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 mini-filament was observed by VTT simultaneously in the He I 10 830 Å triplet by the TIP 1 spectropolarimeter, in Hα by the TESOS Fabry-Pérot interferometer, and in Ca II 8542 Å by the VTT spectrograph. The spectropolarimetric data were inverted using the HAZEL code and Hα profiles were modelled solving a NLTE radiative transfer in a simple isobaric and isothermal 2D slab irradiated both from bottom and sides. It was found that the mini-filament is composed of horizontal fluxtubes, along which the cool plasma of $T \sim 10\,000$ K can flow by very large – even supersonic – velocities.

1. Introduction

The solar chromosphere displays a wide variety of filamentary structures with a typical length ranging from 60 to 600 Mm (Tandberg-Hanssen 1995). A small filament with the length below 60 Mm occurring at a periphery of the NOAA 12159 active region was observed on 2014 Sept 11 from 9:28 to 10:04 UT at Vacuum Tower Telescope (VTT) simultaneously with its Echelle spectrograph in IR and in Hα by the Triple Etalon SOlar Spectrometer (TESOS) Fabry-Pérot interferometer. Such small filamentary structures were called as mini-filaments by Denker & Strassmeier (2008) and we are using this term further in this work. The HMI line-of-sight (hereafter LOS) magnetogram in the left panel of Fig. 1 shows that the left part of the target area involves a patchy and sparse plage with a few pores. However, the target filament seen in the GONG Hα image shown in the right panel of Fig. 1 looks as a prolate structure centered at the position $X = +215$ arcsec, $Y = -420$ arcsec occupying mostly a non-magnetic area. Therefore its nature is imaginable only as a single magnetic fluxtube or a bundle of fluxtubes interconnecting areas of opposite polarities.

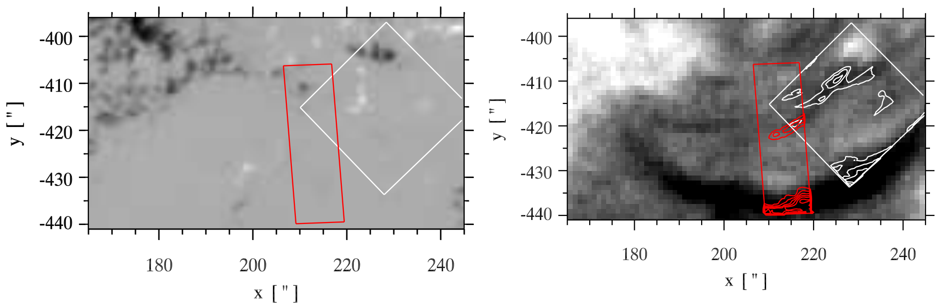

Figure 1. *Left:* The HMI LOS magnetogram of the target area taken on 11 September 2014 at 10:01:20 UT. *Right:* The Hα image of the same area taken by the GONG network station at the Teide Observatory at 10:01:14 UT. The filament visible at the bottom panel occurred at the south edge of the active region NOAA 12159. The white square defines the field of view of TESOS and the red rectangle identifies the area of the TIP scan No. 3. The scanning ran from the west to the east.

2. Observations

Spectropolarimetric observations in full Stokes in He I infrared triplet with wavelengths around 10 830 Å were obtained with the Tenerife Infrared Polarimeter No. 1 (TIP 1) fed by the spectrograph. Together with the spectropolarimetry also spectroscopic observations in the Ca II 8542 Å line were obtained by the spectrograph. The third scan made between 09:56:28 and 10:04:43 UT was chosen for further analysis because of the best quality of the data. The TESOS instrument made 2D intensity images with the field of view (FOV) of $25'' \times 25''$ in 136 wavelength points through the Hα profile within wavelength interval 6561.2 – 6564.5 Å (with wavelength step of 0.025 Å). The TIP 1 and TESOS FOVs co-aligned and correctly oriented according to the solar N are shown in Fig. 2. The overlap of FOVs of the both instruments is marked by the black triangles. More details about the observations used in this work can be found in Schwartz et al. (2016).

3. Results and Conclusions

The HAZEL code (Asensio Ramos et al. 2008) is used for synthesis and inversion of Stokes profiles of several spectral lines of helium (e.g., He I IR triplet, D3, etc.) solving detailed radiative transfer in the 1D geometry taking into account atomic level polarisation and Zeeman, Hanle and Paschen effects. In the model, one or two 1D slabs irradiated from bottom are assumed while properties across the slab are constant. For irradiation of the slab(s), center-to-limb variation is taken into account. We were using the code in the mode of one optically thick slab of the optical thickness τ situated at the height h above the solar surface in a presence of a deterministic magnetic field of arbitrary strength, inclination and azimuth. Also influence of LOS velocity $v_{\rm LOS}$ of the slab plasma on the resulting profiles is assumed. Due to a very low signal-to-noise ratio in Q and U profiles, resulting values of the magnetic field azimuth and inclination were affected by huge errors and therefore not usable. At least, it was possible to reliably fit the intensity profiles and obtain optical thickness in the center of the red component of the He I triplet and $v_{\rm LOS}$. An increase of the optical thickness is well pronounced in the

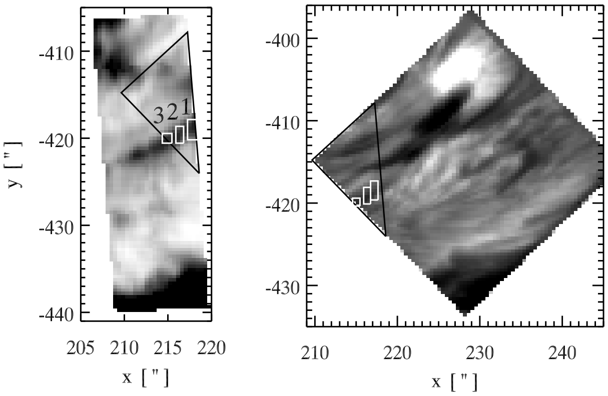

Figure 2. *Left:* The slit-reconstructed monochromatic image of the target area in the line center of the red component of the He I 10830 Å triplet observed by TIP 1. The scanning run from 09:56:28 UT to 10:04:43 UT. *Right:* The Hα line center image of the target taken by TESOS at 10:01:33 UT. The black triangles identify an overlap of TIP 1 and TESOS FOVs. The small gray rectangles mark segments of the filament selected for an analysis.

dark structure of the mini-filament. The values of v_{LOS} estimated there are almost zero not exceeding interval ∓ 1 km/s.

Fitting of very deep and broad Hα profiles observed at the dark structure of the mini-filament using a simple cloud model (Beckers 1964) led to very high temperatures 20 – 50 K which are totally unrealistic for Hα. Thus, the Hα were modelled by a more sophisticated NLTE model in the 2D geometry. It is assumed that the mini--filament is composed of multiple fluxtubes placed one above another with plasma flowing inside them along the magnetic field. For the simple 2D model used in this work, system of fluxtubes is approximated by an isothermal and isobaric 2D slab of a box-like cross-section with two finite dimensions – vertical (Z) and across the filament (X). The dimension along the filament (Y) is infinite. The radiative transfer in the model is solved using short-characteristics method (Kunasz & Auer 1988) together with Multilevel Accelerated Lambda Iterations (Auer & Paletou 1994) similarly as was done for prominences by Heinzel & Anzer (2001). Statistical equilibrium was calculated for the 5-level hydrogen atom. The formal solution of the radiative transfer was made along LOS at $\mu = 0.87$ which corresponds to the position of the mini-filament. It was found by the NLTE modelling that the mini-filament is vertically very large (several tens of thousands km), thus it must be composed of several tens of horizontal fluxtubes of size of about 1 000 km with rather cool plasma of $T \sim 10\,000$ K and density around 1.5×10^{-13} g cm^{-3} flowing along them by very large velocities which are supersonic for such densities. Fluxtubes must be almost horizontal to achieve almost zero LOS component of the flow velocities in order to be consistent with v_{LOS} obtained from the HAZEL modelling of the He I IR triplet intensity profiles. More details about the results obtained in this work is published in Schwartz et al. (2016).

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