# Non-LTE inversion of spectropolarimetric and spectroscopic observations of a small active-region filament observed at the VTT

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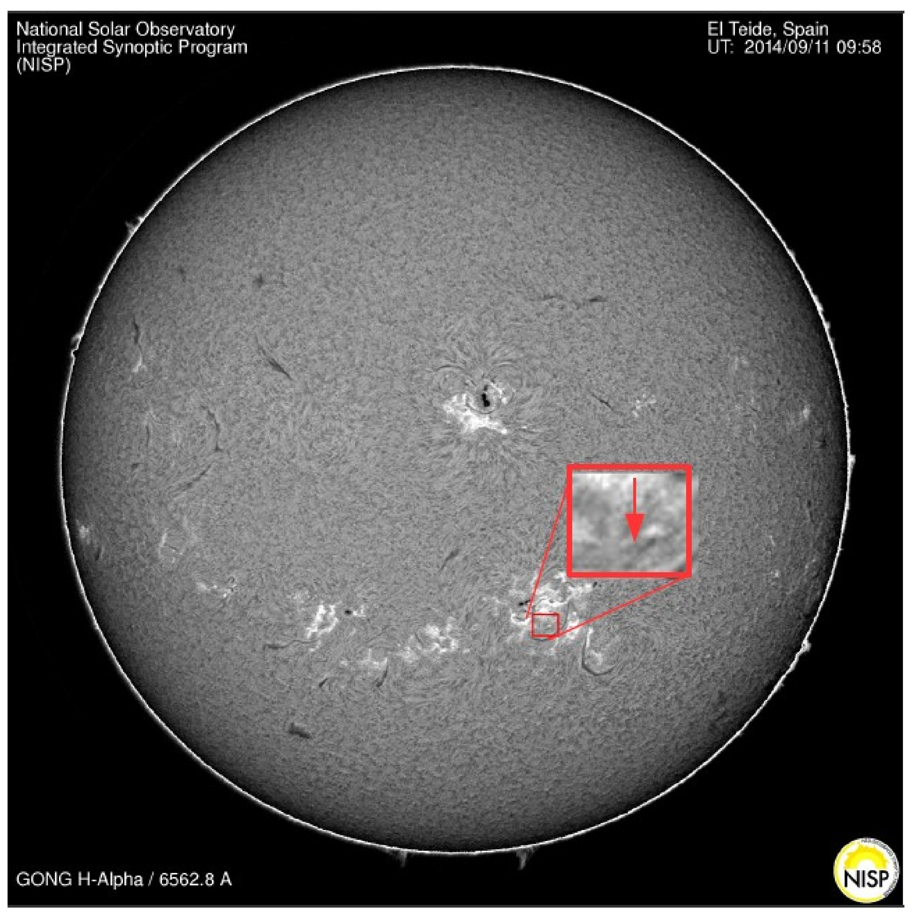
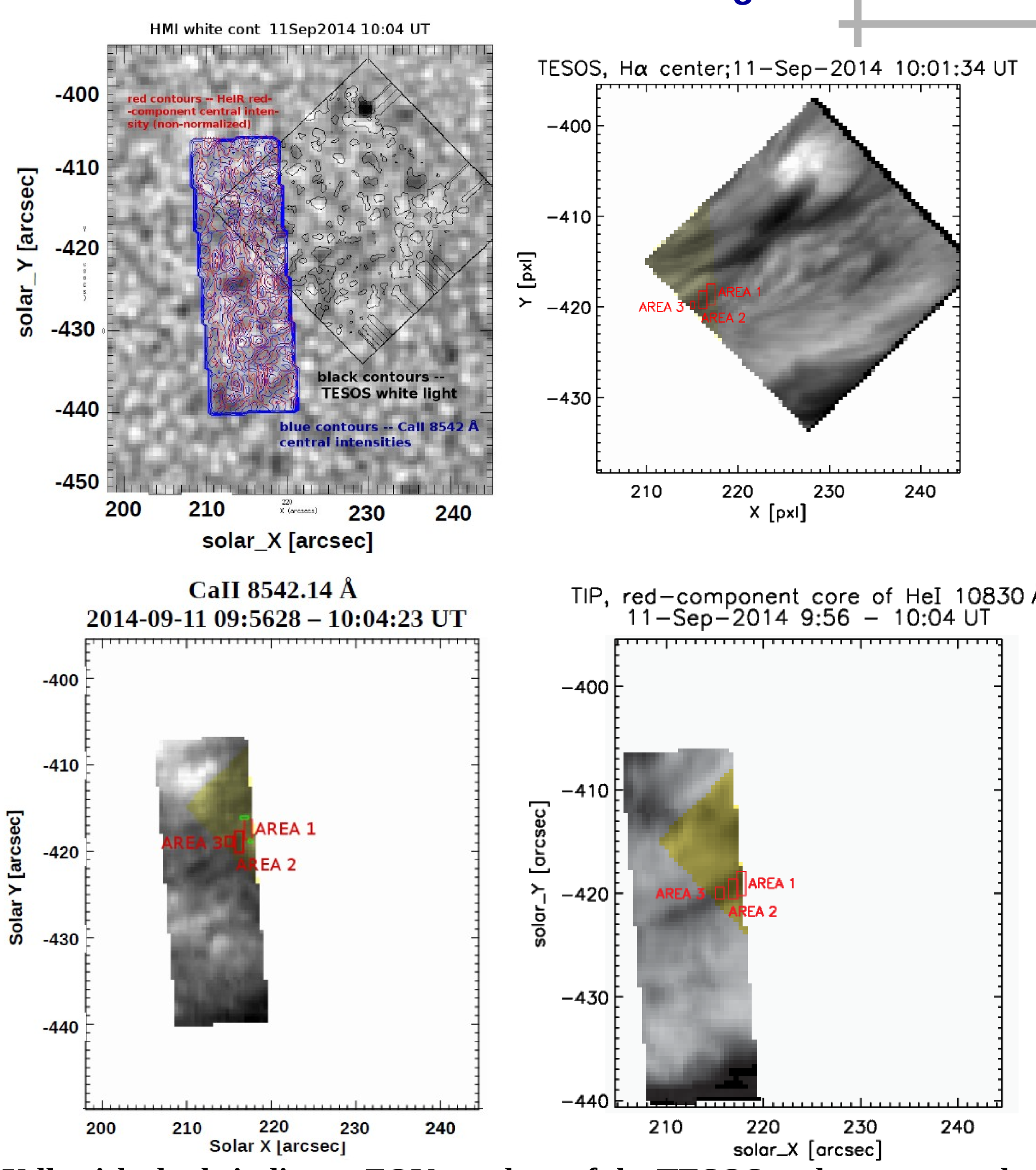
**ABSTRACT.** An active-region filament in the active region NOAA 12159 (at solar disk coordinates [x,y] = [225,-440] arcsec) was observed with the Vacuum Tower Telescope at Tenerife on 11 September 2014. Full-Stokes spectropolarimetric observations of the HeI IR triplet at a wavelength around 10830 Å and of the SiI 10827 Å line were acquired using the VTT Echelle spectrograph together with the Tenerife Infrared Polarimeter (TIP I). Additional simultaneous spectroscopic observations in the CaII 8542 Å line were also obtained with the Echelle spectrograph. With the TESOS Fabry-Pérot interferometer, the filament was observed in Hα in intensity mode with a field-of-view of 25 x 25 arcsec (136 wavelength points within the range 6561 – 6564 Å). The filament shows a structure typical for an active filament composed of thin and long fluxtubes with plasma flowing along the magnetic field lines inside these fluxtubes. Thus, for diagnostics of the filament plasma, observed Hα profiles are simulated using a simple isothermal and isobaric two-dimensional non-LTE model with two finite dimensions -- vertical and across the fluxtube. The velocity of the plasma flows is also taken into account in the model because it can cause a Doppler brightening in the observed profiles. Assuming the flows are parallel to the magnetic field lines in the fluxtube, the LOS component is then projected onto a velocity vector according to the direction of the vector magnetic field that we were trying to obtain from inversions using the HAZEL inversion code (Asensio Ramos, 2008).

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



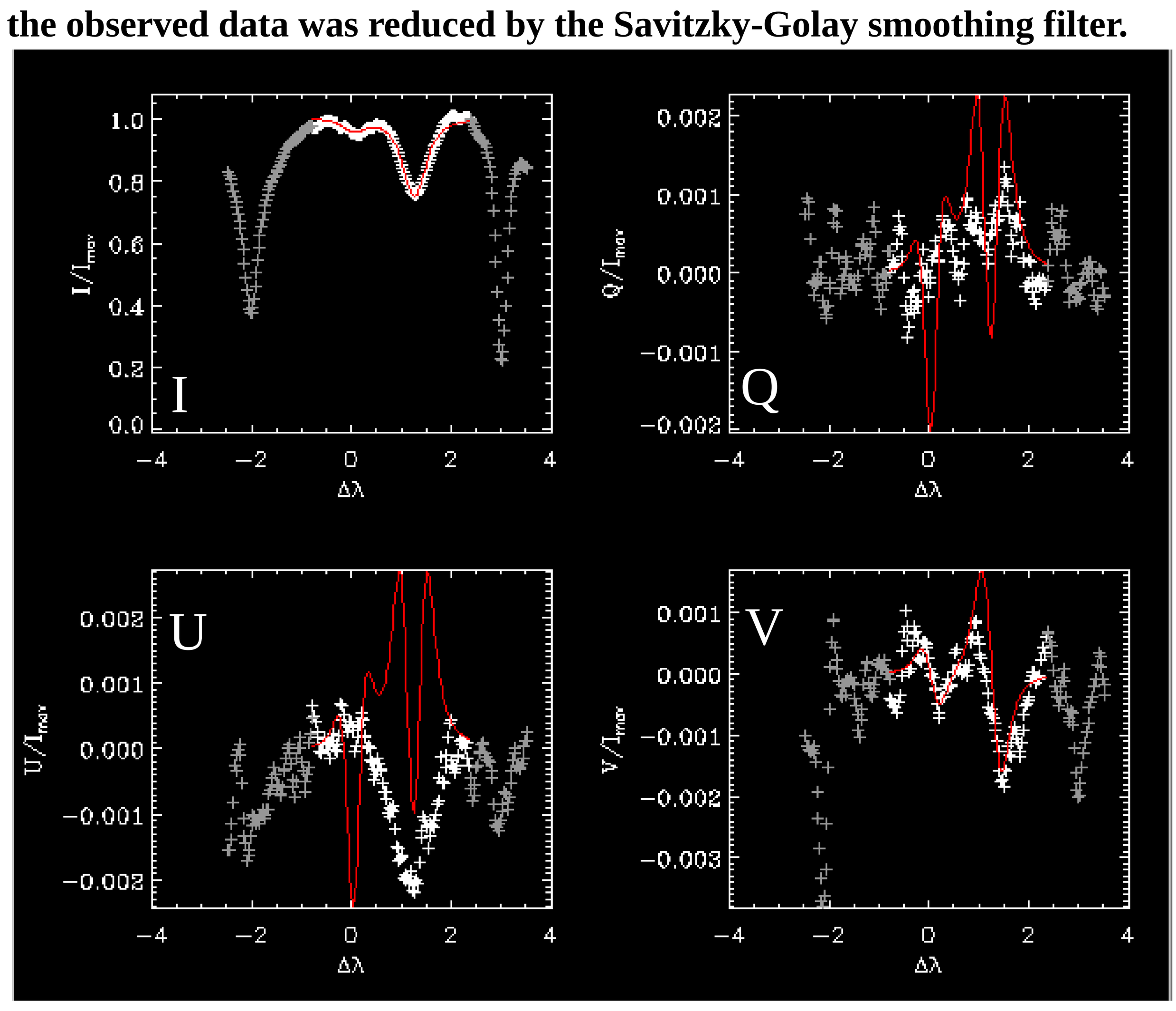

## Images of observations after co-alignment with marked three areas from which Hα profiles observed by TESOS were taken for the non-LTE modelling




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

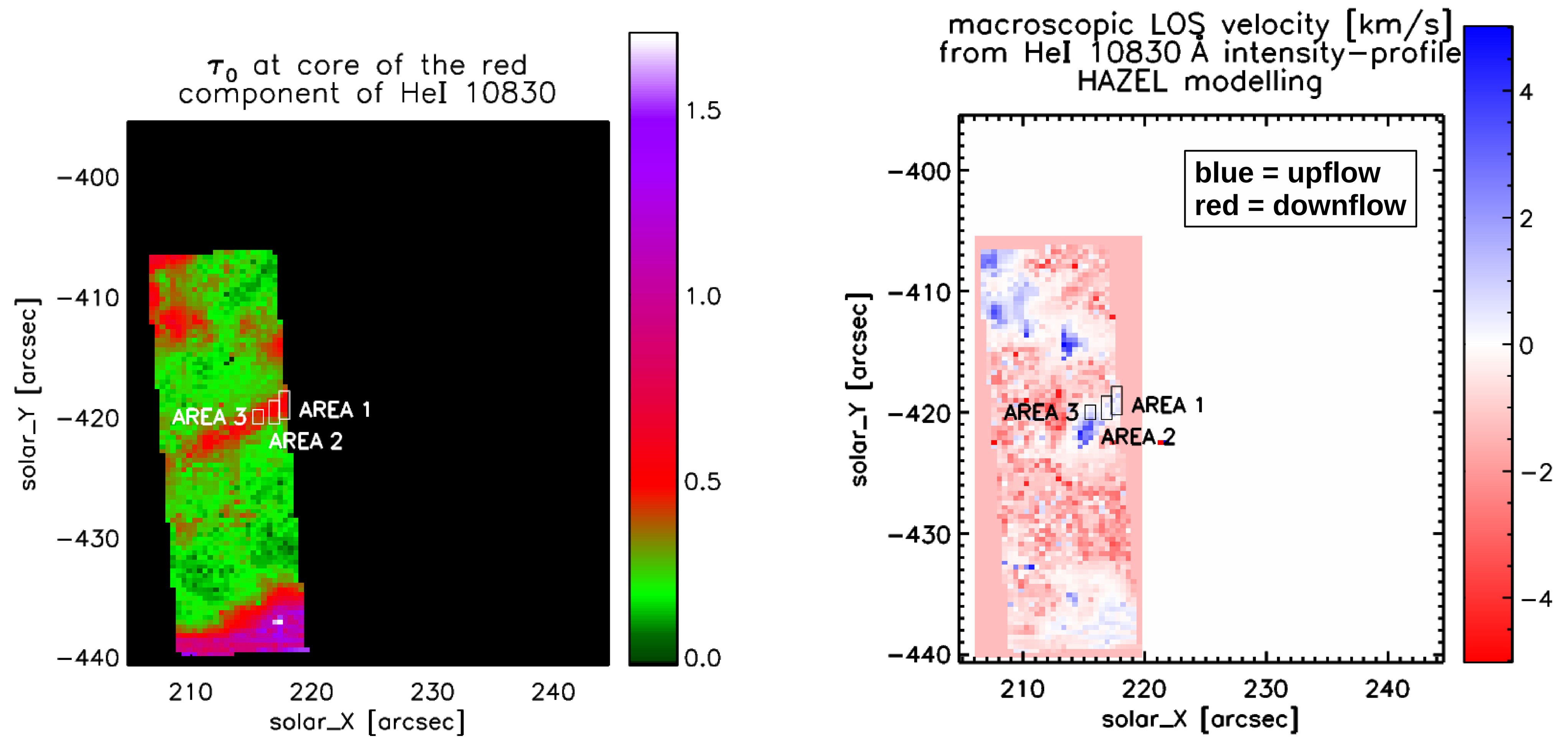
## An attempt to model the full Stokes profiles of the HeI triplet 10830 Å observed in the filament using the HAZEL code (Asensio Ramos et al., 2008)

An example of fitting of the Stokes profiles from a position in AREA 2 which appears to be the darkest in the map of the Hα central intensities. Noise in the observed data was reduced by the Savitzky-Golay smoothing filter.




Unfortunately, the polarization signal is too low (below noise) to reliably obtain the vector of the magnetic field. Thus, only the intensity profiles were fitted to get the optical thickness and the LOS velocity.

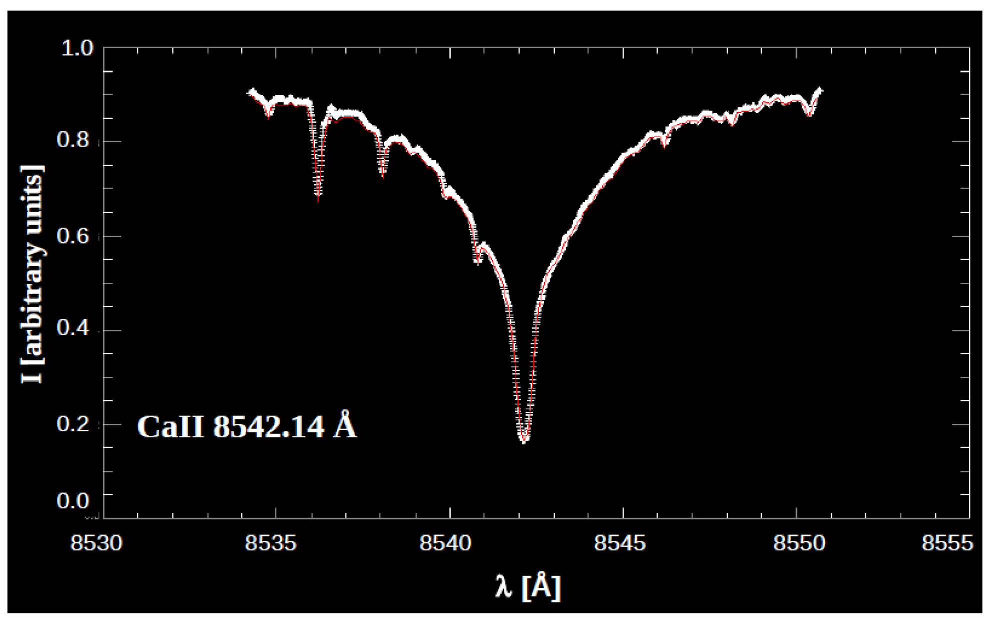
## Maps of optical thickness and LOS velocity obtained from HAZEL modelling of the HeI 10830 Å intensity profiles

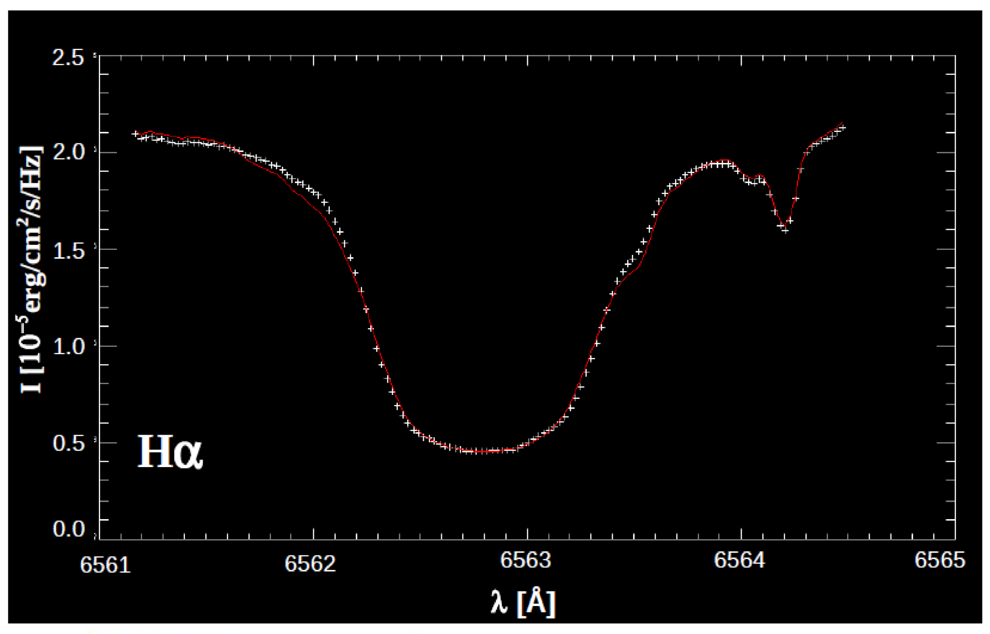



The optical thickness of the filament determined from the red component of HeI 10830 Åvaries around 0.5, and LOS velocities are very small and do not exceed ±1 km/s by much.

## Fitting CaII and Hα profiles using the simple cloud model (i.e. constant source function, Gaussian absorption profile)

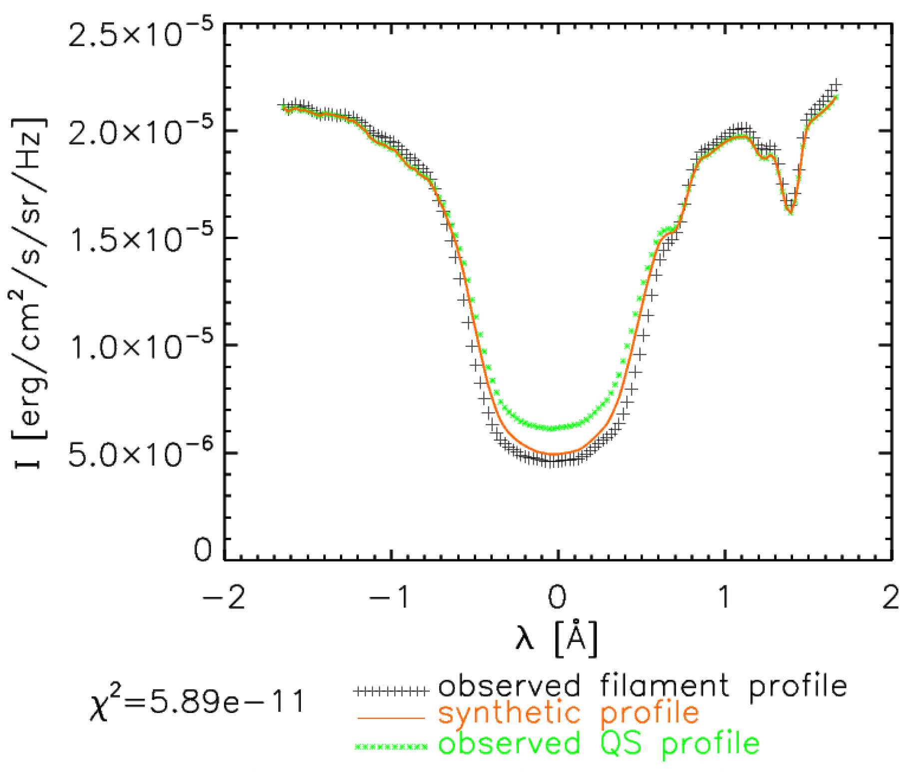
$$I(\lambda) = S\,[1-\exp(-\tau_\lambda)] + I_o \exp(-\tau_\lambda)\;,\; \tau_\lambda = \tau_0(\mathrm{H}\alpha)\,\phi(\lambda), \quad \phi(\lambda) = \exp\left[-\left(\frac{\lambda-\lambda_C}{\Delta\lambda_D}\right)^2\right].$$




Then, from the definition of the Doppler width $\Delta\lambda_D = \dfrac{\lambda_0}{c}\sqrt{\dfrac{2kT}{m_H} + v_{mt}^2}$ , temperature $T$ or velocity $v_{mt}$ of the microturbulence can be derived. From the CaII line simple-cloud-model fitting, values of $v_{mt}$ ranging from 5 up to 10 km/s (for T~$10^4$ K) were estimated. Temperatures obtained from Hα profiles around 30000 K are too high for a filament and unrealistic for the formation of this line. Such broad and rather deep Hα profiles can be achieved with a 2D non-LTE model composed of of isothermal and isobaric horizontal fluxtubes of box-like cross-sections placed vertically one above another with the plasma flowing along individual fluxtubes with various velocities. The 2D model has two finite dimensions – one vertically in radial direction and the other horizon- zontally across a filament. Radiative transfer in 2D was solved using the short characteristics method with Accelerated Lambda Iterations similarly as was done for prominences by Heinzel & Anzer (2001). For computations of the statistical equilibri- um the 5-level hydrogen atom was used.

## Results of the non-LTE modelling of Hα profiles observed at the filament




An example of comparison of observed filament and QS Ha profiles with synthetic one obtained using non-LTE 2D model. Observed filament profile was taken from the darkest position inside of the AREA 3 in map of Hα integrated intensities.

### Results of the non-LTE modelling of Hα profiles from AREAs 1 – 3:

The filament is composed of several tens of fluxtubes each one having a radius of around 1000 km, which are aligned vertically. Value of temperature 9000 K, pressure 0.12 dyn/cm², densities 1.4 – 1.6×$10^{-13}$ g/cm³ and ionization degree of hydrogen 0.3 – 0.5 were estimated from plasma inside the fluxtubes using the non-LTE modelling. The total optical thickness of the whole fluxtube system along LOS (μ=0.87) at the Hα line center is around 0.7 what is somewhat larger than optical thickness of 0.5 estimated in the red-component core of the HeI 10830 triplet. The plasma inside the fluxtubes is flowing along them with the velocities up to ±25 km/s. Much smaller LOS velocities obtained from the HAZEL code fitting of the HeI intensity profiles indicate that fluxtubes along which plasma is flowing must be horizontal (θ≈90°). But large velocity of the plasma flow, although not in LOS direction, still has a large influence on the profiles in the so-called Doppler brightening effect when the 2D radiative-transfer calculations are used (in the 1D radiative-transfer such solution it would not be possible).

**References:**

Heinzel, P., & Anzer, U. 2001, A&A, 375, 1082
Asensio Ramos, A.; Trujillo Bueno, J.; Landi Degl'Innocenti, E. 2008, ApJ, 683, 542

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