Non-LTE inversion of spectropolarimetric and spectroscopic observations of an active filament observed with VTT

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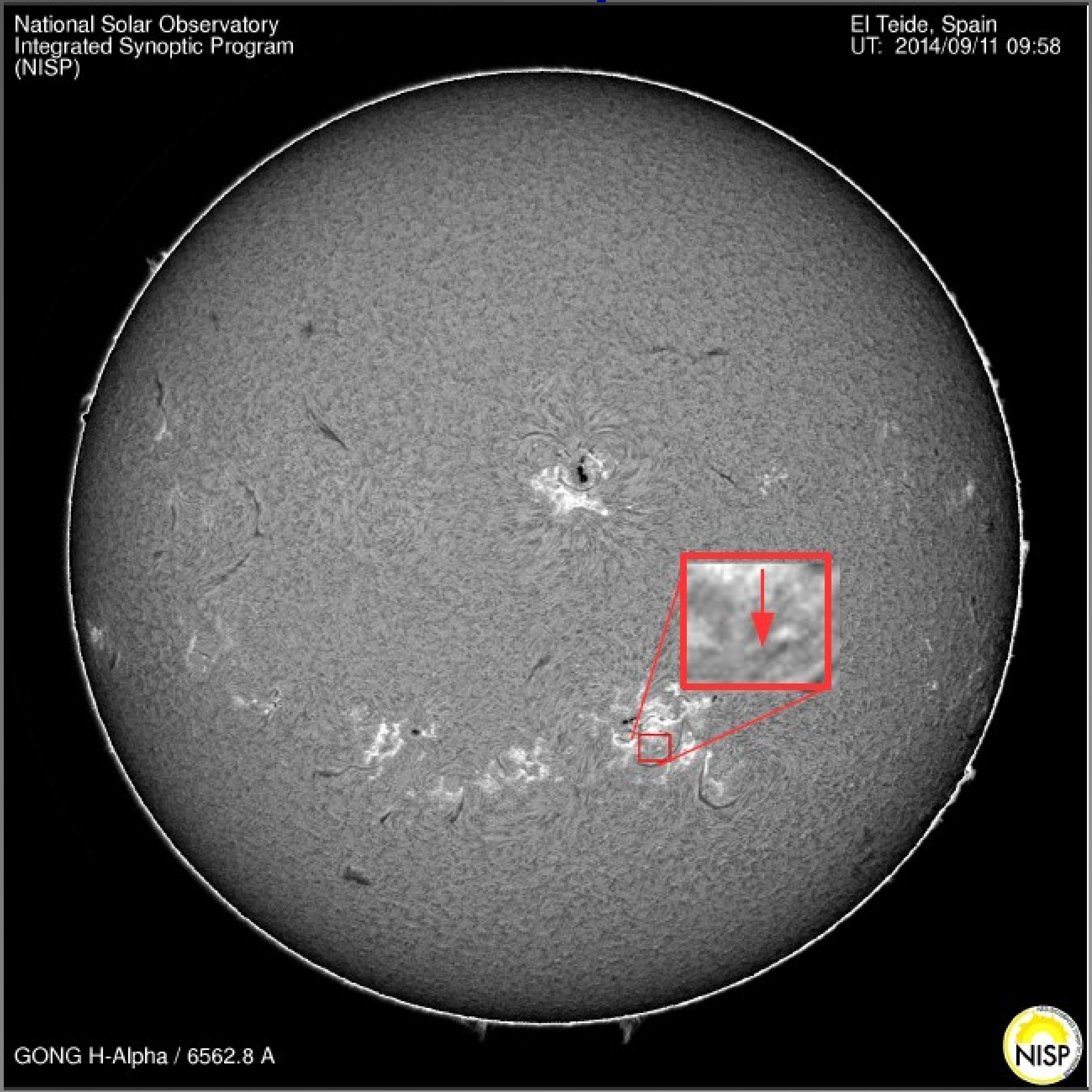
GONG Hα observations from El Teide with marked position of the filament



S18.9 W13.9

μ=0.87

Basic information about the observations

Filament in the NOAA 12159 active region was observed on 11 Sept 2014 9:28 – 10:04 UT at VTT at Tenerife with Eche-lle spectrograph together with TIP1 spectropolarimeter in IR and simultaneously in Hα by the TESOS Farbry-Pérot interferometer:

– position of the filament: 215 arcsec, -420 arcsec; 3 scans made with spectrograph between 9:28 – 10:04 UT

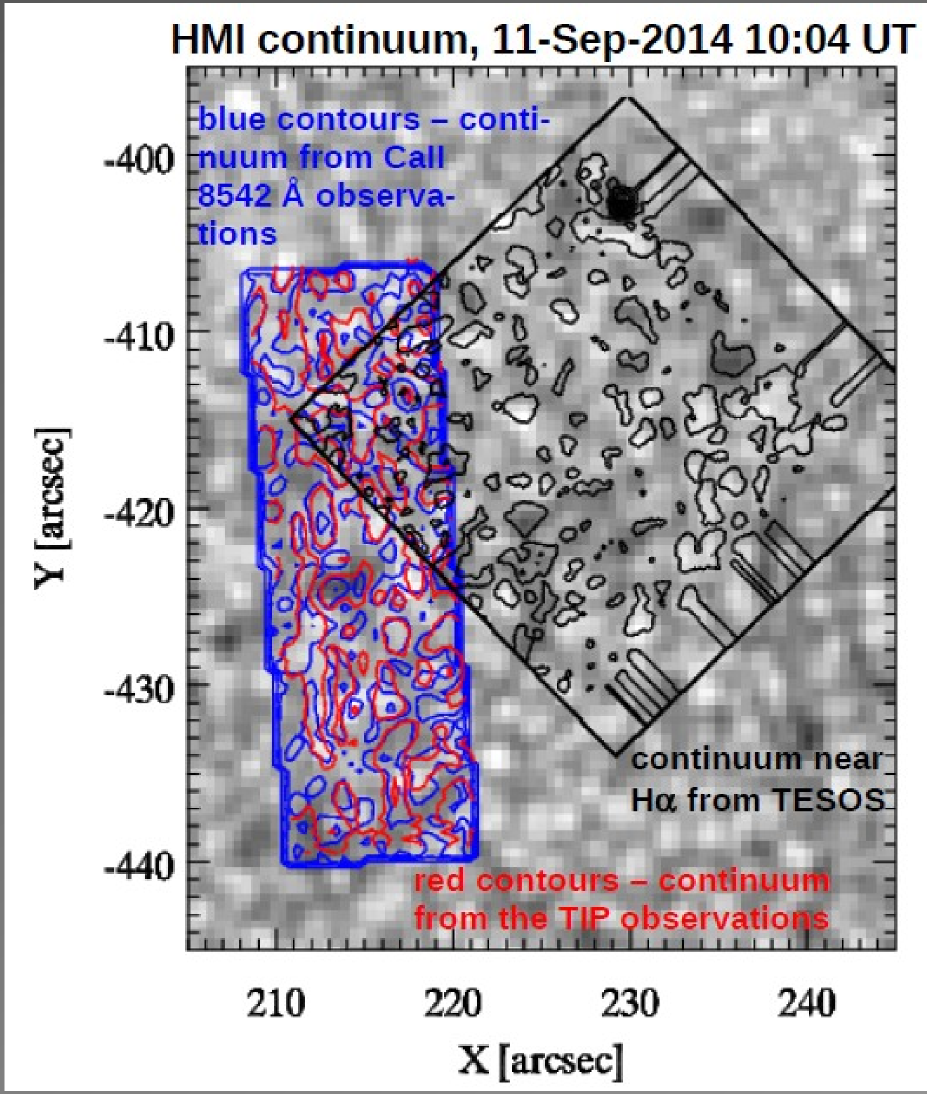
– spectropolarimetric observations in chromospheric HeI IR triplet with wavelength around 10830 Å, photospheric line SiI 10827 Å; height of the slit approx. 30'', 1 pxl along the slit 0.35'', scan step of 0.45'', scanned approx. 10''

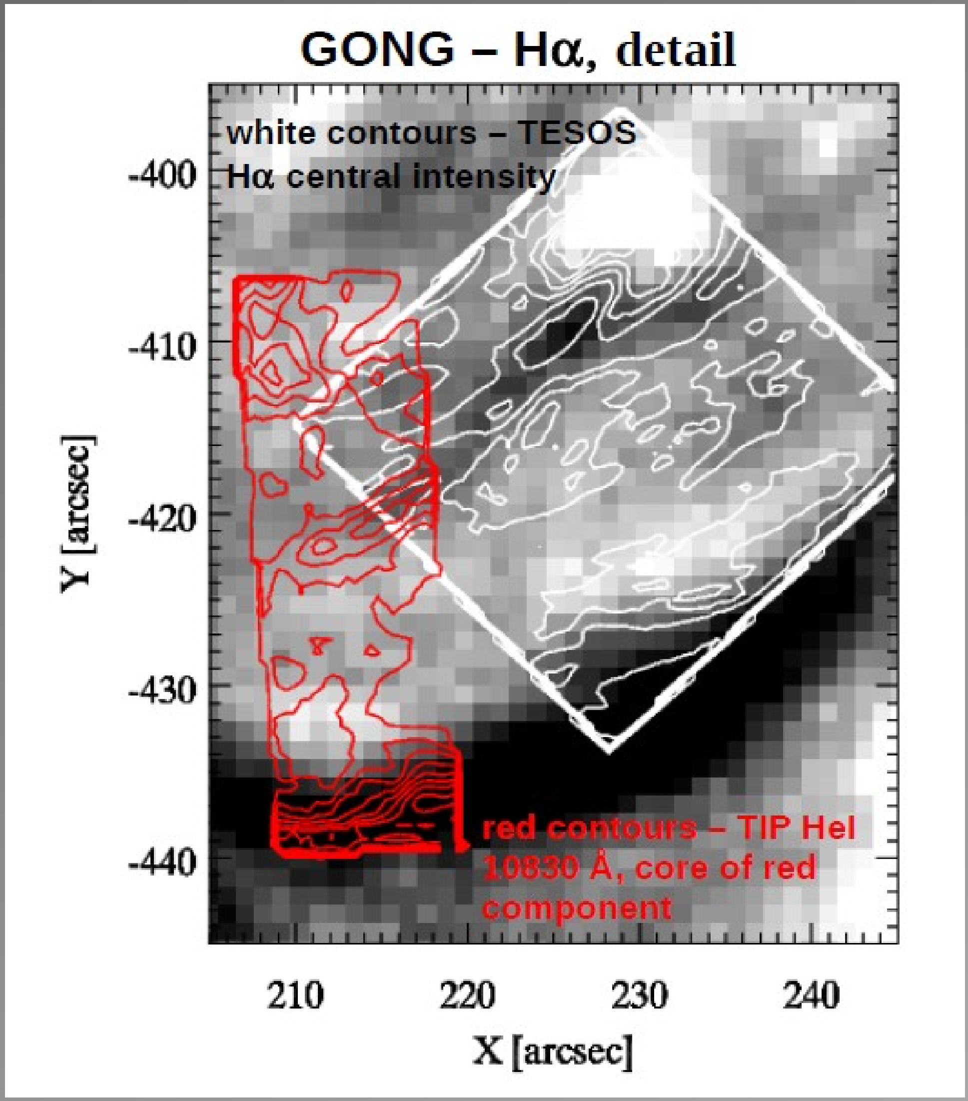
– spectroscopic observations in CaII 8542 Å

– 2D observations with the TESOS Fabry-Pérot interfero-meter, FOV of 25''×25'', step 0.025 Å of scanning in λ within interval 6561.2 – 6564.5 Å

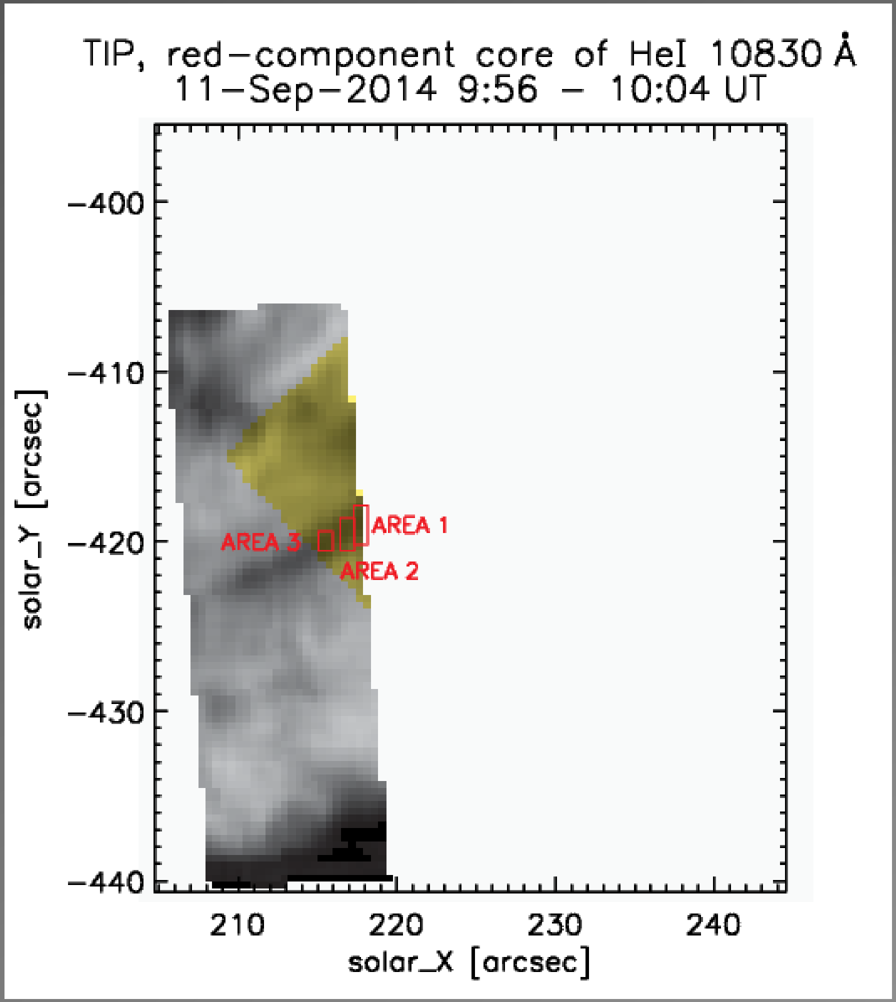
– the 3rd scan was used, and TESOS observation No.33

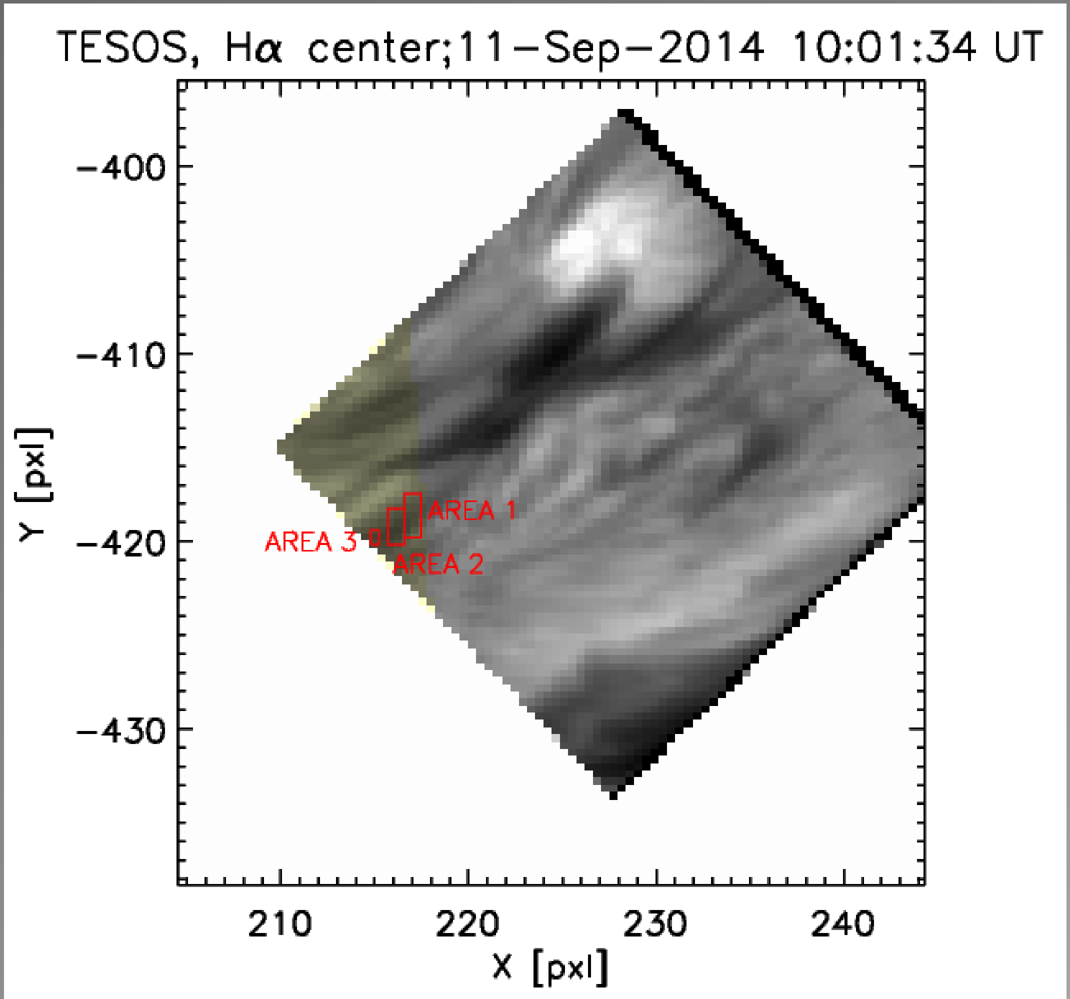
Co-alignment of the observations





Images of co-aligned data





Yellowish shade indicates FOV overlaps of the TESOS and spectrograph +TIP I instruments during scan 003 of the observations of 11 September 2014

Fitting the simple cloud model to CaII 8524 Å

$$I(\lambda) = S\,[1 - \exp(-\tau_\lambda)],$$

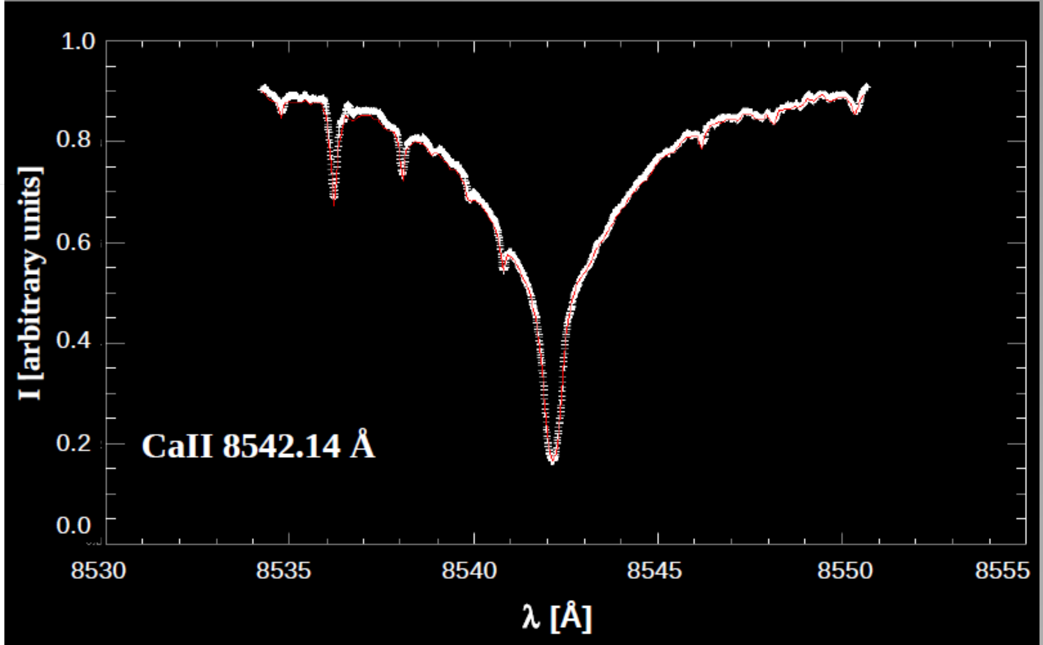
$$\tau_\lambda = \tau_0(\mathrm{H}\alpha)\,\phi(\lambda),$$

$$\phi(\lambda) = \exp\left[-\left(\frac{\lambda - \lambda_C}{\Delta\lambda_D}\right)^2\right]$$

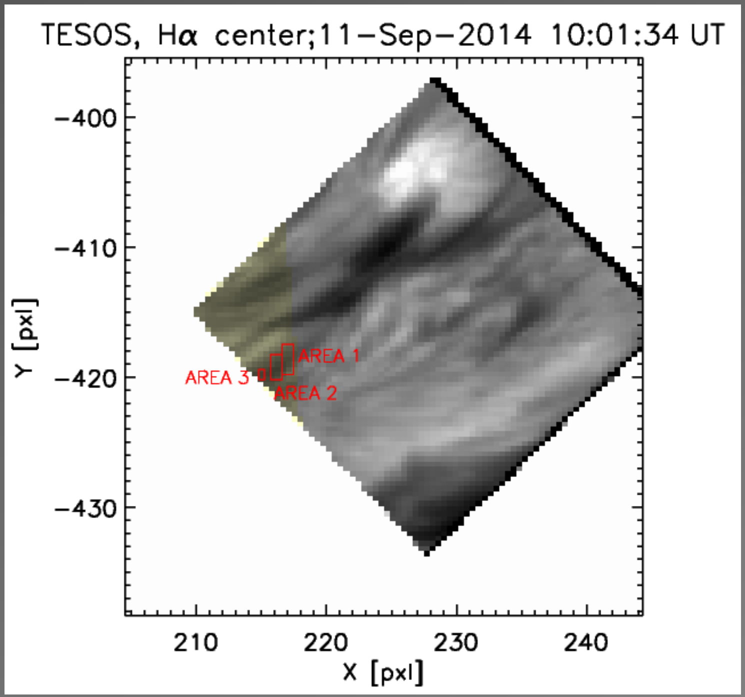
$$\Delta\lambda_D = \frac{\lambda_0}{c}\sqrt{\frac{2kT}{m_H} + v_{mt}^2}$$

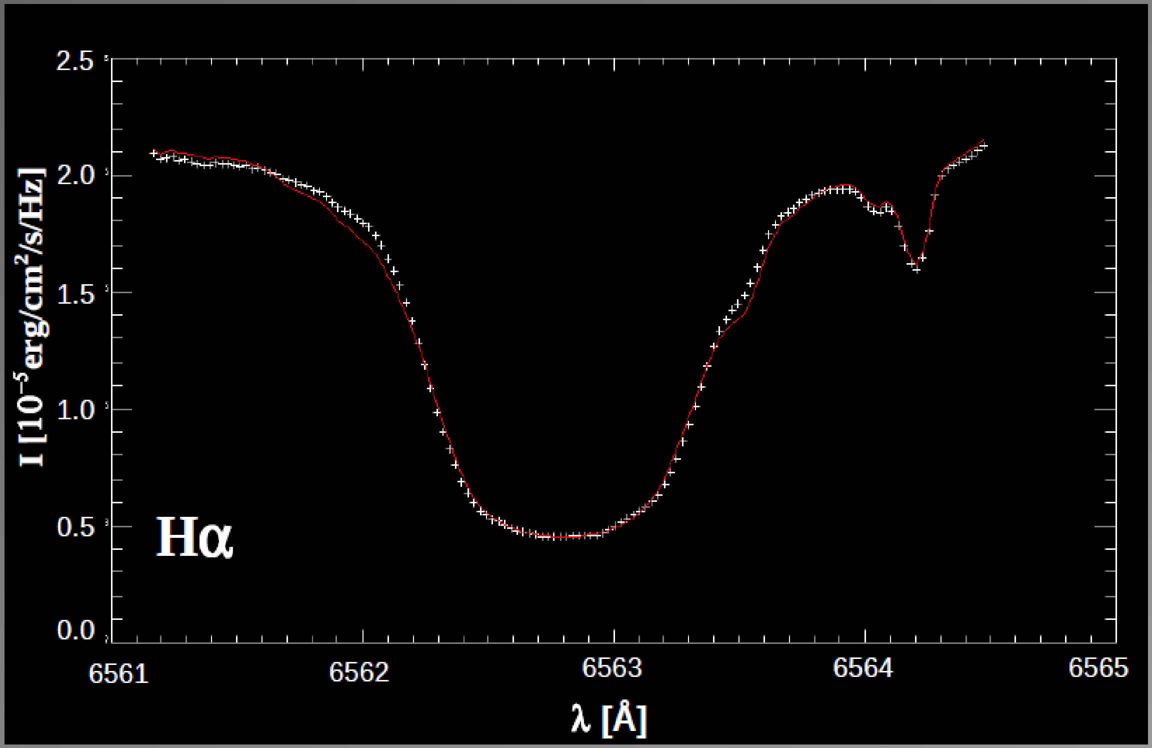
- S – source function independent of λ and τ
  - τ_o – optical thickness at the centre of the line
    - for an absorption profile *Φ* the Gauss fnc is used
- from definition of Doppler width $\Delta\lambda_D$, temperature or velocity v_{MT} of microturbulence can be derived.

m(Ca)=4×m(H), thus $\Delta\lambda_D$ is 3 – 6 times mes more sensitive to v_{MT} than to T at 8000 K and v_{MT} within 5 – 10km/s. (Schwartz et al. 2015). Values of v_{MT} of 5 – 13 km/s derived from profiles in all 3 areas.



The simple cloud model fitting of Hα profile obtained by TESOS



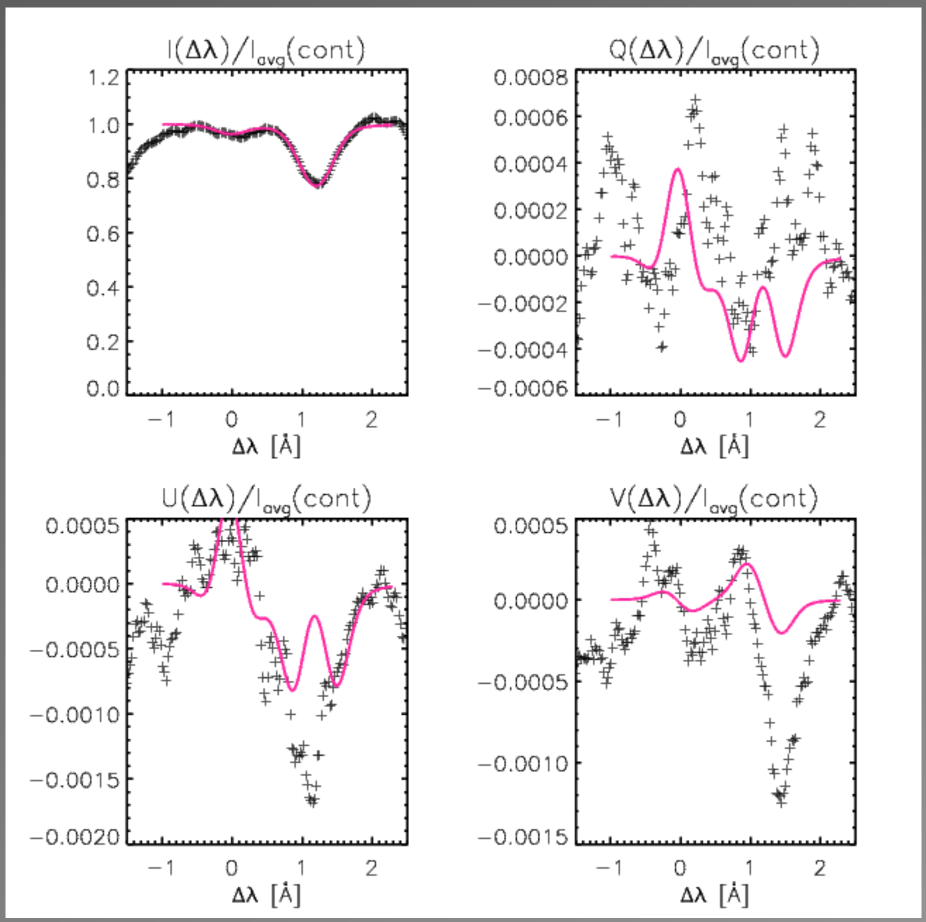


Results of the fitting:

- **small LOS velocities within the range -1 – +1 km/s**
- **τ_o = 0.4 – 0.7, in the AREA3 up to 0.9**
- **Temperatures 25000 – 70000 K, what is unrealistic for Hα**

Such very broad profiles can be explained by presence of multiple unresolved fluxtubes with different velocities

An attempt to estimate inclination and azimuth of the magnetic field from inversion of Stokes profiles of HeI 10830 Å triplet using the HAZEL code (Asensio Ramos et al. 2008)



avg profiles from the AREA 1

RESULTS:

B=507 Gauss

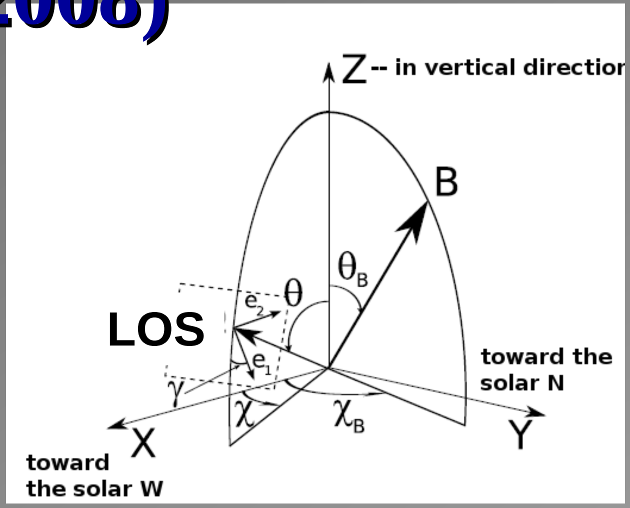
$\Theta_B = 63^o$

$\chi_B = 27^o$

$\Delta\lambda_D = 0.27$ Å

v = – 0.6 km/s

height above the solar surface: 8700 km

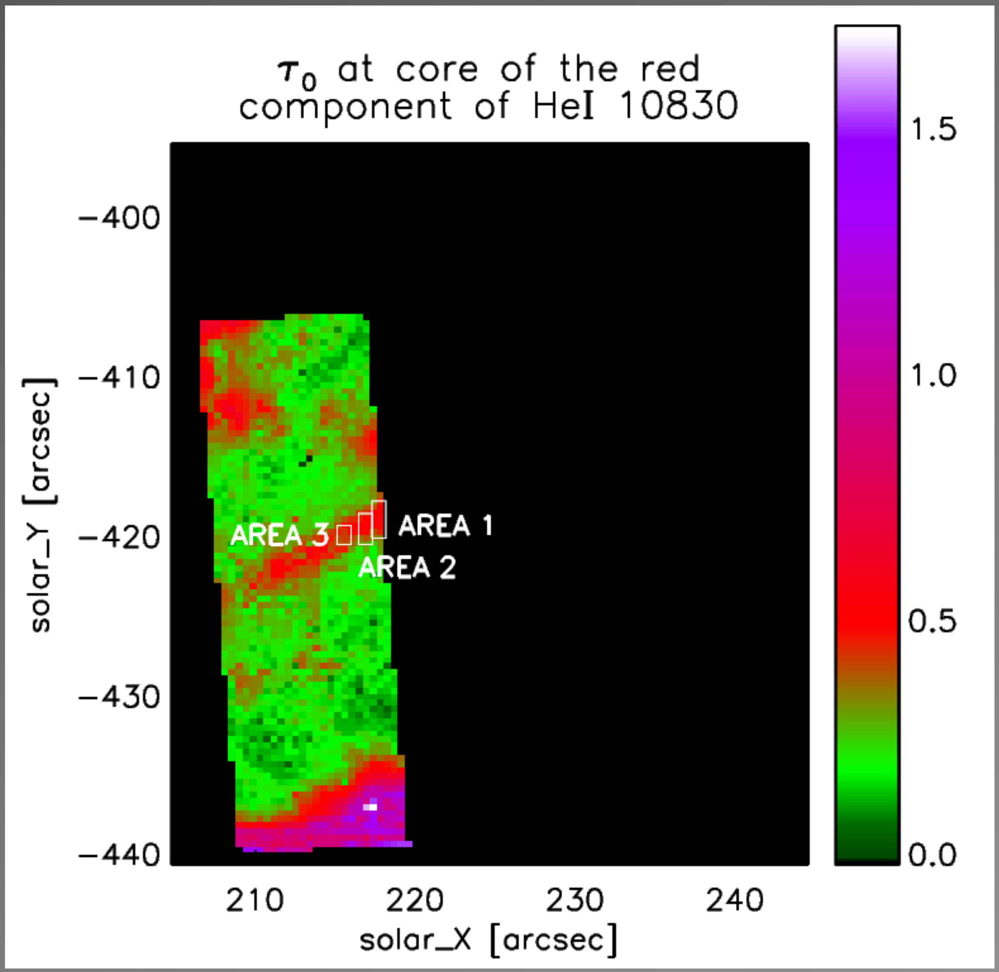


optical thickness at the center of the red component τ=0.4

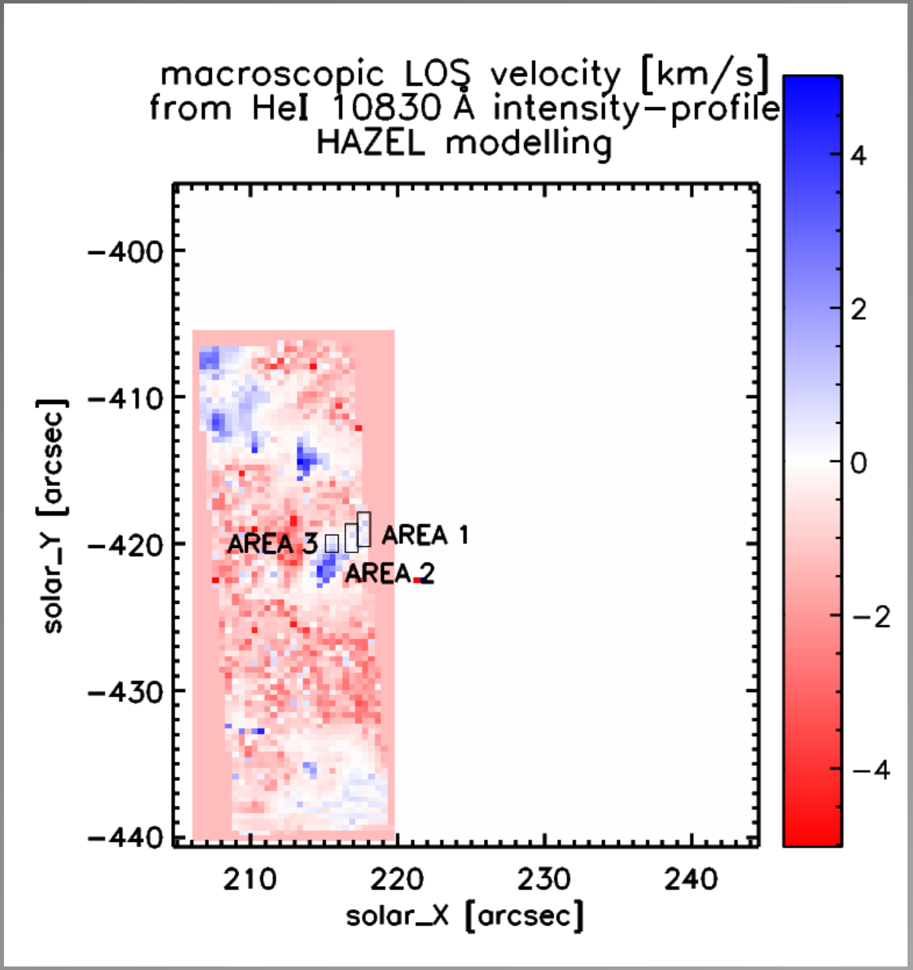
But large uncertainties (more than 100% for Θ_B , Φ_B , τ and v)

NOT USABLE !!!!

Thus, fitting only I profiles of HeI 10830 Å triplet using the HAZEL inversion code



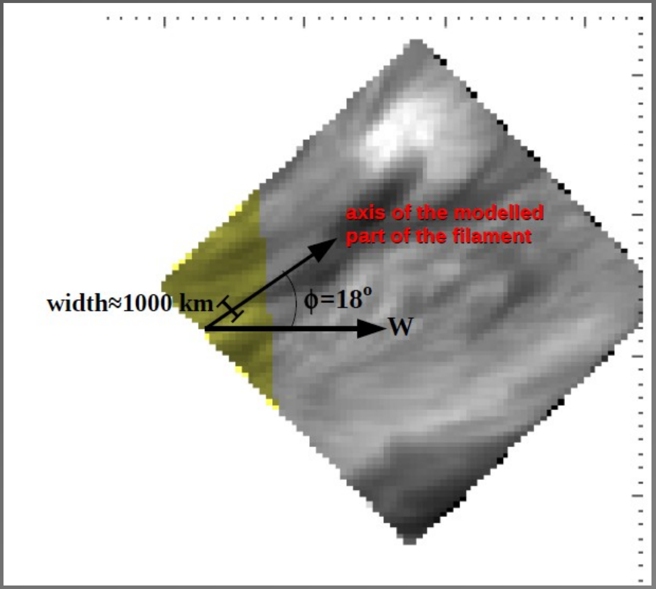
the optical thickness at the center of the red component of the HeI 10830 Å triplet at the dark filament structure around 0.5



in the dark structure upflows of very small velocities not exceeding 3 km/s

Modelling of the Hα profiles using a simple 2D NLTE model

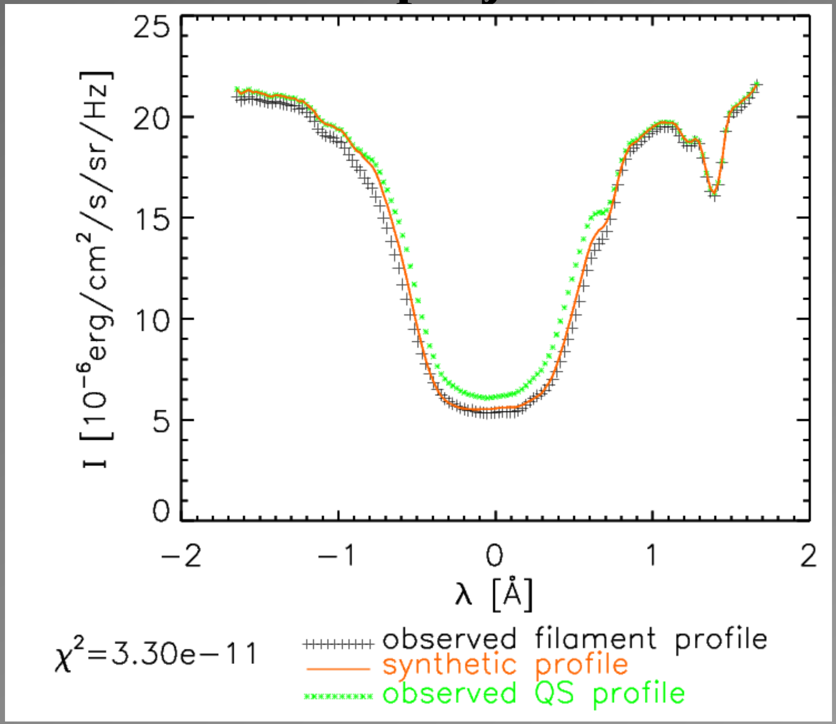
- fluxtubes are assumed placed vertically (in radial direction) one above another
- system of fluxtubes is approximated by the horizontal isothermal and isobaric 2D slab with two finite dimensions – vertical (Z) and across the filament (X), the dimension along the filament (Y) infinite

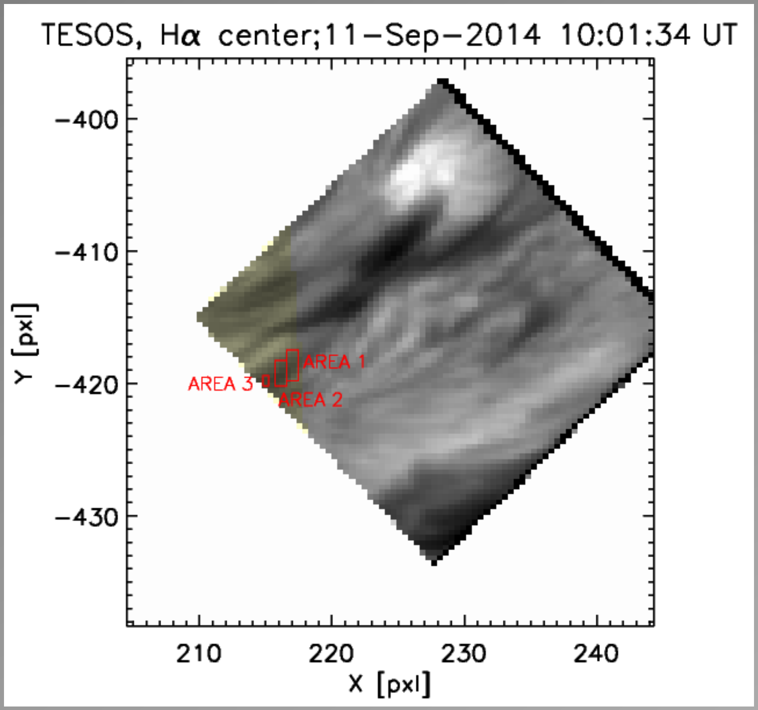


- the slab cross-section has a box-like shape
- X-axis is in direction along the filament axis (under angle of 18^o according to the solar W),
- Z-axes is in vertical direction perpendicularly to the solar surface
- radiative transfer is solved using short-characteristics method with Accelerated Lambda Iterations similarly as was done for prominences by Heinzel& Anzer (2001), formal solution along LOS at $\mu=0.87$
- statistical equilibrium was calculated for the 5-level hydrogen atom
- to simulate fluxtubes in which plasma is flowing in different velocities, profiles from two slab were calculated with plasma-flow velocities of the same size but of opposite sign, and then profiles were added together with filling factors of 0.5
- it is assumed that plasma flows in fluxtubes along them and the fluxtubes are oriented along the axis of the filament at angle $\phi=18^o$, while angle θ of inclination from the vertical (Z) is taken as a free parameter

Parameters of the simple 2D NLTE model for which the best agreement was achieved

- **vertical dimension (along Z): 60 000 km**
- **temperature: 9 000 K**
- **plasma pressure: 0.12 dyn/cm^2**
- **height above the solar surface: increasing from approx. 9 000 km in AREA 1 up to 13 000 km in AREA 3**
- **angle of inclination from the vertical Θ decreases from 100^o in AREA 1 down to 98^o in AREA 3**
- **velocities along the fluxtubes: -25/+25 km/s, which correspond to values of -14/+14 km/s when projected into LOS**



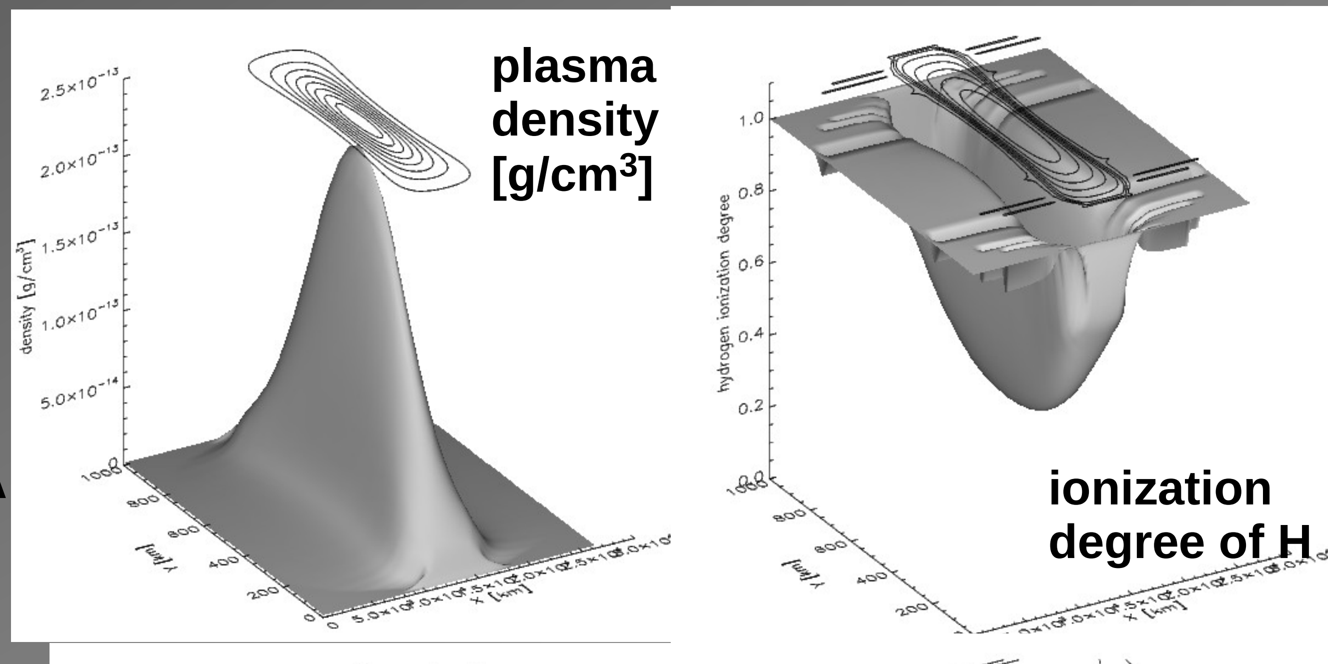


Comparison of the plasma density and hydrogen ionisation degree estimated for a quiescent prominence with results obtained for the active filament studied in this work

<u>Prominence:</u>

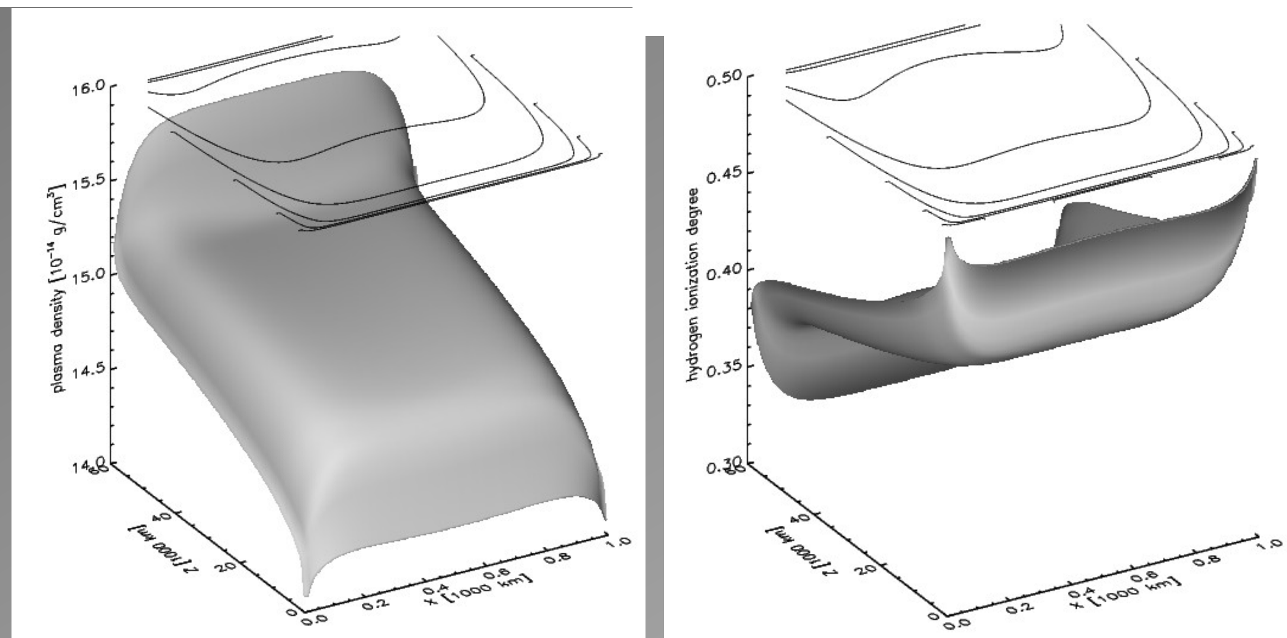
- densities up to 2.5×10^{-13} g/cm^3
- min. ioniz. degree around 0.3
- p_{inner}=0.2 dym/cm^2

(Schwartz et al., 2015, A&A 577, A92; Gunár et al., 2010, A&A 514, A43)

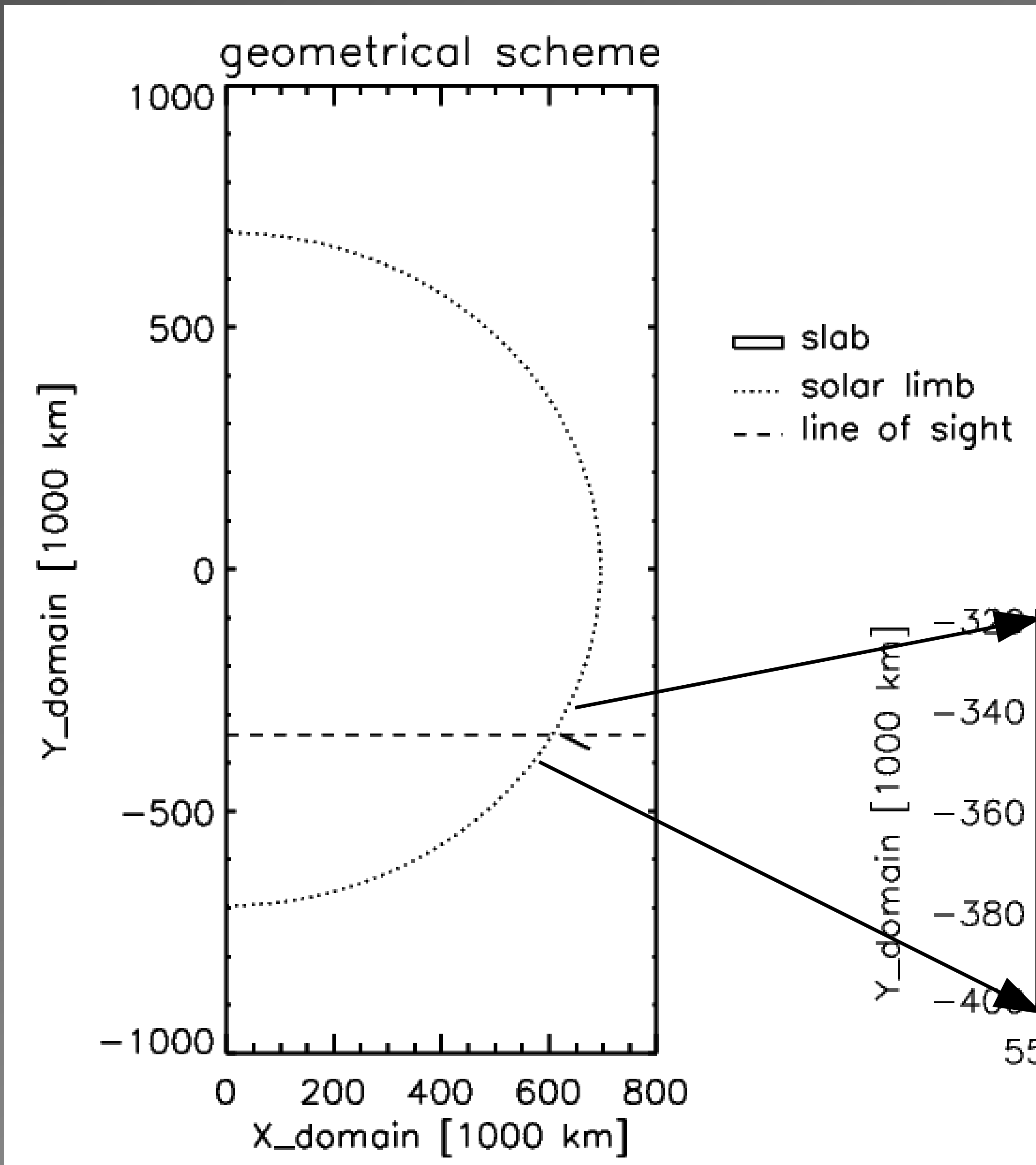


<u>Active filament:</u>

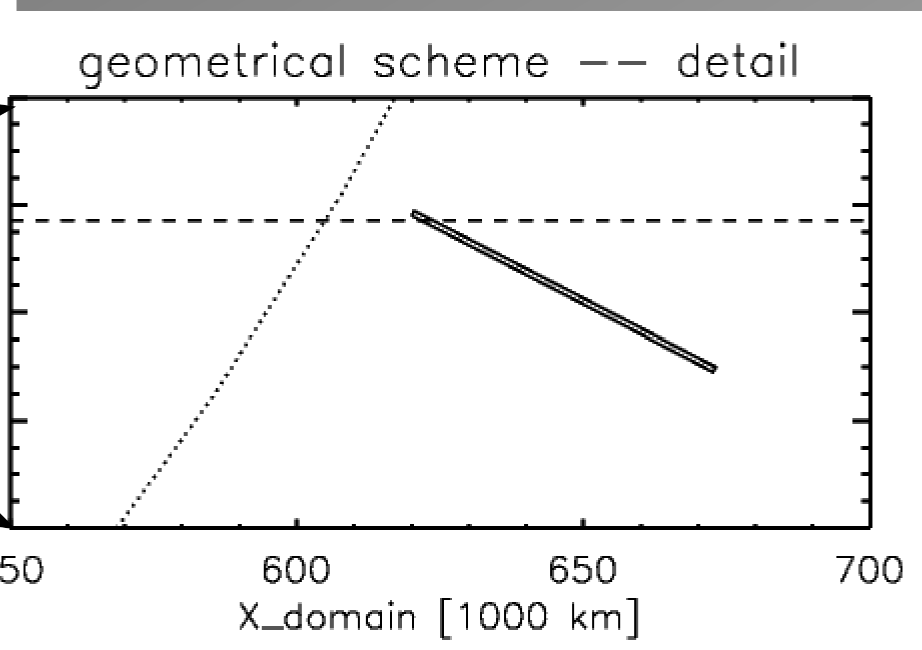
- densities up to 1.6×10^{-13} g/cm^3
- min. ioniz. degree around 0.3
- p_{inner}=0.12 dym/cm^2



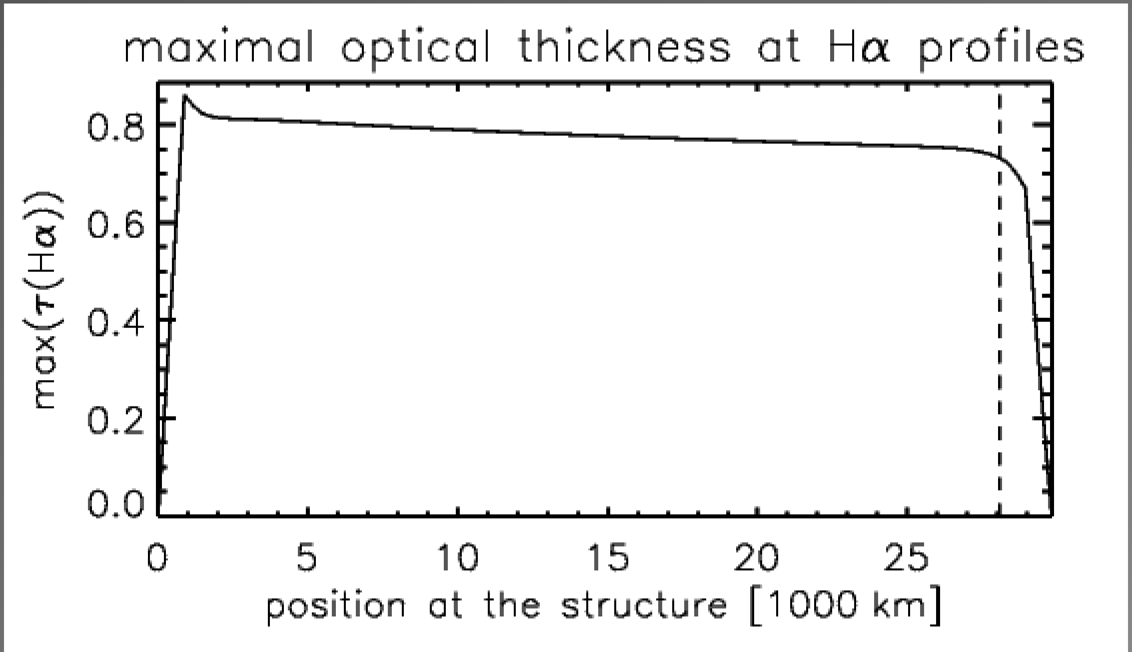
Geometrical scheme of the LOS intersecting the slab

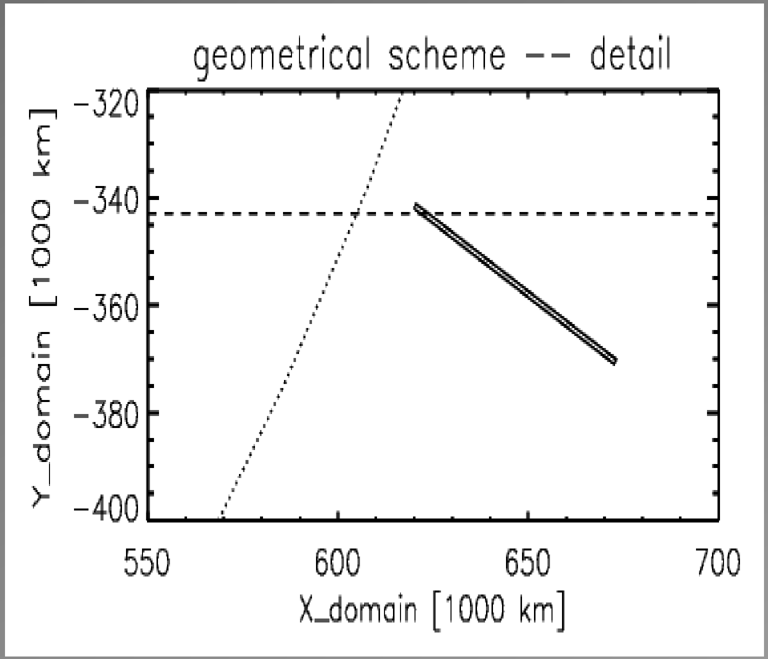


For all observed Hα profiles from all three chosen areas (within the dark structure as seen in TESOS map of central intensities) LOS intersects the slab in its lower end.



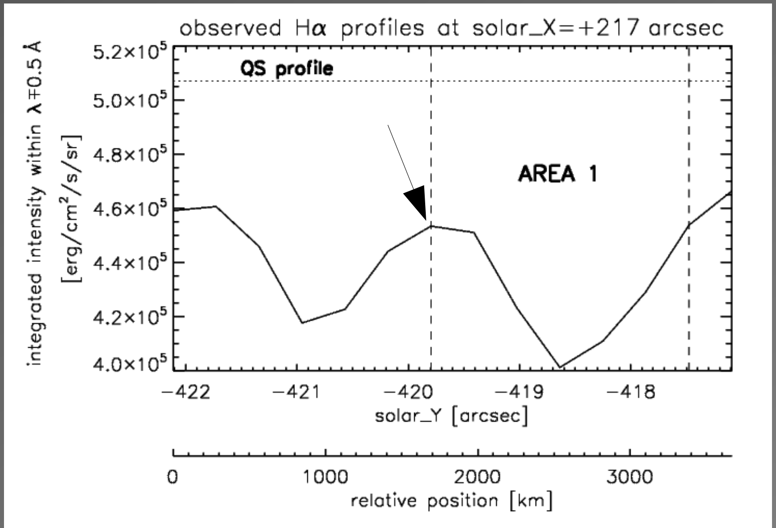
Maximal optical thickness at the Hα profiles for profiles in the filament dark structure

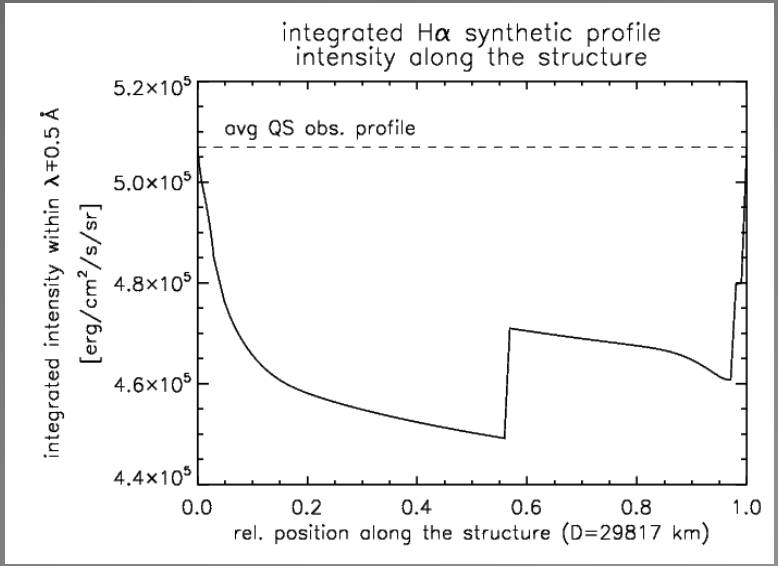


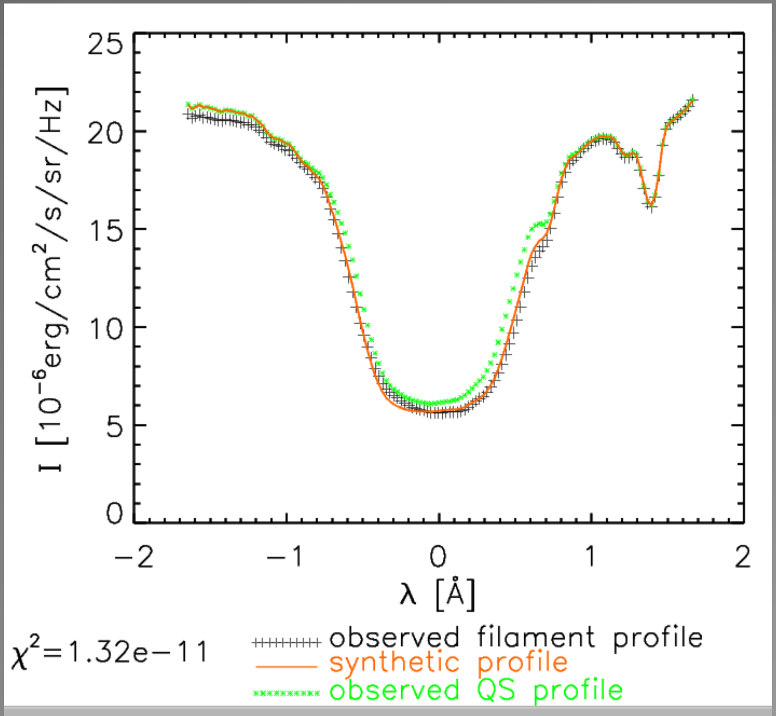


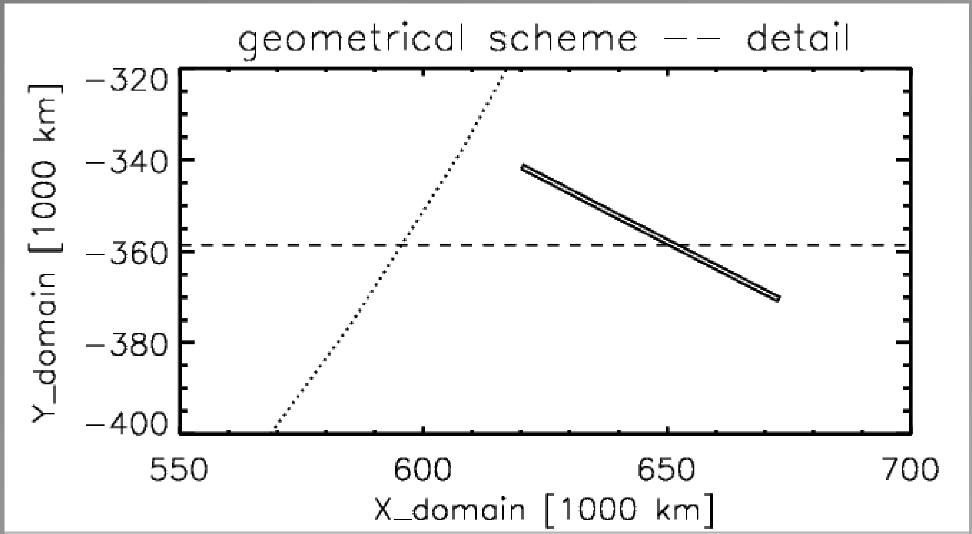
Maximal optical thickness at Hα profiles in the dark filament structure around 0.75 what is larger then 0.5 estimated for center of HeI 10830 Å red component by the HAZEL code

Comparison of the observed and synthetic Hα intensities integrated within – 0.5 – +0.5 Å around the profile center









Conclusions

- **broad and very deep Hα profiles observed at the active filament were model-led using the 2D non-LTE slab model, vertically very extended, of temperature 9000 K and plasma pressure of 0.12 dyn/cm^2 with velocities of -25 and +25 km/s along the filament axis. The slab approximates system of fluxtubes aligned Vertically one above another and inclined from vertical at angles of around 99º**
- **fitting of such broad Hα profiles with a simple cloud model (with source fnc in-dependent of wavelength and optical thickness) leads to estimating of very high unrealistic temperatures (several tens of kK) and very low LOS velocities**
- **the darkest part of the filament is radiated out from the bottom part of the slab while adjacent brighter part originates from higher heights above the solar sur-face**

To do ...

- **more sophisticated 2D model of fluxtube system instead of the simple mono-lithic slab**
- **fluxtubes of cyrcular cross-section**
- **temperature increasing continuously from interiors of fluxtubes to their egdes to avoide numerical problems**