Determining the magnetic field vector in solar prominences

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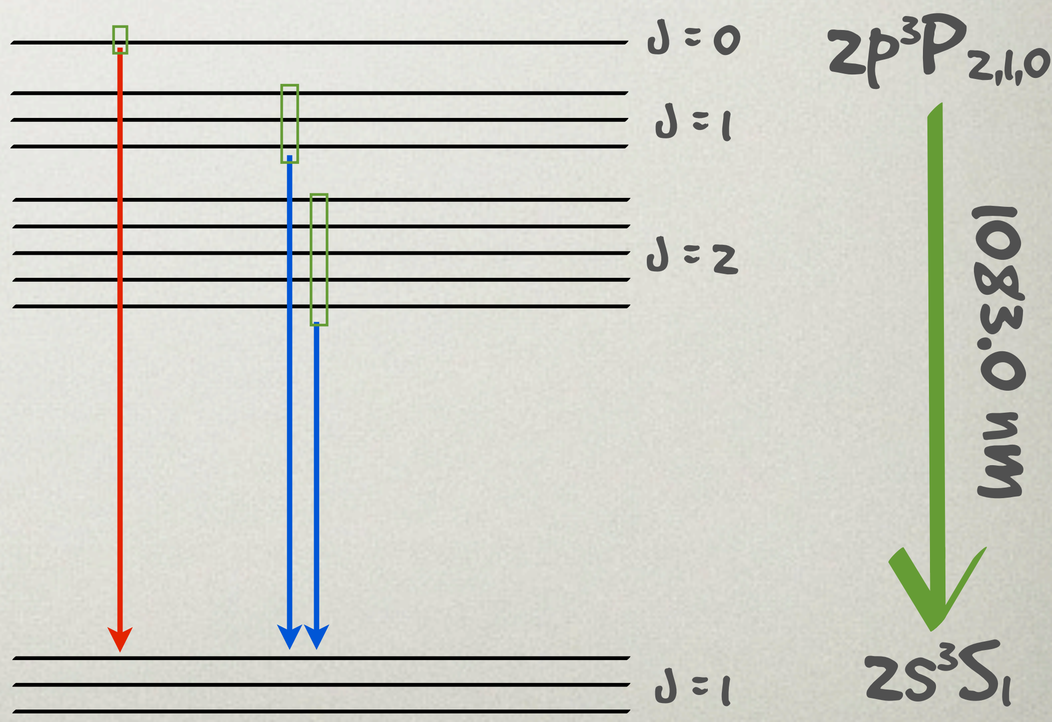
Measuring the magnetic field vector in prominences

- Presently, the magnetic field configuration of solar prominences can be inferred from spectropolarimetric observations taken in the 1030 nm spectral range.
- This spectral range contains **the He I 10830 Å triplet** which is sensitive to the joint action of **atomic level polarization** (i.e., population imbalances and quantum coherences among the level's sublevels, generated by anisotropic radiation pumping) and the **Hanle** (modification of the atomic level polarization due to the presence of a magnetic field) and **Zeeman** effects.
- This triplet is sensitive to a wide range of field strengths. The Stokes Q and U signals are dominated by atomic level polarization and the Hanle effect and what basically allows us to determine the field orientation while Stokes V is mostly dominated by the longitudinal Zeeman effect and make possible a robust determination of the field strength.

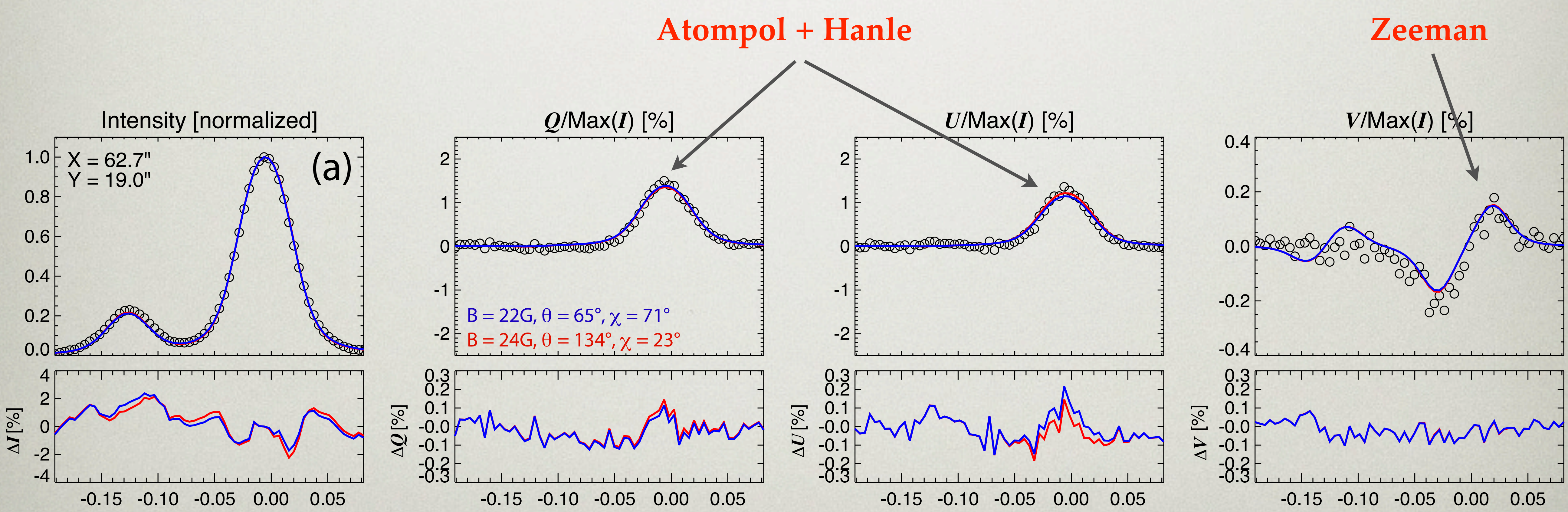
- The physics of the Hanle and Zeeman effects in this triplet is described in:

- Trujillo Bueno, J., et al, 2002, Nature, 415, 403
- Socas-Navarro, Trujillo Bueno, Landi Degl'Innocenti, 2004, ApJ, 612, 1175
- Trujillo Bueno , J., & Asensio Ramos, A., 2007, ApJ, 665, 642
- Based on the quantum theory of polarization (Landi and Landolfi 2004)



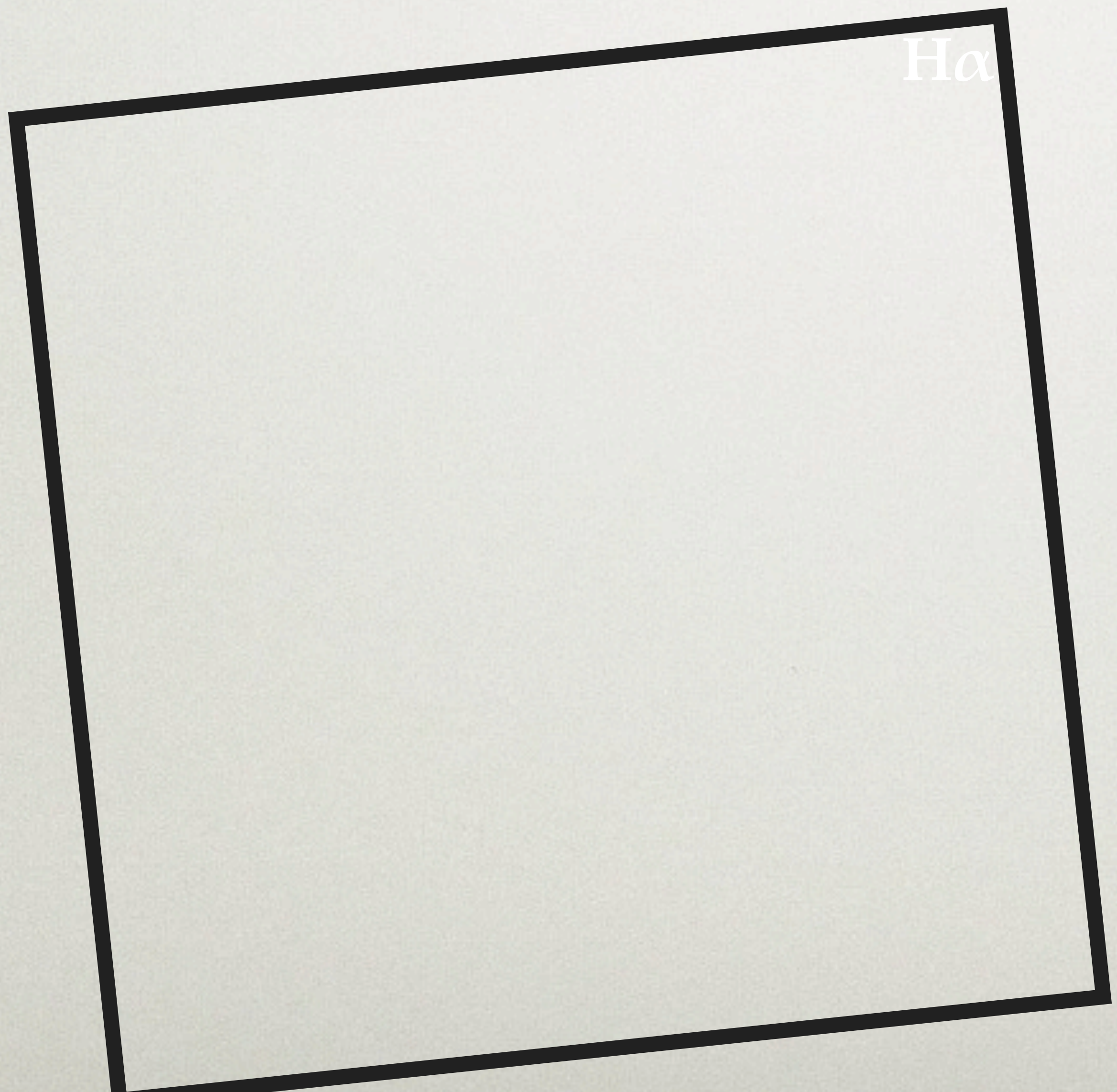
He I 10830 Å triplet profiles (in a prominence)

- Example of a prototypical He I 10830 Å in 90° scattering geometry (emission) profile showing the fine structure of the multiplet, with a weak blue component at 10829.09 Å ($^3S_1$-$^3P_0$) separated about 1.2 Å from the other two components at about 10830.29 Å ($^3S_1$-$^3P_1$ and $^3S_1$-$^3P_2$), which are indistinguishable.
- Interpreting Stokes Q, U, and V signals we can determine the three components of the magnetic field vector.
  - Example fit of the **HAZEL code** (Asensio Ramos, Trujillo Bueno & Landi Degl'Innocenti 2008, ApJ, 683, 542).



Measuring the field vector in prominences
(Sept. 2012 data)

- Tenerife Infrared Polarimeter installed at the German Vacuum Tower Telescope (Tenerife, Spain)
- Pixel sampling: 0.5”; Spectral sampling: 1.1μm. ; Spatial resolution of about **1”-1.5”**.
- The exposure time per slit position was about 30 seconds to achieve high signal-to-the-noise ratios in linear and circular polarization = 1.5 hours to scan about 60”x80” field-of-view.
- Small-scale structures, i.e., vertical “threads”, cavity, and plumes are visible in the observations



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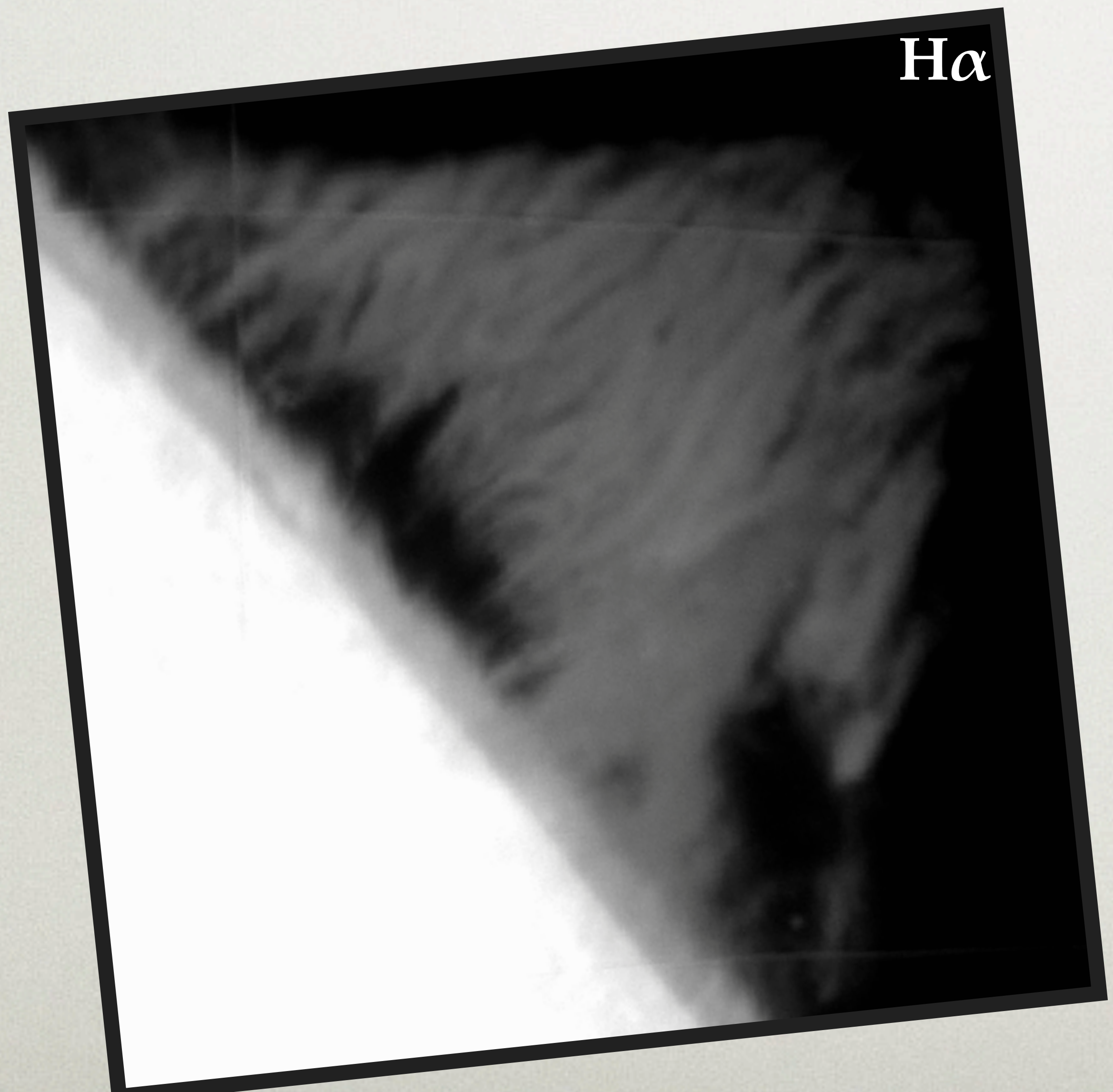

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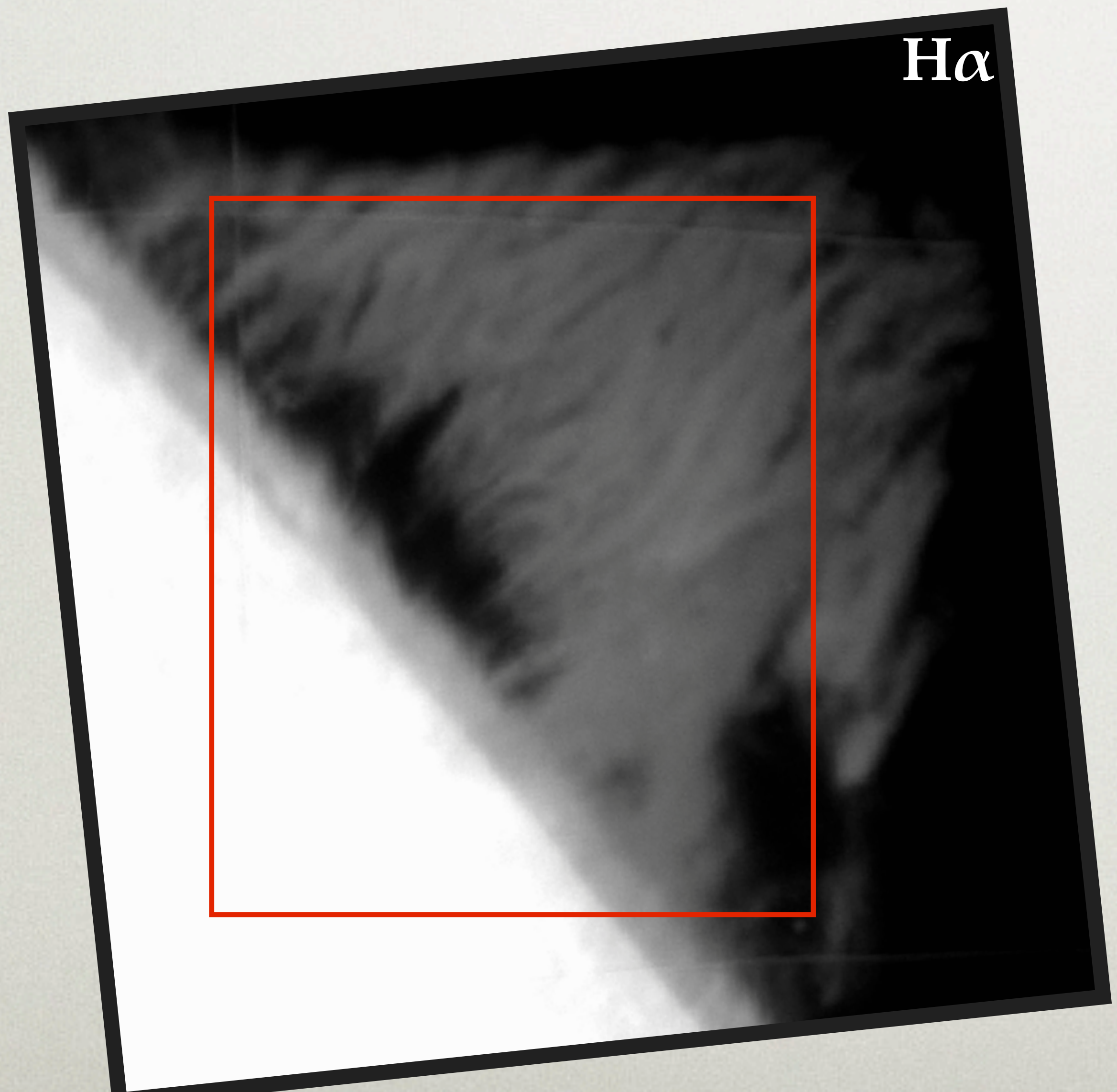
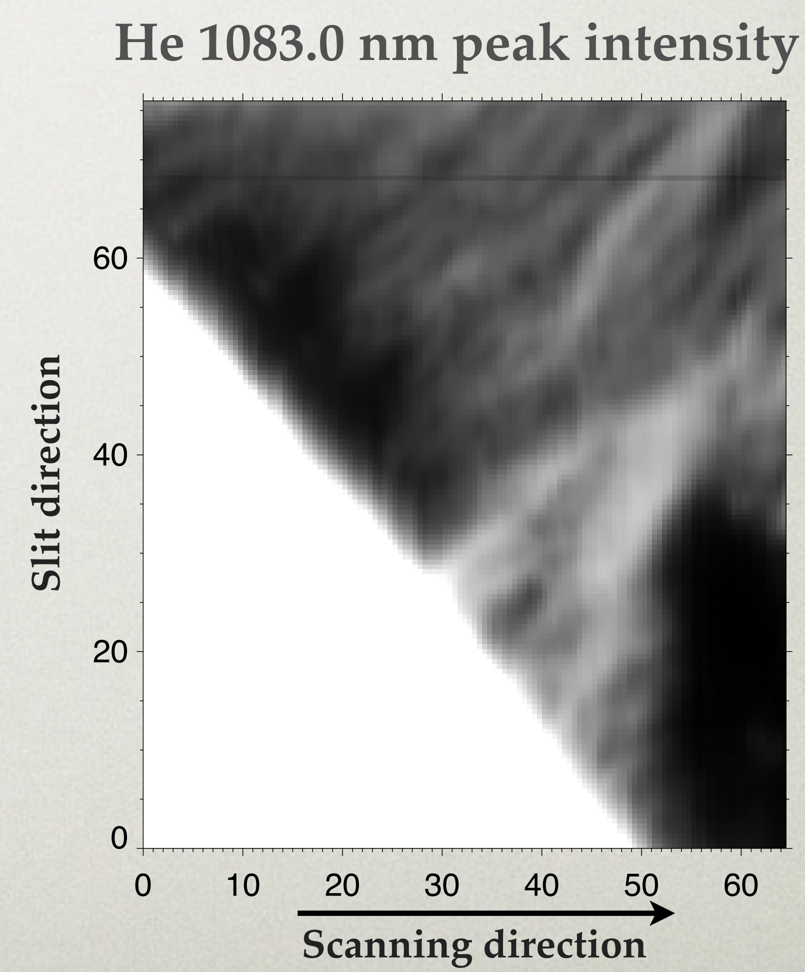
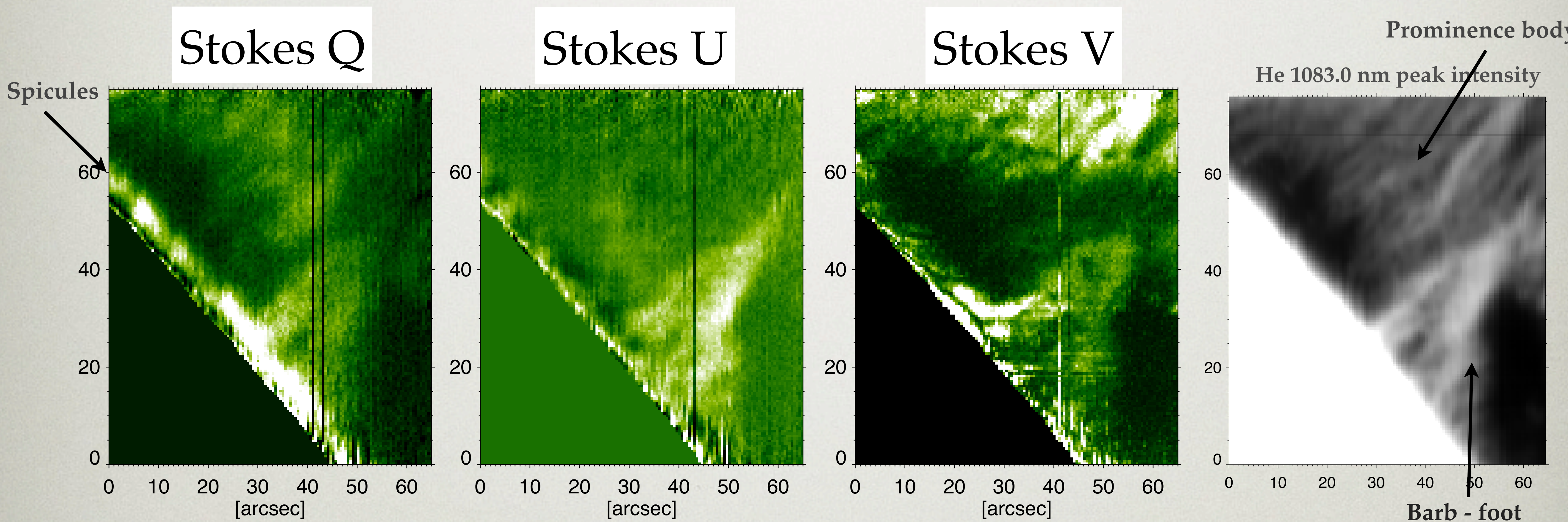




Polarization signals



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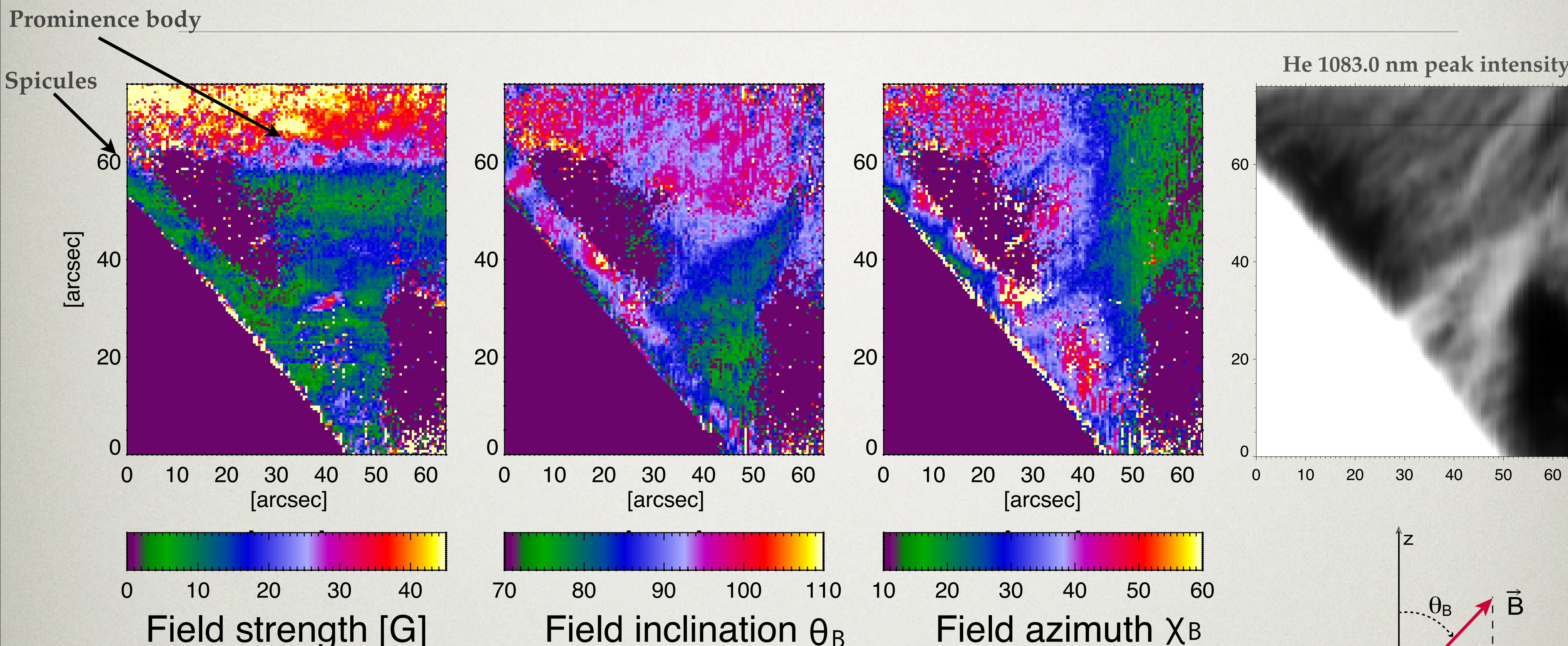
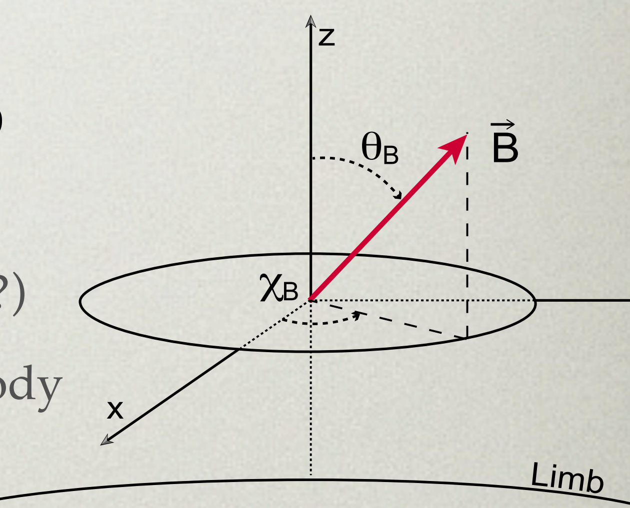
Inversion Results ("horizontal" solution)

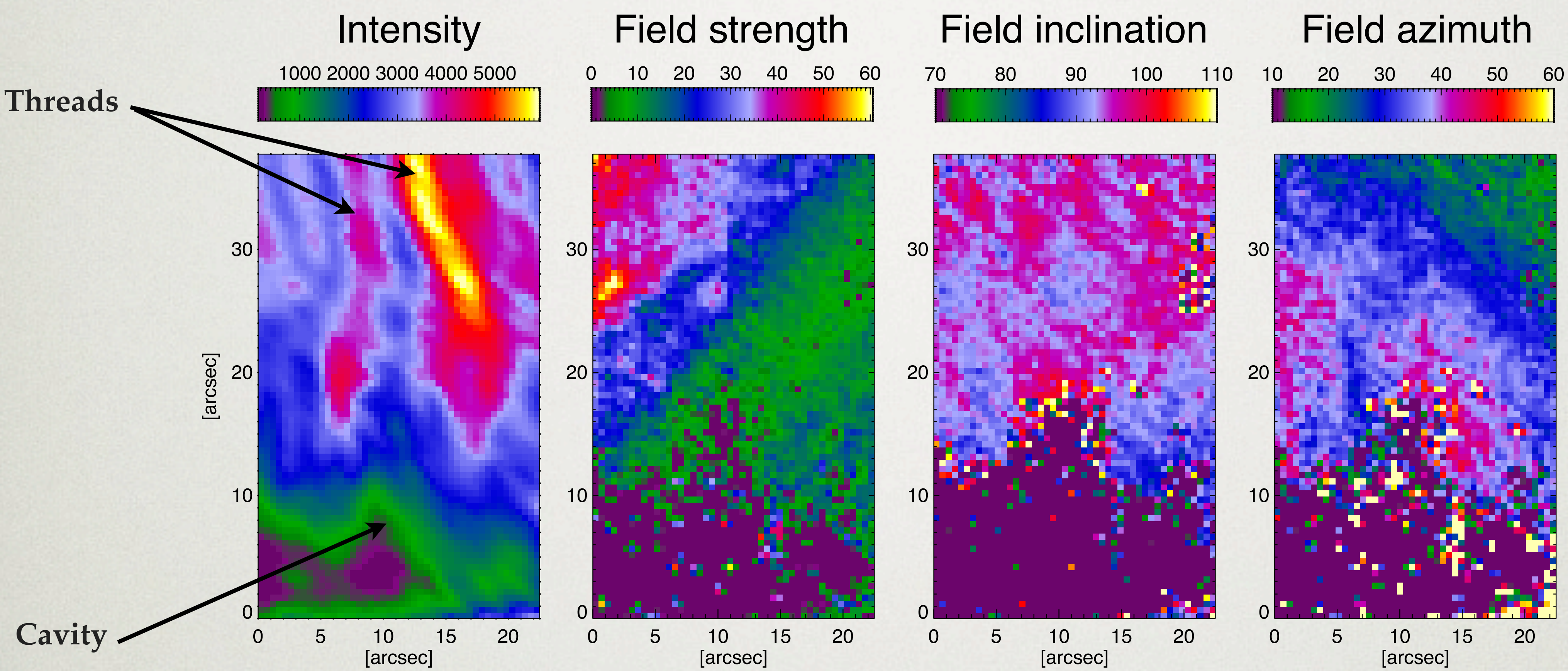




- The field strength is about 10-15 Gauss and increases up to 40 G: projection effects (?)
- The field is 90 degree inclined with respect to the local vertical in the prominence body and becomes slightly more vertical at the "barb"
- The field is oriented about 10-15 degree with respect to the prominence main axis (inferred with the help of STEREO images and the azimuth). The field is more aligned to the line-of-sight in the upper part of the prominence.

Orozco Suárez, Asensio Ramos, and Trujillo Bueno, A&A, in preparation

Magnetic field vector in small scales prominence structures

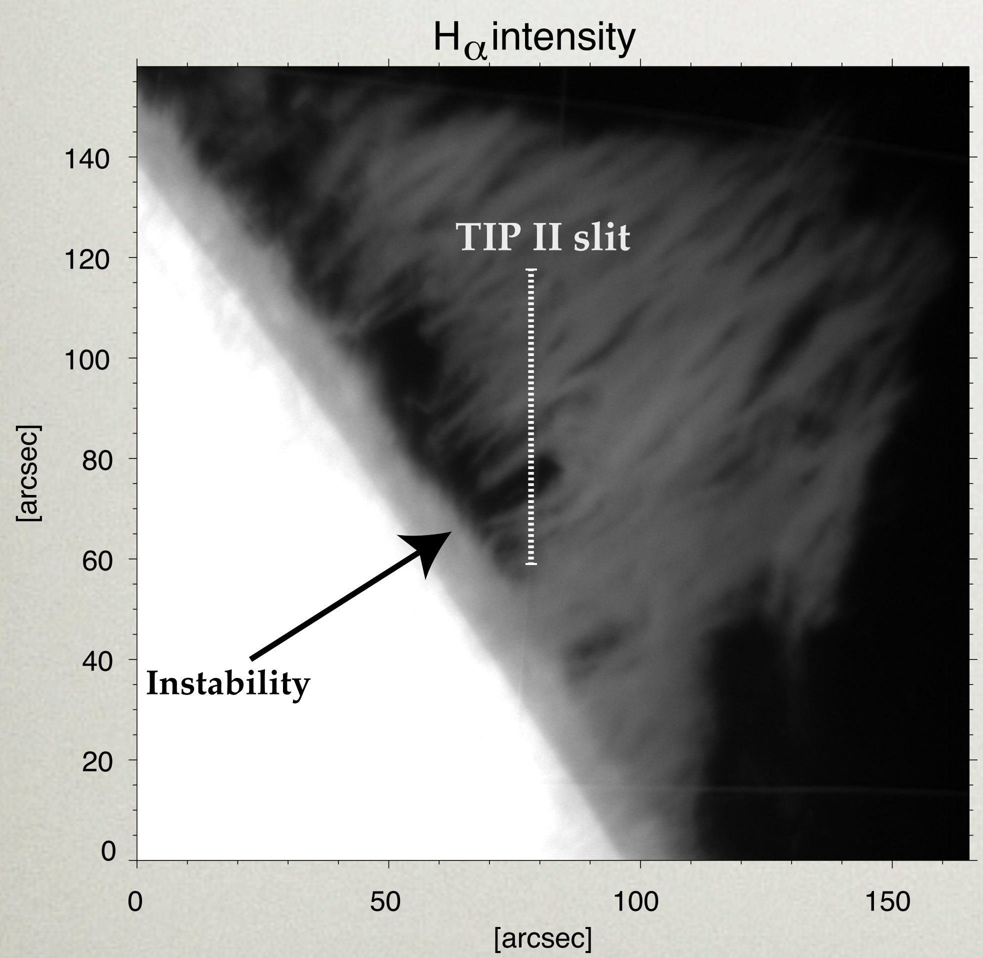


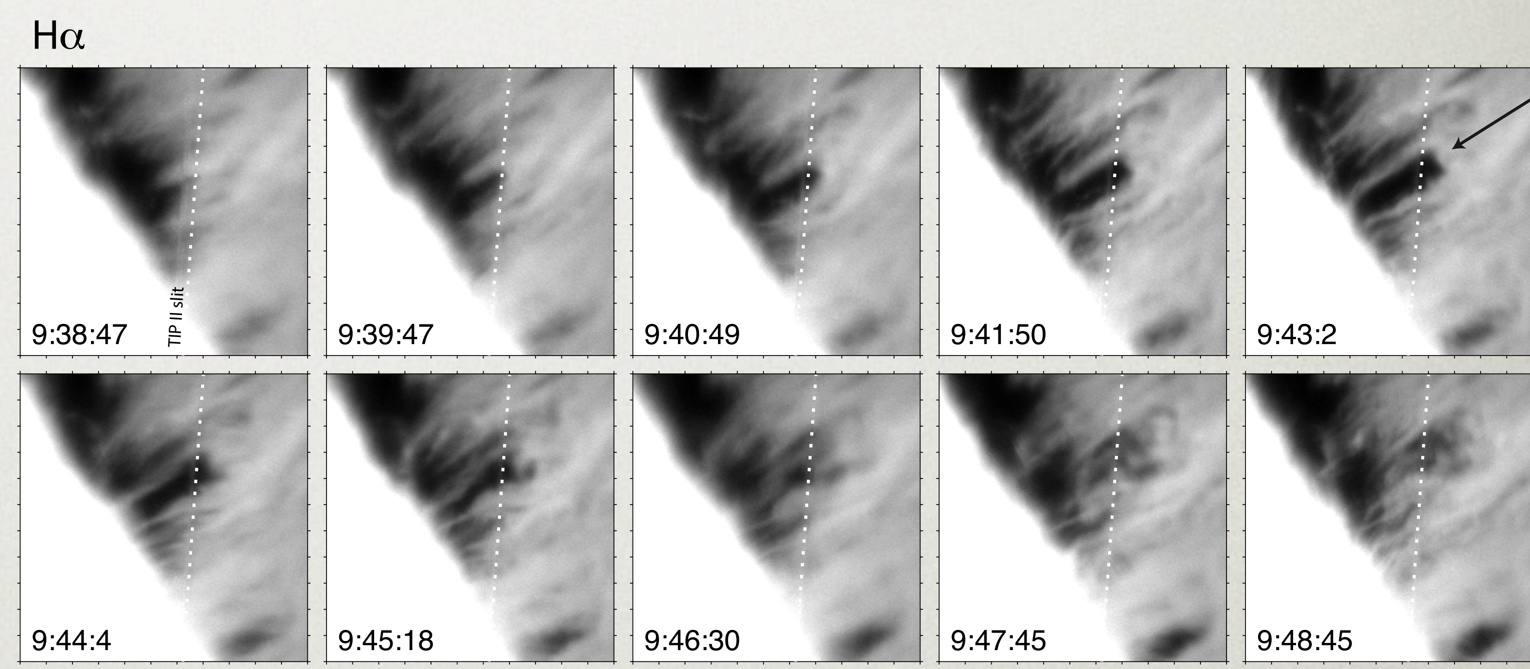
- Neither local variations of the field vector or correlations between the thread pattern in the intensity images and the magnetic field vector
- Long integrations times (+ 30 s) and/or lack of spatial resolution (1″-1.5″) may be hampering the analysis (e.g., highly dynamic structures may blur the field information)

Orozco Suárez, Asensio Ramos, and Trujillo Bueno, IAUS300, 2013

Doppler shifts and magnetic field vector in a prominence instability

- Dark cavity rises from below the prominence and become a plume
- The TIP II slit was taking a time series and recorded the pass of the rising plume





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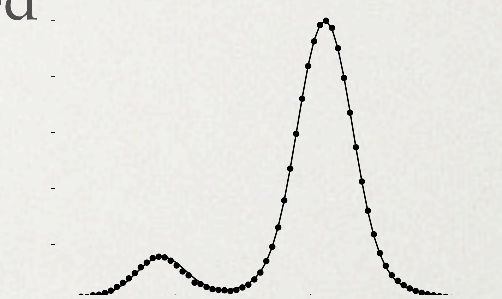

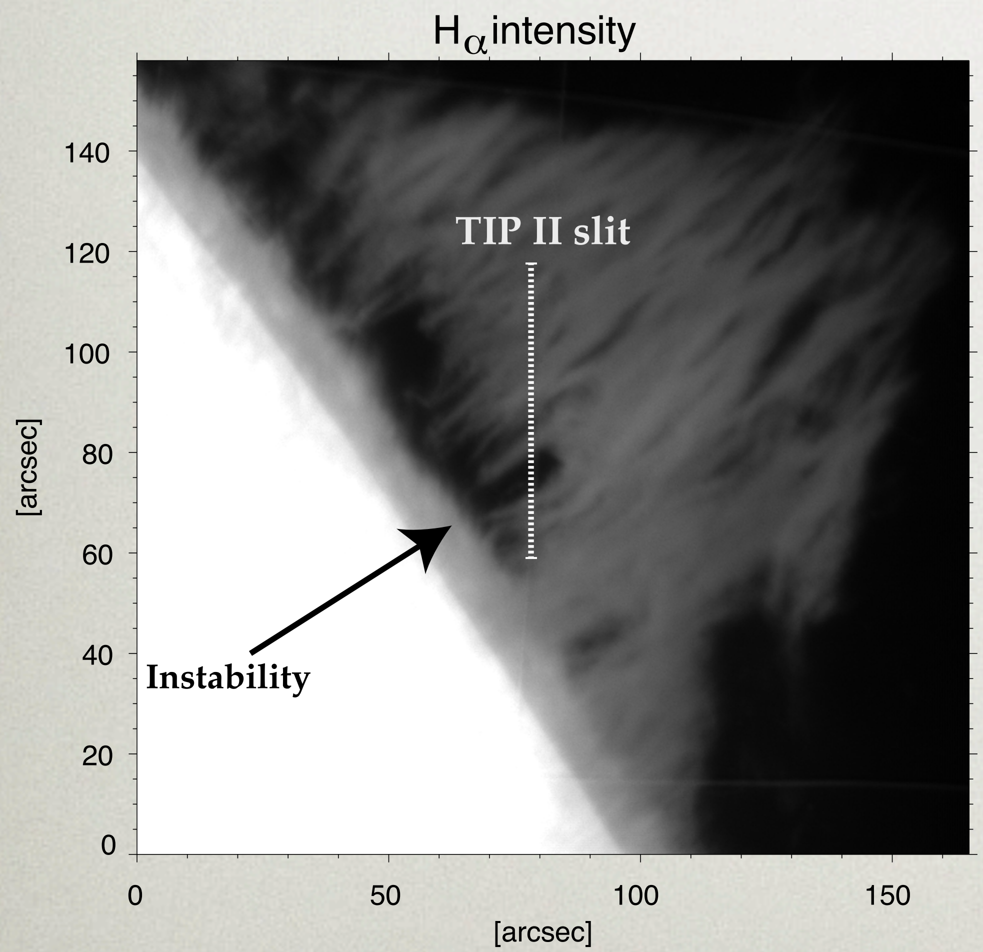

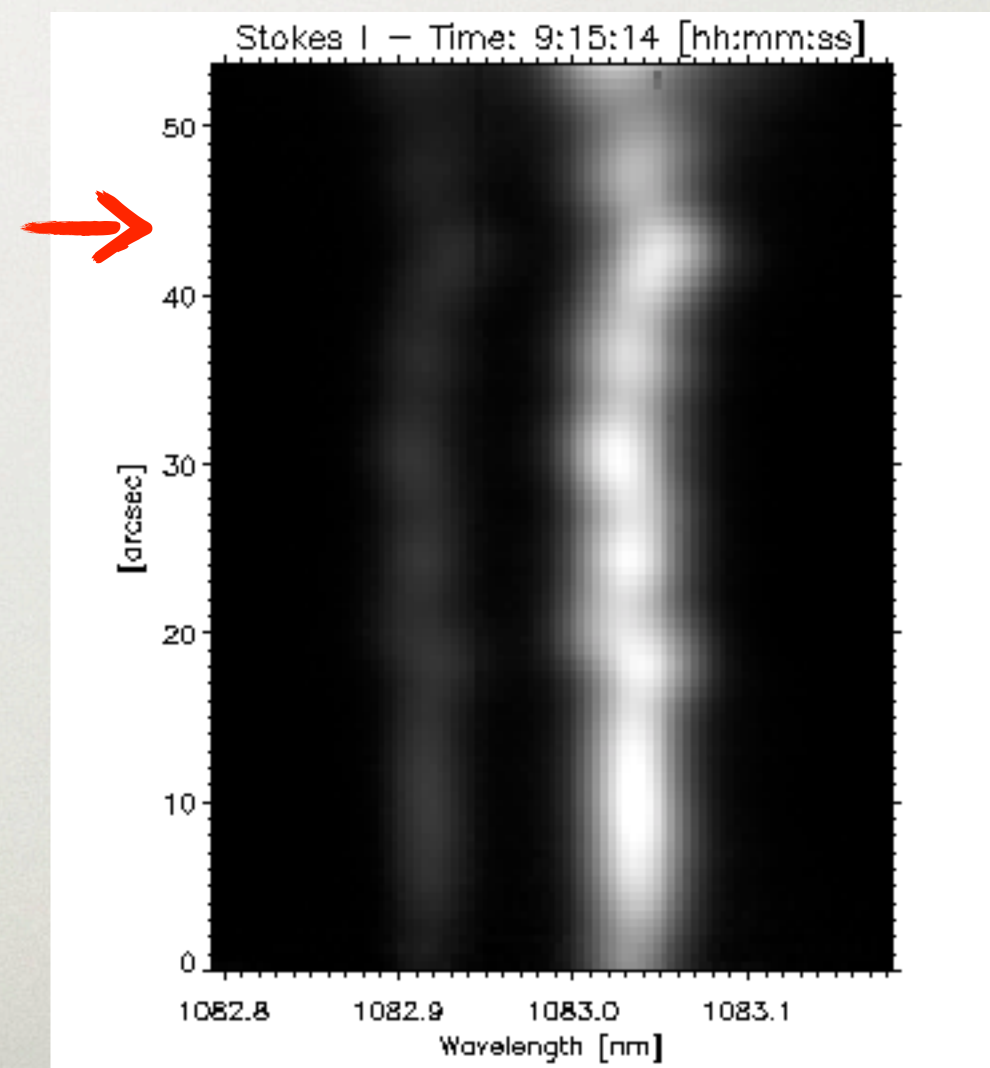

6 seconds cadence

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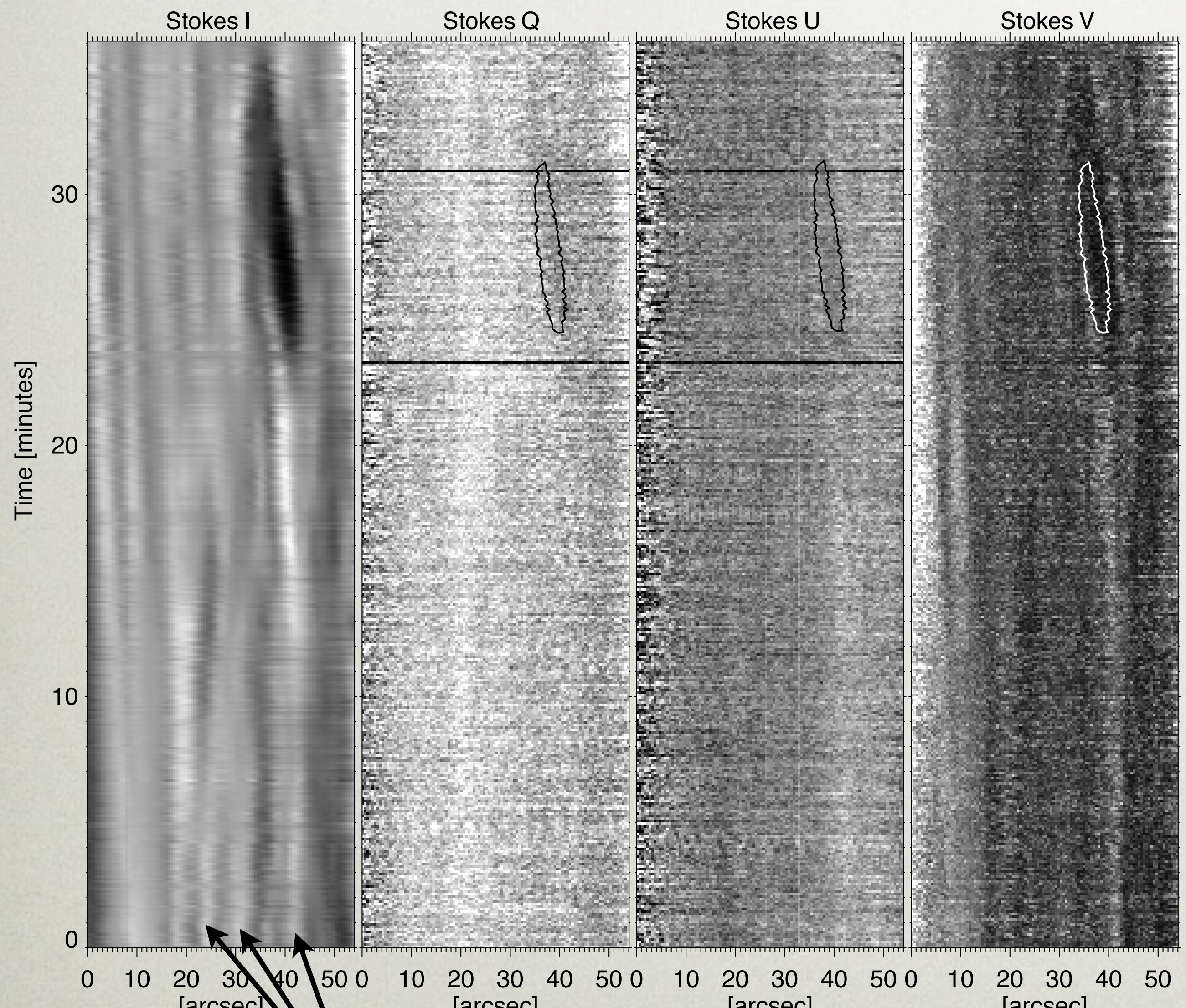
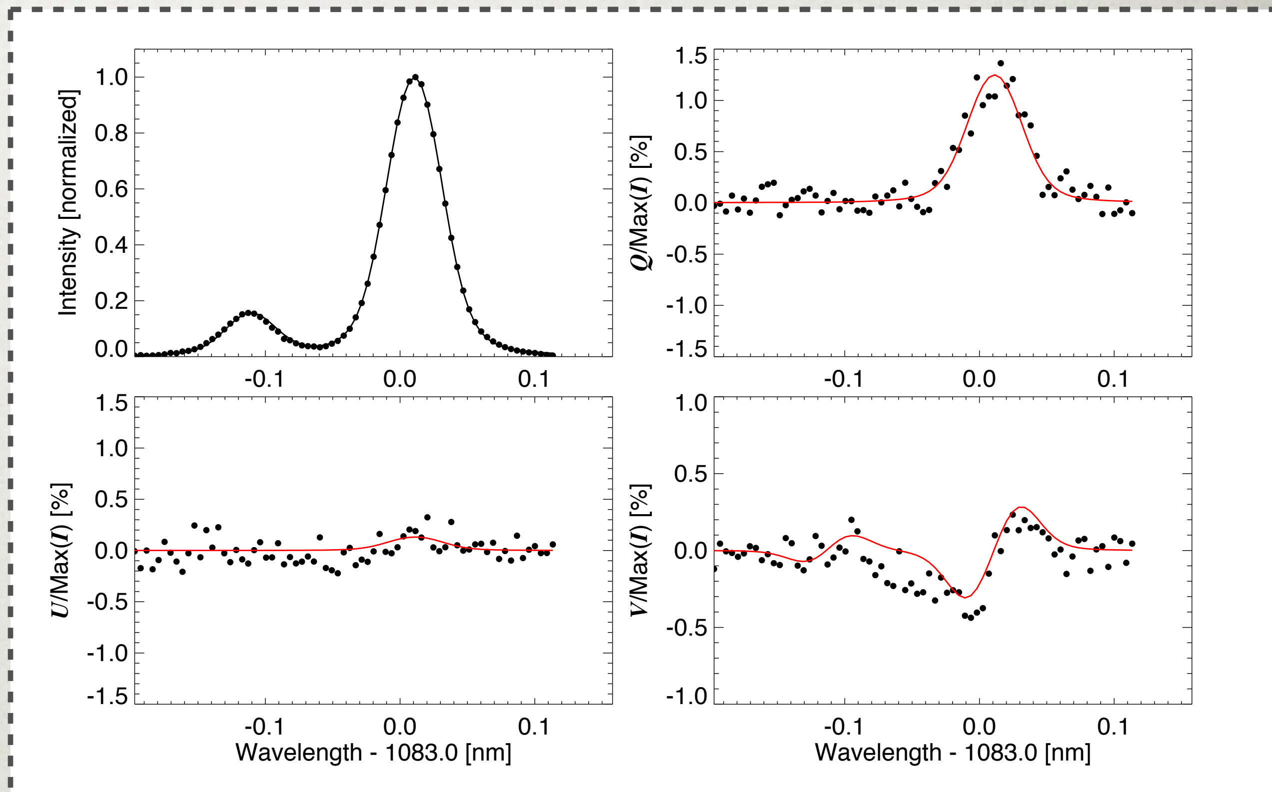


Threads cross sections

- Next step: determination of the magnetic field vector in and around the bubble



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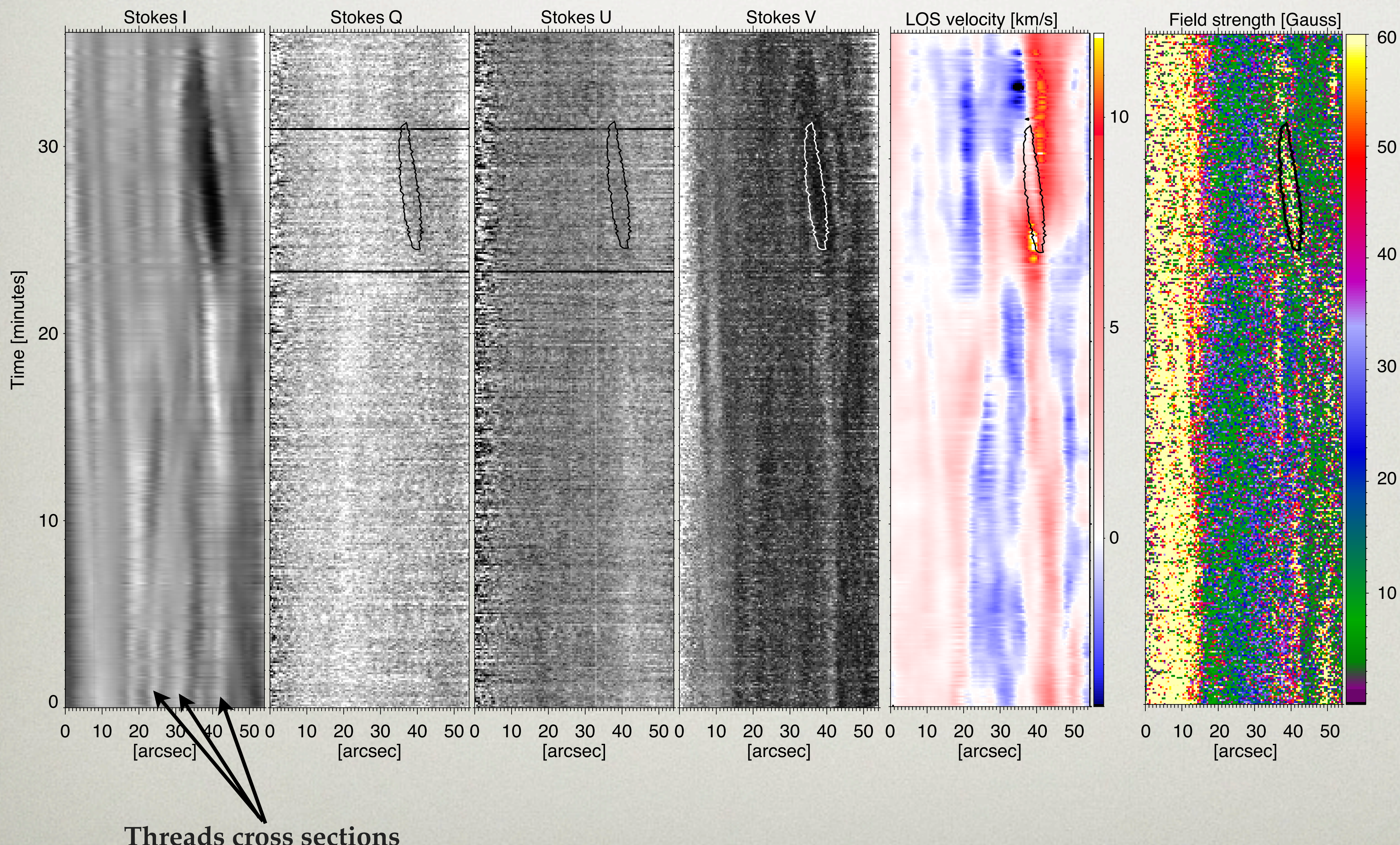
Doppler shifts and magnetic field vector in prominence instabilities

- Strong red-shifts (away from the observer) in the boundaries
- No field strength variations during the pass of the instability through the TIP-II slit



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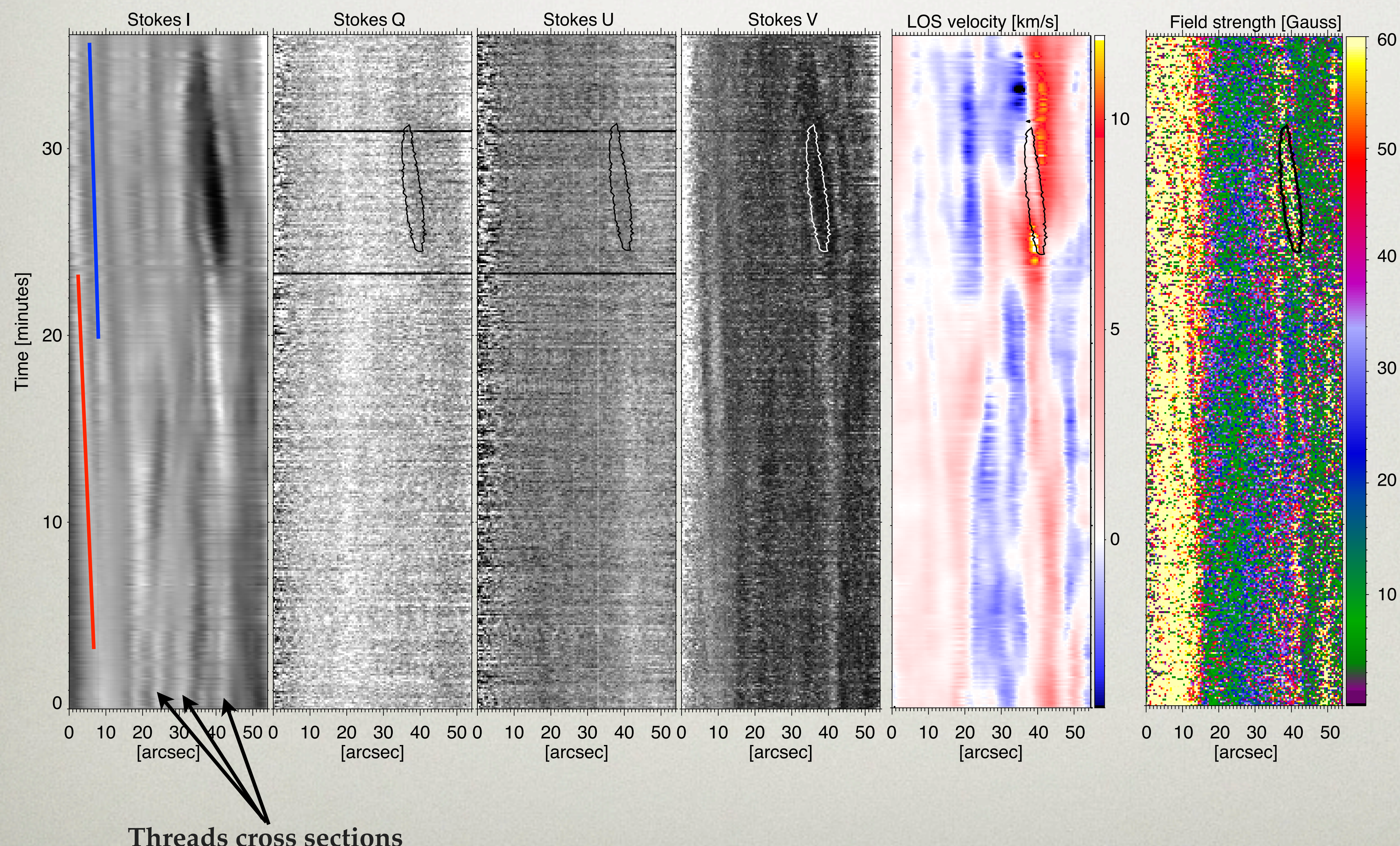
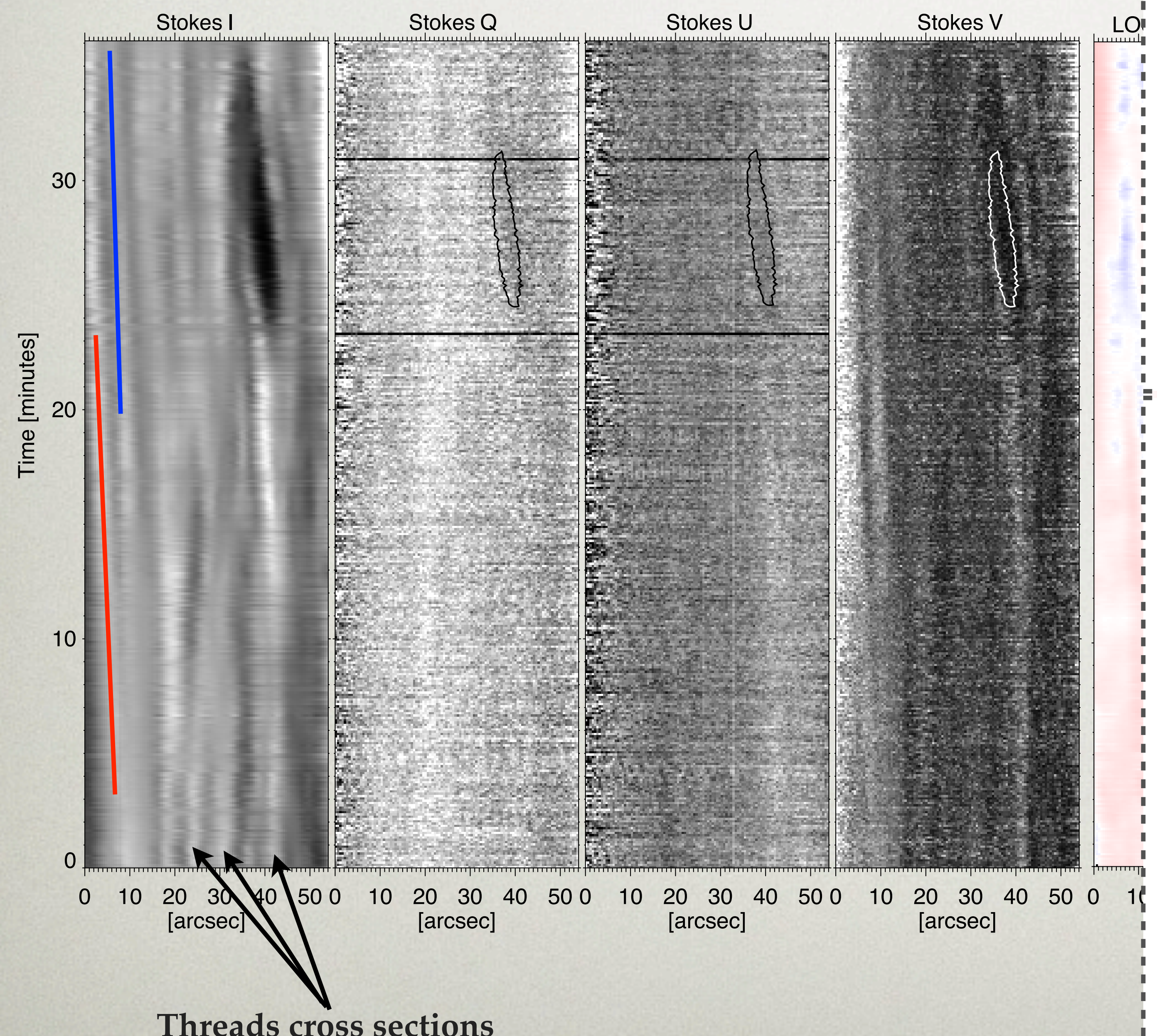
Oscillations in individual structures

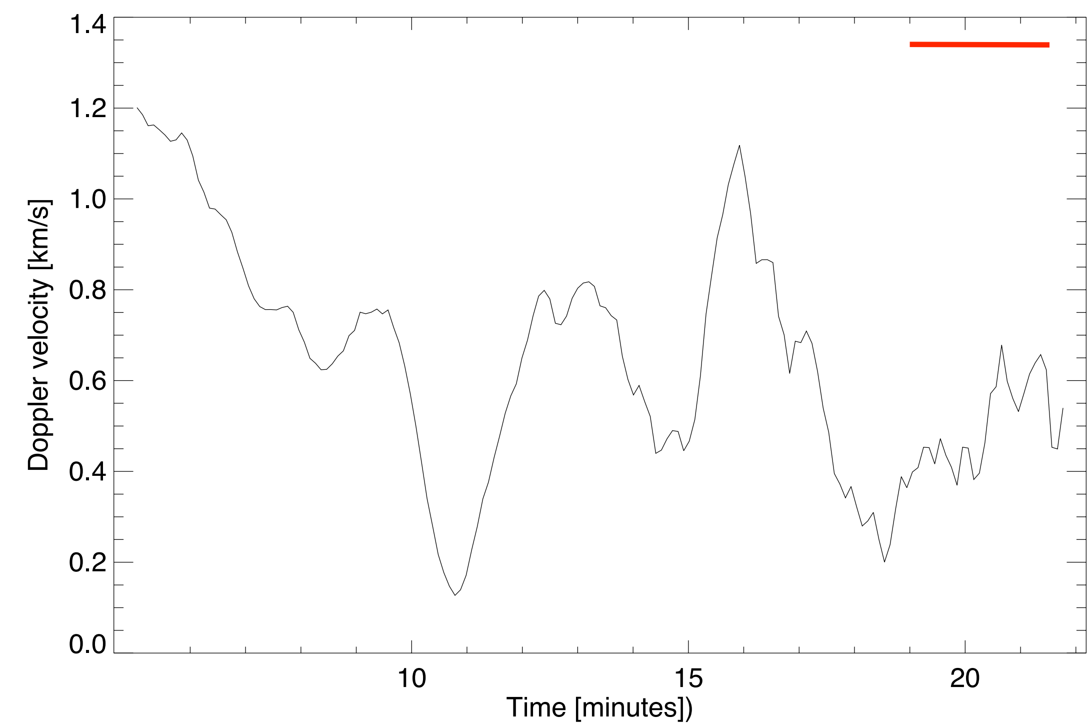
- Evolution of individual prominence fine scale structures

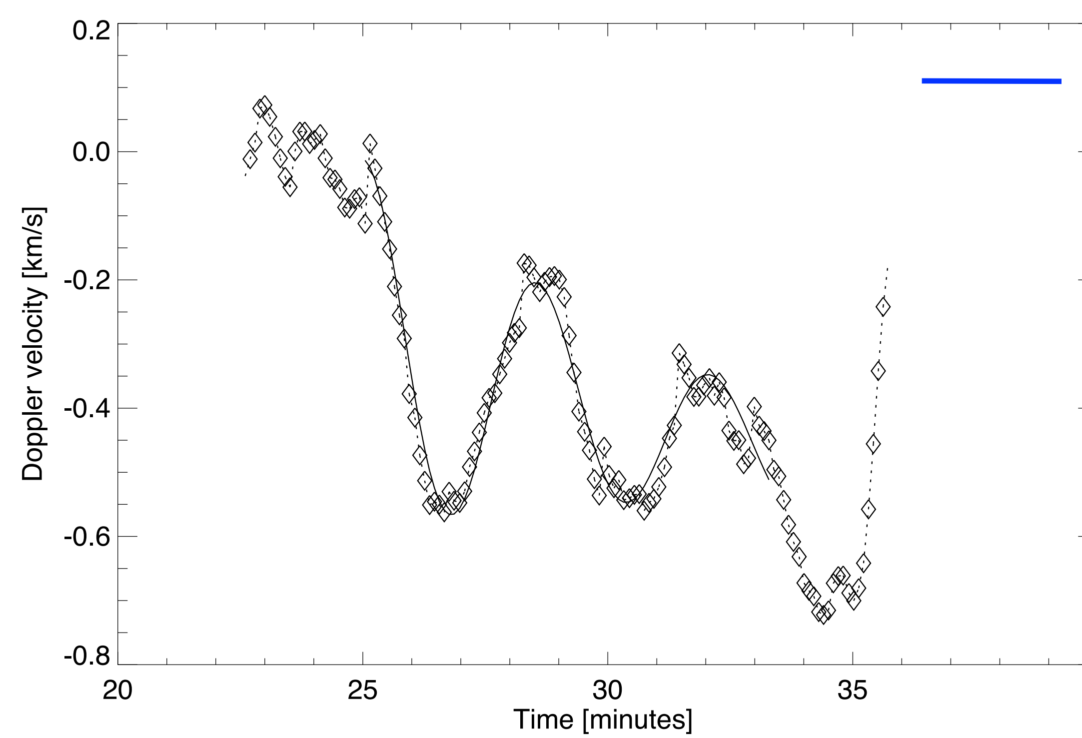


Oscillations in individual structures

- Evolution of individual prominence fine sca
- Detection of damped oscillations







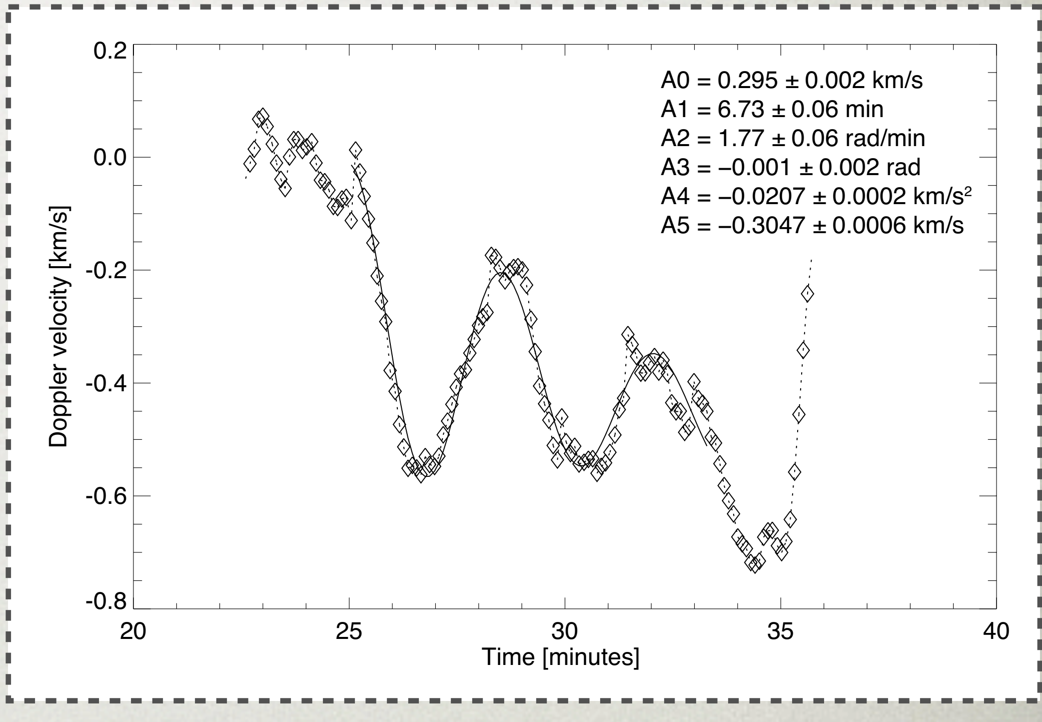
OSCILLATIONS IN INDIVIDUAL STRUCTURES

- We can apply seismology techniques to other infer plasma parameters assuming that the damping is produced by resonant absorption (Arregui et al. 2008, ApJL, 682, L141; Arregui & Ballester 2011, SSRv, 158, 169). To this end we infer first the oscillation period P and the damping time following Soler et al. (2010, ApJ, 722, 1778)

$$P = \frac{\pi L}{C_{\mathrm{A_p}}}\sqrt{\frac{w}{L}\left(1-\frac{w}{L}\right)\frac{1+\rho_c/\rho_p}{2}} \approx \frac{\pi}{C_{\mathrm{A_p}}}\sqrt{\frac{wL}{2}}$$

$$\frac{\tau}{P} = \frac{4}{\pi^2}\frac{R}{l}\frac{\rho_p+\rho_c}{\rho_p-\rho_c} \approx \frac{4R}{\pi^2 l}$$

$$C_{\mathrm{A_p}} = B_0/(\mu\rho_p)^{1/2}$$



- Then, we can obtain L, the density, or the field strength. For instance, if we assume values for L = 10^5 km and ρ = 10^{-10} kg/m^{-3}, with w=15000 km, we can infer the field strength. In this case B=44 G which is in agreement with the average field strength of B=49 G inferred from the interpretation of the Stokes profiles with HAZEL.

Summary

- Presently, we can determine the strength and orientation of the magnetic field in solar prominences by interpreting the Stokes I, Q, U, and V profiles of the He I 1083 nm triplet.

- The analysis of the data corresponding to a quiescent hedgerow prominence shows that the magnetic field vector does not vary along the prominence body, i.e., it does not show spatial variations as those seen in the intensity.

- We also analyzed a time serie containing the pass of a prominence instability (plume). We found strong red-shifts associated with the cavity boundaries. We also found that, at the attained spatial resolution, there is no changes in the magnetic field strength while the plume is pushing the prominence plasma.

- We found damped oscillations that can help the determination of additional prominence plasma parameters.

- New observations in the He I 1083.0 nm triplet with large aperture telescopes, such as those that will be possible with TIP-II installed at the german GREGOR telescope, will revolutionize our understanding of prominences.