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Spectropolarimetry of the solar spicules using the 53-cm coronagraph of the Abastumani Astrophysical Observatory

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Abstract. In this paper we present the test spectropolarimetric observations of the spicules in the Hα and He I D3 multiplet for different high chromospheric altitudes from 5000 km to 7000 km using the innovative Polarization-Holographic Imaging Stokes Polarimeter (PHISP) mounted on the 53-cm coronagraph of the Abastumani Astrophysical Observatory (Georgia). The laboratory tests and first spectropolarimetric observations show that the resulting uncertainties are estimated to be of the order of 10^{-3}.

Key words: Solar chromosphere – solar spicules – spectropolarimetry – polarization holography

1. Introduction

The solar spicules are thin and very dynamic needle-shaped plasma jet structures, best seen at the solar limb, whose magnetic properties are not well constrained to date. The magnetic field in spicules has been determined using direct analyses of spectral lines in polarized light, mostly using the He I spectral multiplets (Lopez Ariste and Casini, 2005; Trujillo Bueno et al., 2005; Centeno et al., 2010; Orozco Suarez et al., 2015; Ramelli et al., 2011). The polarization signals in these multiplets are generated by the joint action of the transversal Zeeman effect and scattering polarization modified by the Hanle effect.

Here we present the test spectropolarimetric observations of the spicules in the Hα and He I D3 multiplet for different chromospheric altitudes using the innovative Polarization-Holographic Imaging Stokes Polarimeter (PHISP) mounted on the 53-cm coronagraph of the Abastumani Astrophysical Observatory (Georgia), depicted in Figure 1.

Polarization-holography was first proposed by Kakichashvili (1972, 1974). This method was used to develop a unique polarization optical element providing instant and full analysis of the polarization state of an incoming light in the visual and near infrared spectral ranges (Kilosanidze & Kakauridze, 2007; Kilosanidze & Kakauridze, 2009; Kakauridze & Kilosanidze, 2011). The PHISP

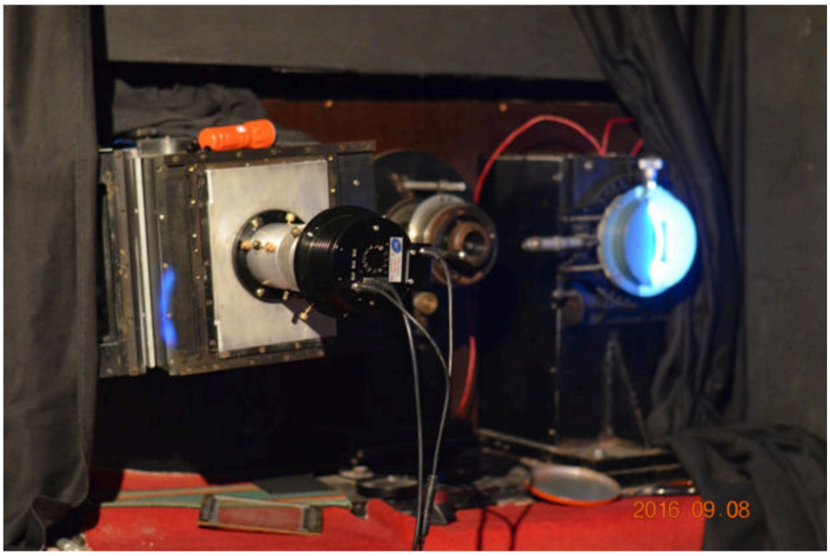

Figure 1. The PHISP mounted at the spectrograph of the 53-cm coronagraph of the Abastumani Astrophysical Observatory (Georgia).

is designed on the basis of such element being the only polarization optical part of the instrument (Kvernadze et al., 2016).

2. Method, design, calibration and test observations

The polarization-holographic element decomposes incident light into circular and linear diffraction orders. As a result we get two orthogonal circularly polarized beams with intensities I_{+c} and I_{-c}, two linearly polarized beams with intensities $I_{+1,45}$ and $I_{-1,45}$ and position angle $+45°$, two linearly polarized beams with intensities $I_{+1,90}$ and $I_{-1,90}$ and position angle $+90°$ and also none diffracted beam with a state of polarization identical to incoming beam and with intensity I_0.

The measurements of intensities of diffracted orders allow us to determine all four Stokes parameters through the following relations:

$$\begin{aligned} I_\lambda &= k_{+c,\lambda} I_{+c} + k_{-c,\lambda} I_{-c}, \\ Q_\lambda &= (k_{+c,\lambda} I_{+c} + k_{-c,\lambda} I_{-c}) - 2k_{90,\lambda} I_{90}, \\ U_\lambda &= 2k_{45,\lambda} I_{45} - (k_{+c,\lambda} I_{+c} + k_{-c,\lambda} I_{-c}), \\ V_\lambda &= k_{+c,\lambda} I_{+c} - k_{-c,\lambda} I_{-c}, \end{aligned} \quad (1)$$

where k terms are coefficients connected with absorption of light in an element, diffraction efficiency of an element and the optoelectronic transformations by the photo-detectors. The values of these coefficients are determined experimentally during calibration. The principal scheme of PHISP and configuration of diffraction orders is shown in Figure 2 (Kvernadze et al., 2016).

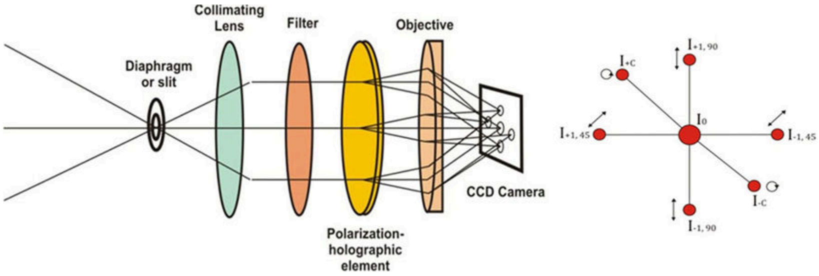

Figure 2. Principal scheme of PHISP and configuration of diffraction orders.

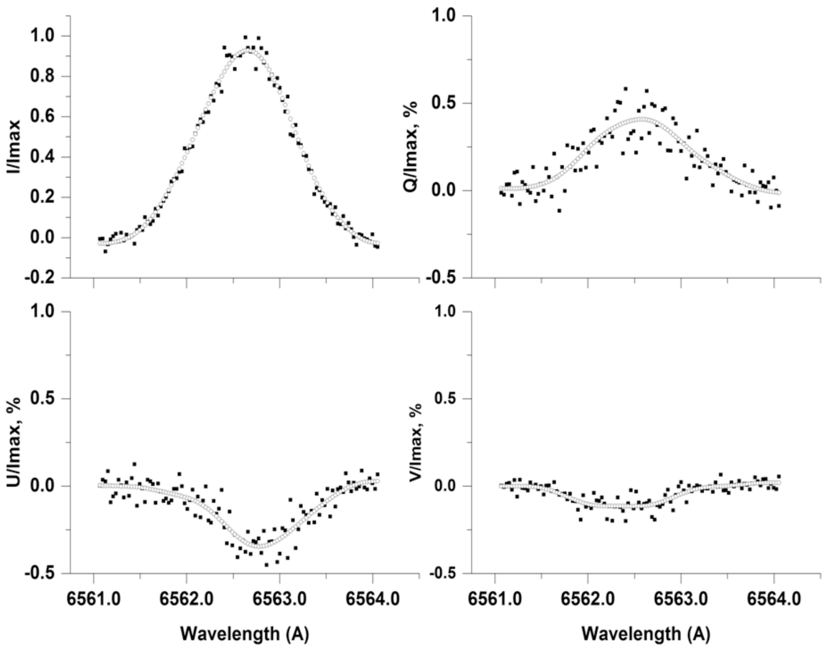

Figure 3. Observed Hα Stokes profiles normalized to Imax value.

For calibration purposes the special spectropolarimetric observations of the photosphere near the solar center were carried out in the Hα and D3 absorbtion lines immediately after the observations of the spicules with identical setup of the telescope and the polarimeter. The polarizer were placed in front of the spectrograph slit and rotated by 15° in the range of 0°-360° to obtain linear polarization light beam with different phase angles. The spectral line minima were used to calculate the calibration parameters. The measured intensities and known values of the Stokes parameters of every position of the polarizer were used in the formulas above to calculate the calibration coefficients (Kilosanidze et al., 2015).

The intensity profiles of the spicules were transformed to the Stokes profiles using the calibration coefficients. The resulting normalized Stokes profiles are depicted below (Fig. 3). Also fitted curves are shown which are calculated using a spline smoothing algorithm. The residuals between measurements and fitted curves show that the uncertainties are of the order of 10^{-3}.

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