# Magnetic field inference in the chromosphere and lower corona

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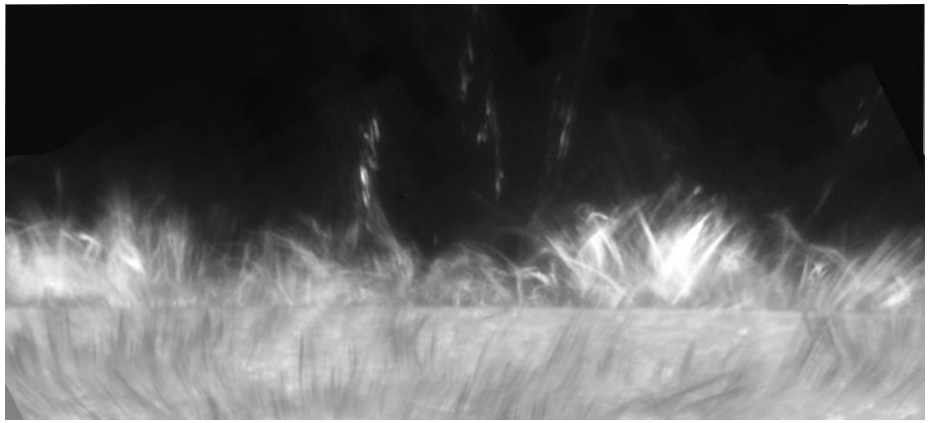
The Weak Field Approximation (WFA) is used to infer the line-of-sight magnetic field of the solar chromosphere and lower corona. Using near limb spectropolarimetric observations in the Ca II 8542 Å line taken with the CRISP instrument at the Swedish 1-metre telescope in La Palma, the presence of an active region near/in the field of view allows for the presence of chromospheric spicules and coronal rain blobs to be detected. This work focuses mostly in the inference of magnetic fields of off-limb spicules, but a successful attempt to obtain Stokes V signal from the coronal rain blobs allowed for the inference of coronal magnetic fields. A careful treatment of the data pixels is undertaken in order to guarantee the correct application of the WFA, and the results show the presence of ubiquitous hundred-Gauss magnetic fields in the spicular material and in the coronal rain blobs. A Bayesian approach is used to infer the results.

# Context of research

Chromospheric spicules are cold and dense jets that originate at the photosphere and reach lower coronal heights. They are highly dynamic with lifetimes of a few minutes.

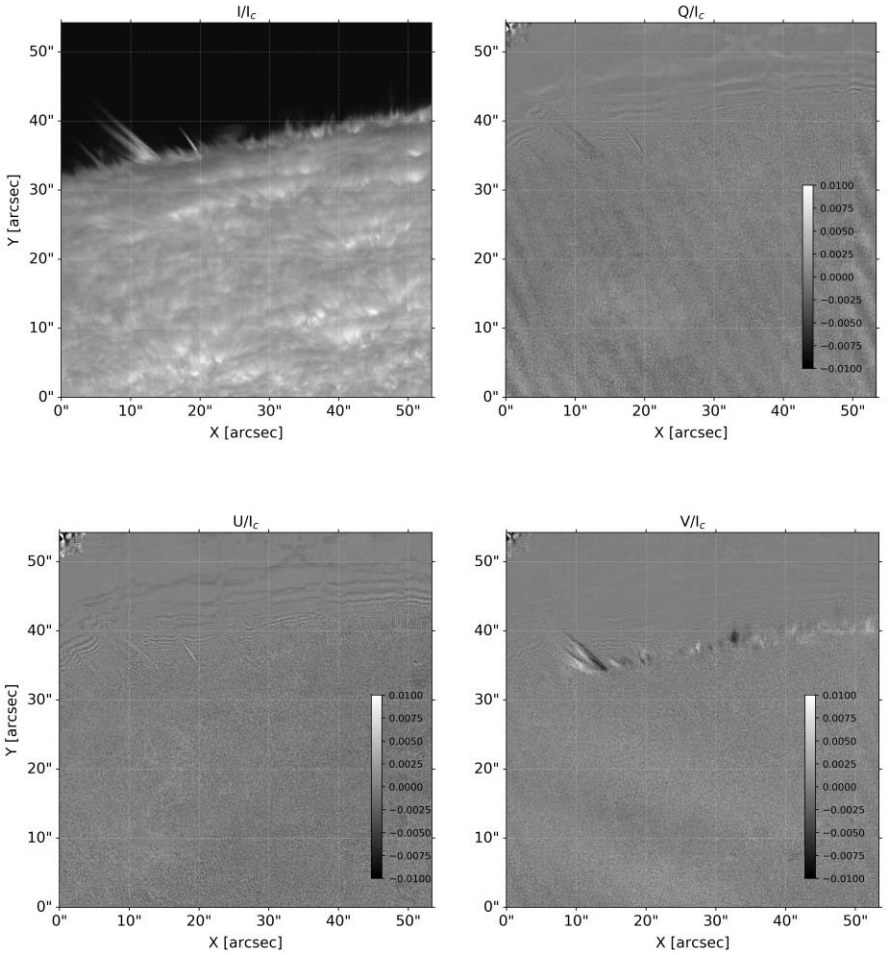
Coronal rain is formed as a result of condensation at the apex of coronal loops by means of catastrophic cooling.



Spicules at the limb and coronal rain blobs seen at Hα 6563 Å (*J. de la Cruz, 2010)*

Different observations were taken on 02, 03 and 09 June 2016 with the CRISP instrument at the SST, spanning the Ca II 8542 line with full Stokes spectro-polarimetry. 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.

Stokes vector at 03 June 2016 16:27:42 UT



# Method

The line-of-sight (LOS) component of the magnetic field vector is inferred using the weak field approximation (WFA). A relation between the intensity ($I$) and the circular polarisation ($V$) is obtained:

$$V(\lambda) = -4.67 \times 10^{-13} \bar{g} f \lambda_0^2 B_{\mathrm{LOS}} \frac{\partial I(\lambda)}{\partial \lambda}$$

where the proportionality is given by the Landé factor of the line, the filling factor, the wavelength of the transition, and the LOS magnetic field component. Expressions for the Stokes $Q$ and $U$ components can be used to infer the plane-of-the-sky component of **B** but the data used have poor $Q$ and $U$ signals and therefore they were not used.

In order to properly use this expression, the Zeeman splitting of the line needs to be much smaller than the Doppler width, and the magnetic field must be uniform along the LOS.

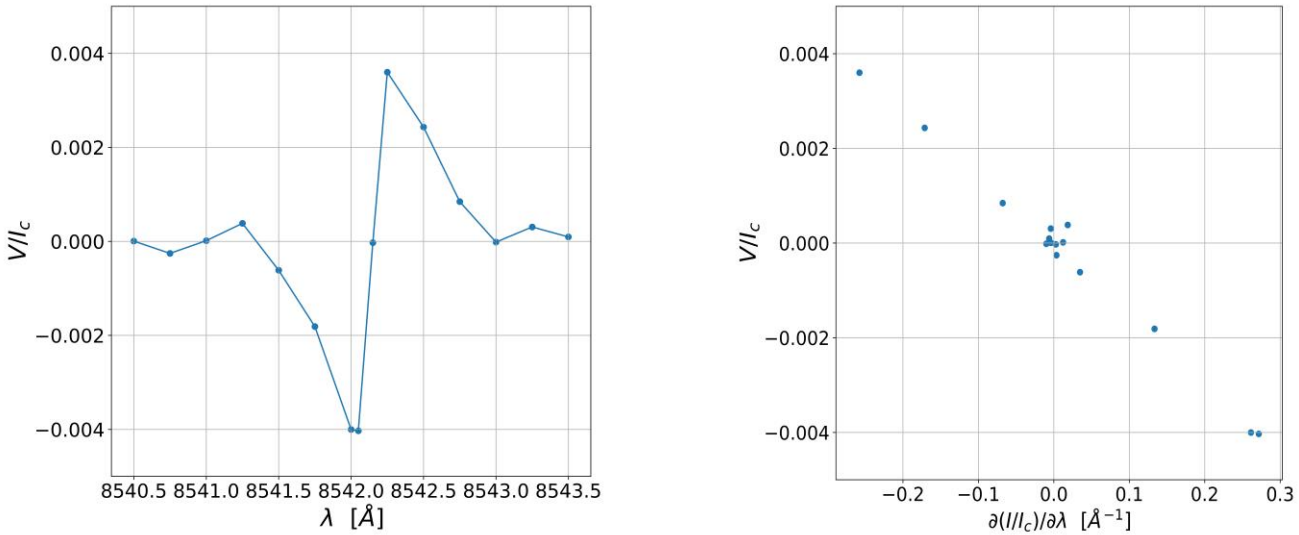
For the Ca II 8542 Å line the first condition translates into measuring fields for which $|\mathbf{B}| \ll 2650$ G. This condition is assumed to be satisfied for the chromosphere.

The second condition is more difficult to check, and it is analysed through the imprint that a gradient of **B** leaves on the Stokes $V$ profile in the form of asymmetries. This is assessed by analysing the amplitude asymmetry of the $V$ profiles.

Given the linear nature of the relation used, a correlation analysis through Pearson's correlation coefficient ( **R** ) is done. Only profiles for which **R** is greater than 0.9 are used.

The amplitude asymmetry of the Stokes $V$ profile of the pixels that satisfy the correlation criterion is measured, and only the pixels for which the difference of the amplitudes of the red and blue lobes is much smaller than the average noise present on the data are then used to infer the LOS magnetic field component.

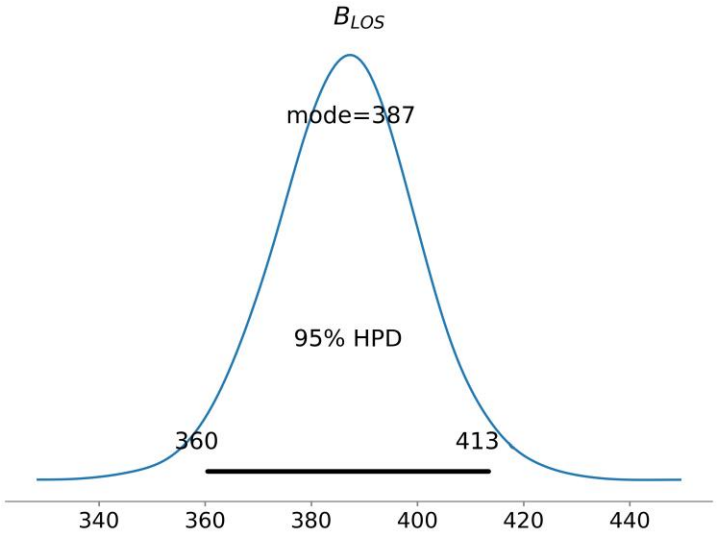
Example of a Stokes $V$ profile that satisfies the correlation and asymmetry criteria



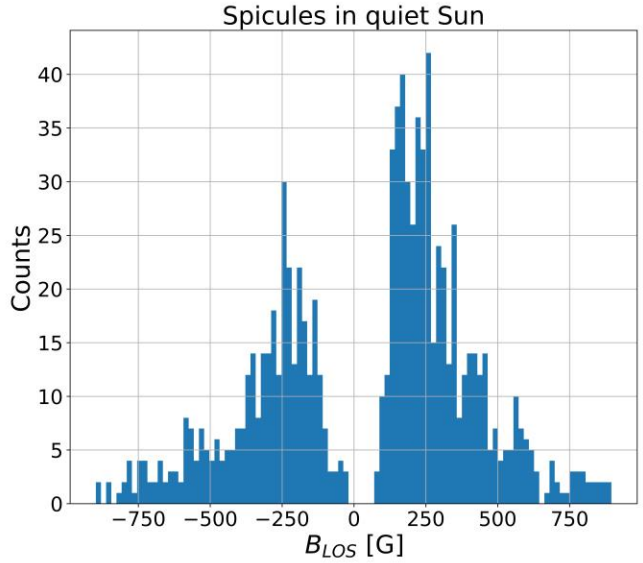

In the case of coronal rain blobs, each blob is studied in detail, and a spatial averaging over the shape of the blob is undertaken in order to increase the SNR before the correlation and asymmetry analyses. The spicule data are not spatially or temporaly averaged.

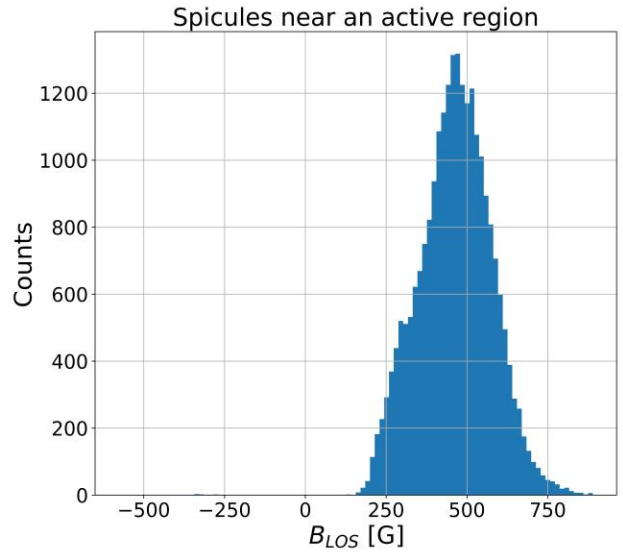
A Bayesian inference is done in order to obtain a probability distribution for the LOS magnetic field component. From this distribution, the mode and the Highest Posterior Density interval (HPD) are extracted as statistical results.

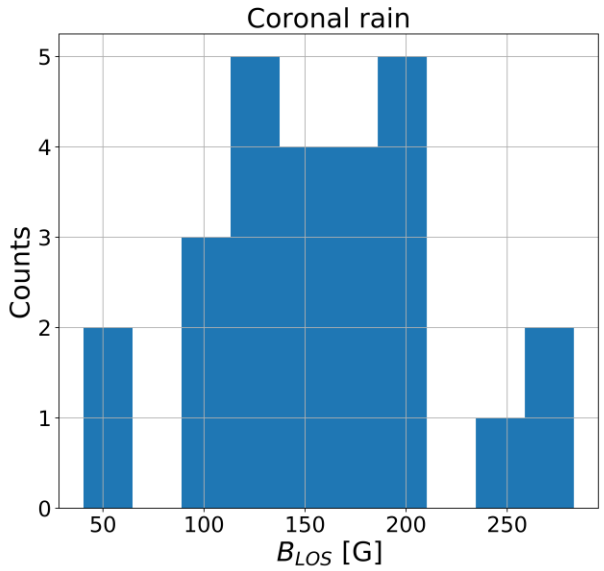
# Results




Example of a probability distribution for the LOS component of **B** with its mode and 95 % HPD interval




Top: Example histograms showing the inference results for 2 of the 11 data sets depending on the location of the spicules.

Bottom: histogram of the results for coronal rain blobs adding all data sets together and taking the absolute value of the LOS component of B

# Conclusions

- We have found that in order to apply the WFA, a careful analysis of the validity of its assumptions needs to be undertaken in order to obtain reliable results. The magnetic field vector must be constant along the LOS, and here we decided to verify this condition by studying the asymmetry of the Stokes *V* profile.

- We have found that the magnetic fields present in spicules is in general of the order of hundreds of gauss, and no evidence has been found of any difference in the values inferred from quiet sun spicules and those spicules n ear active regions.

- Near an active region, the sign of the LOS component of the magnetic field is directly related to the relative position of the spicules with respect to the nearest magnetic polarity, while for spicules in quiet Sun their inclination is not restricted, a fact that allows both signs of the LOS component of **B** to be inferred with an almost symmetric histogram as expected.

- We have also found that the magnetic fields in the lower corona are of the order of a few hundred gauss, devising a new method that can be used to infer information about the magnetic structure at such heights.

- The full magnetic field vector could be inferred with the WFA if the linear polarisation signal is strong enough to be above noise level.

The spicules results have been submitted for publication: https://arxiv.org/abs/2006.01809