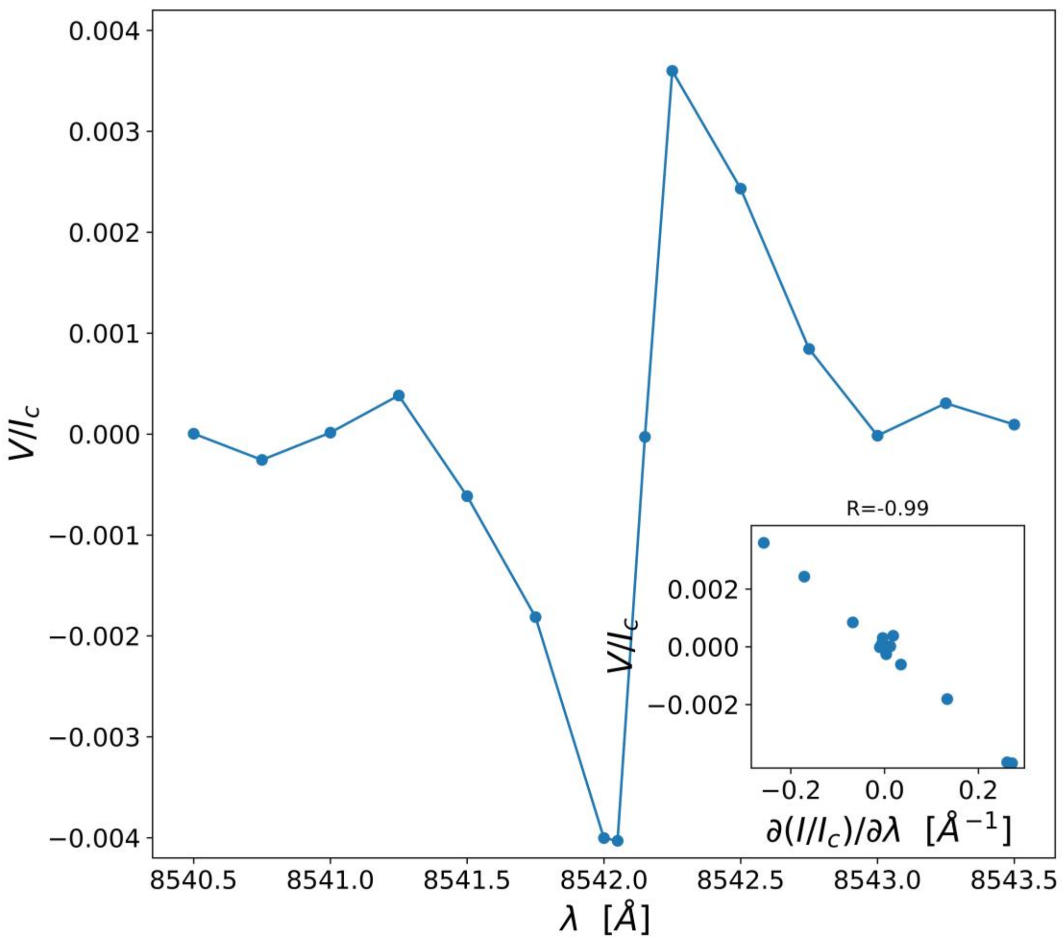
- The Zeeman splitting is much smaller than the Doppler width of the line

$$\bar{g}\frac{\Delta\lambda_B}{\Delta\lambda_D} << 1$$

$$\Delta\lambda_D = \frac{\lambda_o}{c}\sqrt{\frac{2k_B T}{m} + \xi} \qquad \Delta\lambda_B = 4.67 \cdot 10^{-13}\lambda_o^2 B$$

- The magnetic field is uniform along the line of sight.

$$V = -\Delta\lambda_B f \bar{g} \cos(\theta) \frac{\partial I}{\partial \lambda}$$



# Data analysis

1. Pearson's correlation coefficient is calculated (R>=0.9).
2. The Stokes V asymmetry is studied.
3. A least-squares fit is performed to have an initial guess of $B_{LOS}$ .
4. A Bayesian Inference is performed on the data points to infer the probability distribution $B_{LOS}$ and its 95 % Highest Posterior Density Interval (HPI). The mode of the $B_{LOS}$ distribution is used alongside the 95 % HPI as the inference result for each pixel.

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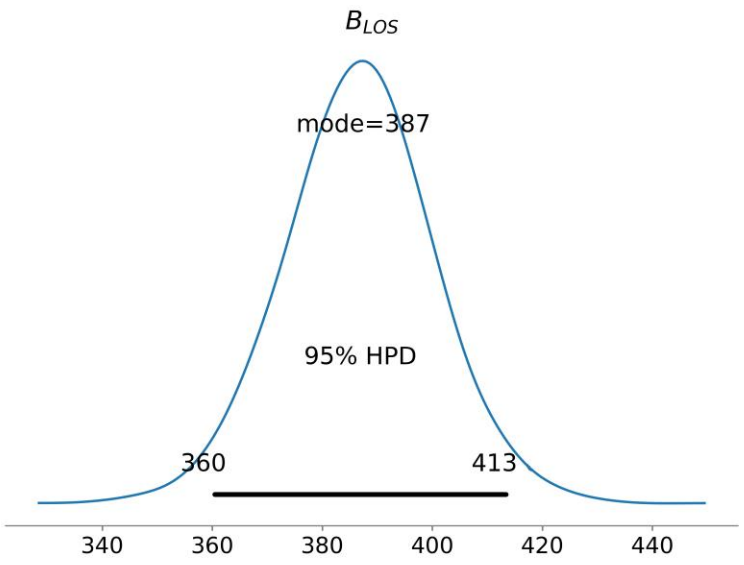


# Magnetic field strength

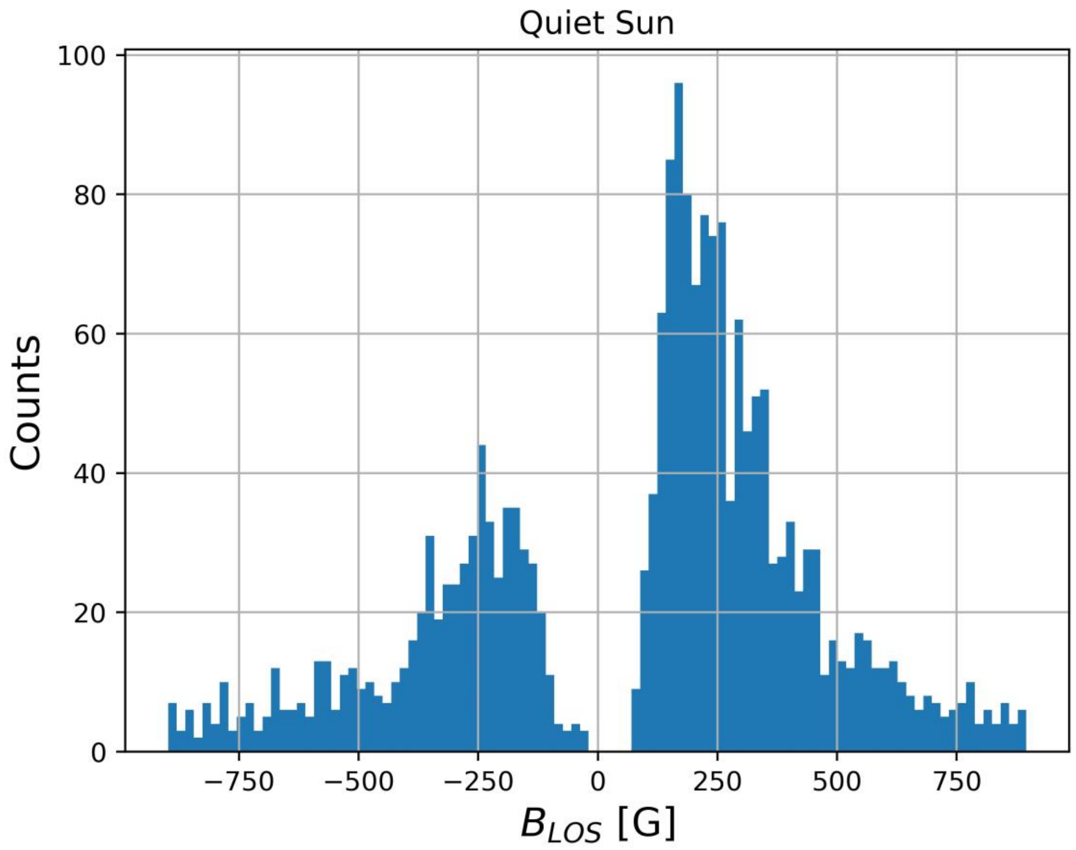
If a coronal rain clump is seen more than once, its velocity on the plane of the sky can be measured. Coupled with the Doppler displacement, the full velocity vector can be inferred.

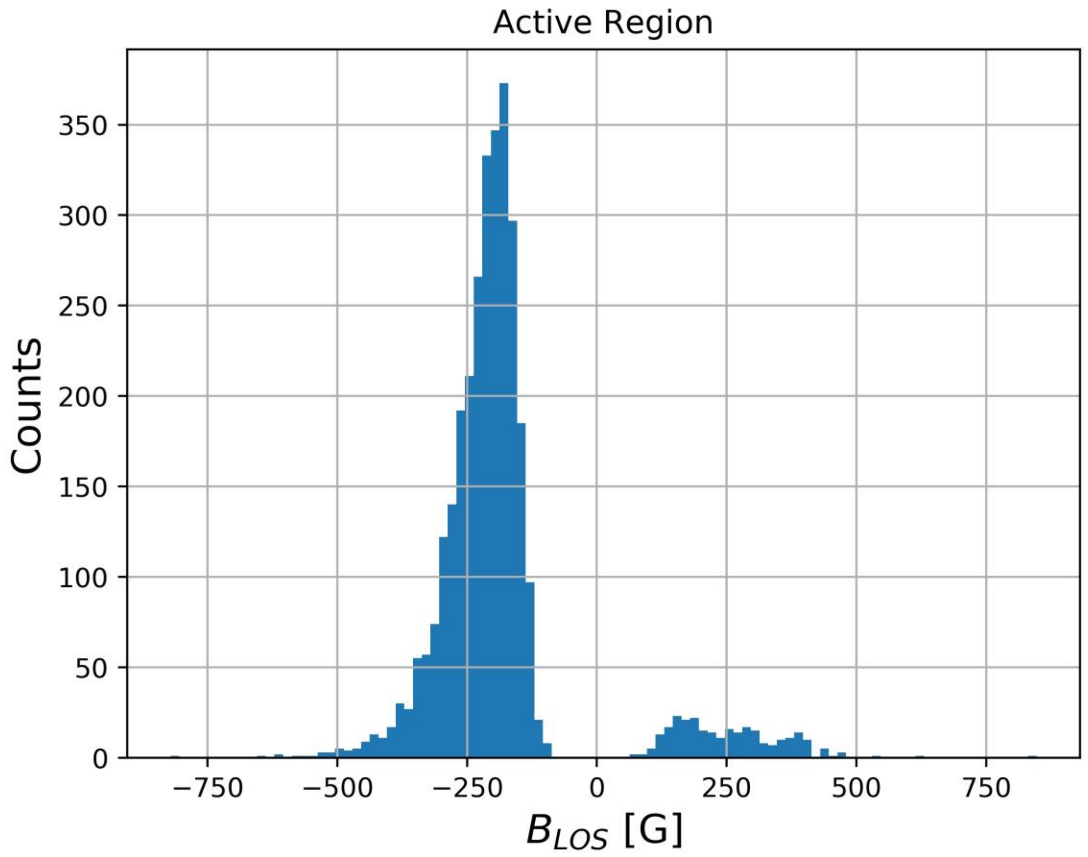
$$v = \sqrt{v_{POS}^2 + v_{LOS}^2}$$

Since the plasma moves along the magnetic field lines, this allows for the inference of the magnetic field strength. B can be introduced as a deterministic variable into the Bayesian inference scheme.

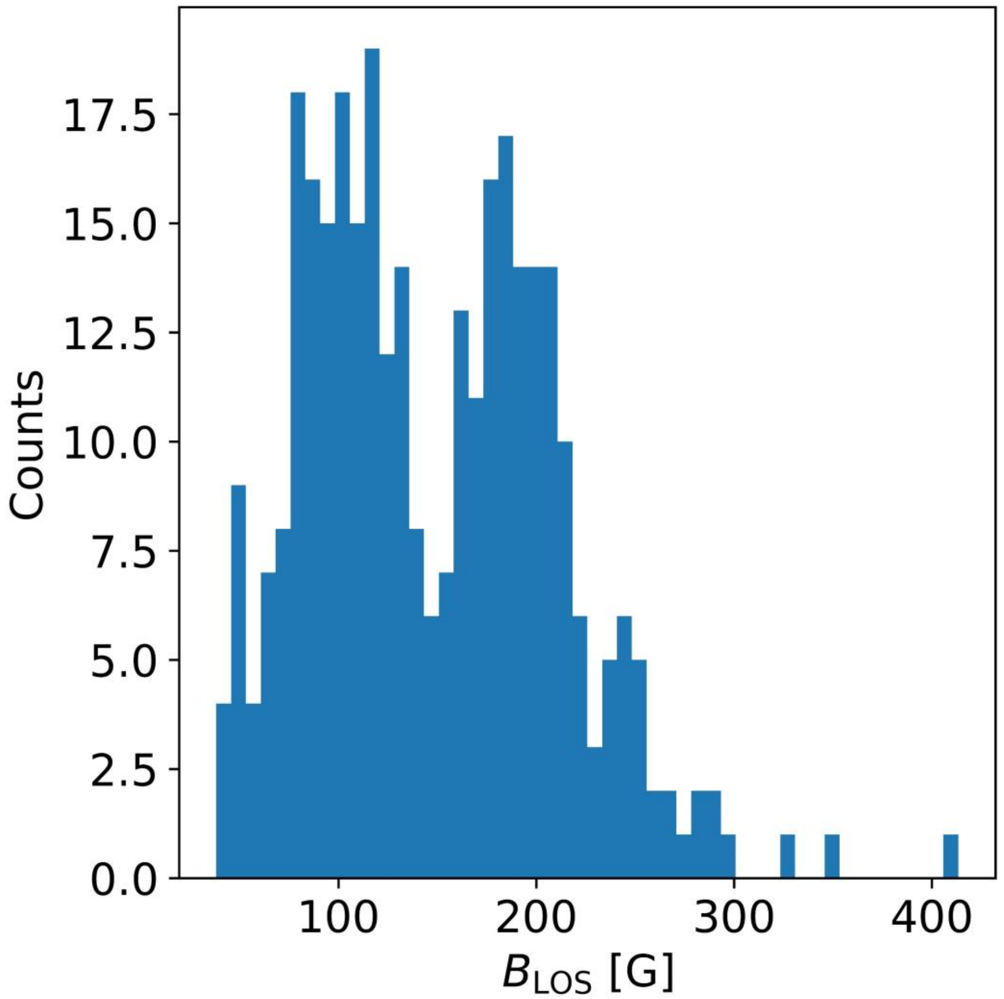
$$B = B_{LOS}\sqrt{1 + \frac{v_{POS}^2}{v_{LOS}^2}}$$

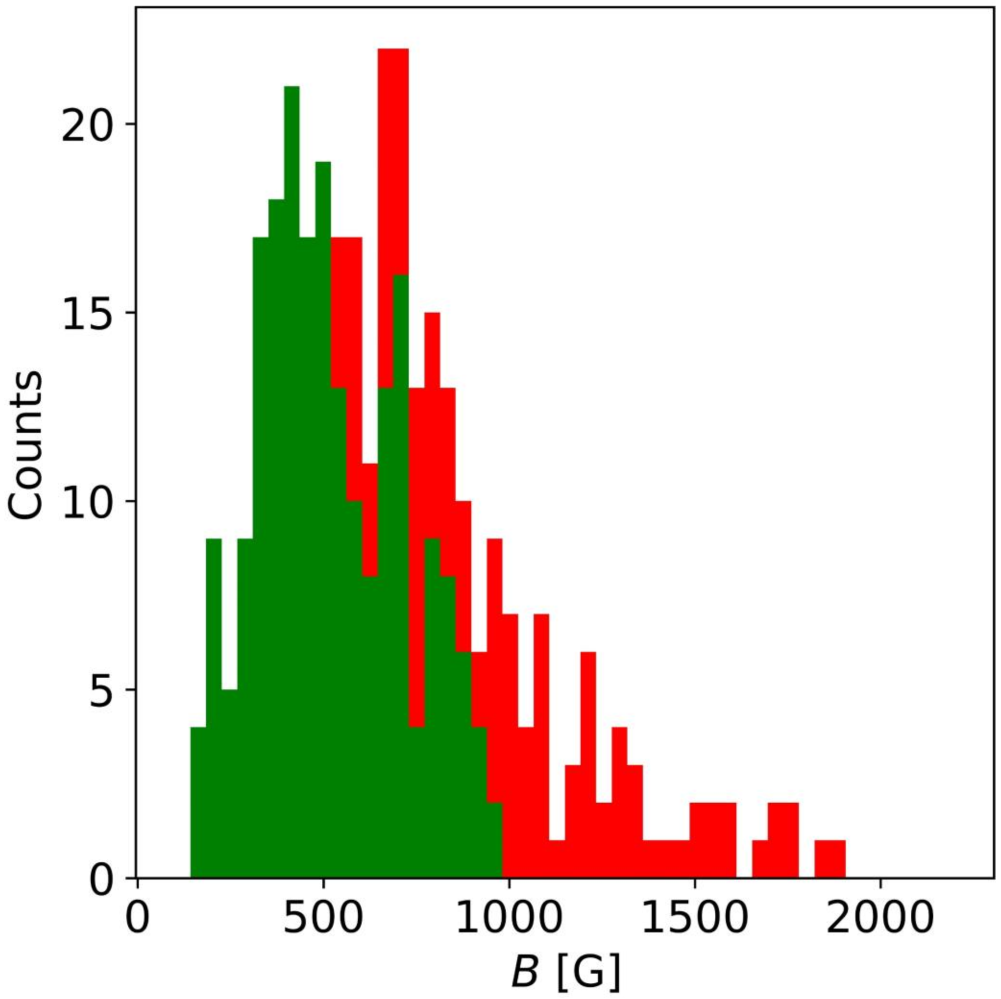
# Spicules results



# Coronal rain results




$$B \ll \frac{\Delta\lambda_D}{4{,}67 \times 10^{-13}\, \bar{g}\lambda_0^2} \approx \frac{\sigma_I}{4{,}67 \times 10^{-13}\, \bar{g}\lambda_0^2}$$

# Conclusions

- The WFA cannot be blindly applied to a whole dataset, a meticulous consideration of its validity is necessary.
- The results lead us to believe that the magnetic field present in spicules and coronal rain clumps is mainly of the order of hundreds of Gauss. Lower values are not inferred possibly due to noise level limitations.
- There seems to be no difference between the order of magnitude of the value of the magnetic field present in quiet Sun spicules and active region spicules.
- It is possible to couple the WFA with the velocity measurement in order to obtain the magnetic field strength. Magnetic fields of up to 1000 G could be safely inferred, although the results suggest that even larger values can be present.

The results were published as Kriginsky et al. (2020, 2021) in A&A.

Paper 1

Paper 2