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New atmosphere models to reconstruct solar irradiance

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Summary. — We aim at contributing to the refinement of the atmosphere models employed in solar irradiance reconstructions by deriving observation-based atmospheres from spectropolarimetric measurements of the solar atmosphere. Here we present results obtained from analysis of photospheric and chromospheric observations of quiet Sun, umbral, and penumbral regions, performed on May 20th 2016 with the IBIS Interferometric Bidimensional Spectrometer under excellent seeing conditions.

1. – Introduction

Present-day semi-empirical models of solar irradiance (SI) variations reconstruct SI changes measured on timescales larger than a day by using spectra computed in atmosphere models representative of the thermal structure and plasma properties of the different features observed on the solar surface [1]. These models are either one-dimensional plane-parallel semi-empirical atmospheres (1D models) or snapshots from three-dimensional magnetohydrodynamic simulations [2, 3, 4, 5]. In this framework, a recent study [6] has proved observational-based atmospheres derived from state-of-the-art high-resolution spectropolarimetric photospheric measurements of various solar disc features to agree within 10% with most of the 1D models employed to reproduce SI variations. We aimed at extending the latter study, by deriving atmosphere models of various solar regions from spectropolarimetric measurements that sample the solar atmosphere from the low photosphere to the middle chromosphere.

2. – Data and Methods

We analysed series of full-Stokes measurements taken on May 20th 2016 with the Interferometric BIdimensional Spectropolarimeter (IBIS) [7] at the Richard B. Dunn Solar Telescope (DST). The data were acquired along the Fe I 617.3 nm and Ca II 854.2 nm lines by targeting the large sunspot in the active region (AR) NOAA 12546 at the time located near disc center. The observations were assisted by the DST high-order

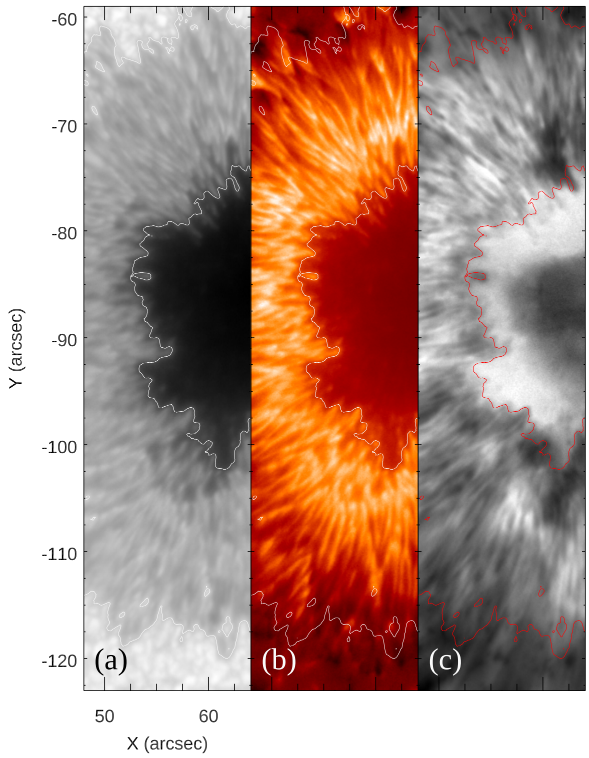

Fig. 1. – Example of the observations analysed in our study: line-continuum image (panel a) and circular polarization map (panel b) from Fe I 617.3 nm measurements, and line-core image (panel c) from Ca II 854.2 nm data. The line contours show the UM-PEN boundary and the outer PEN boundary that are set, as described in [10]. The solar region displayed here represents half of the FOV of the IBIS observations.

Adaptive Optics (AO) system [8] under excellent conditions of the atmospheric seeing. The data were taken at 21 spectral points in each line, with a spectral sampling of 20 mÅ and 60 mÅ for the Fe I 617.3 nm and Ca II 854.2 nm lines, respectively. The field of view was 500×1000 pixels with a pixel scale of 0.08 arcsec. For further details on the data see [9] and [10].

The observations were processed with the standard reduction pipeline([1]), to compensate for the dark and flat-field response of the CCD devices, instrumental blueshift, and instrument- and telescope-induced polarizations [11]. They were also restored for seeing-induced degradations, by using the Multi-Frame Multi-Object Blind Deconvolution technique [12].

We extracted sub-arrays (hereafter referred to as subFOV) of 70×70 pixels represen-

([1]) http://ibis.oa-roma.inaf.it/IBISA/

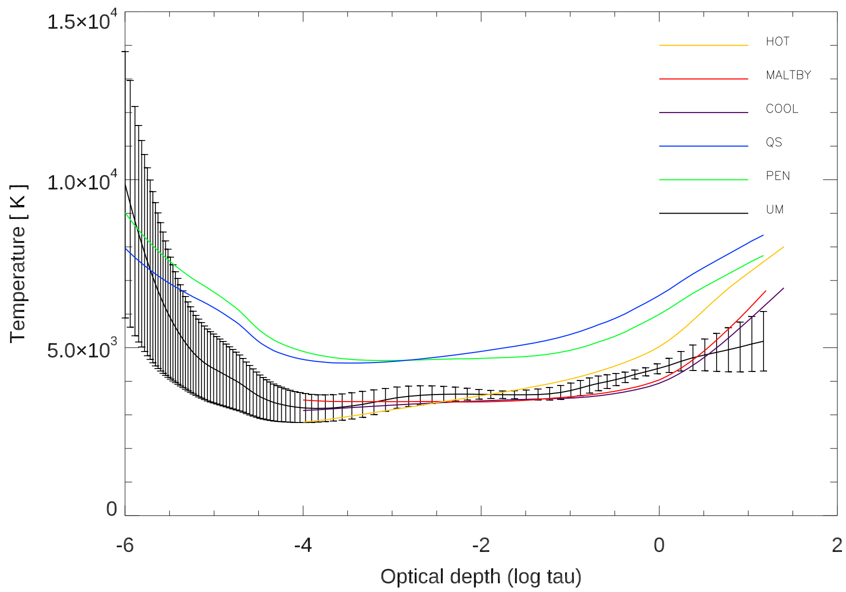

Fig. 2. – Comparison of the T(τ) derived from the data inversion for different subFOV in the analysed observations and the 1D models in the literature, as specified in the legend. The error-bars represent the 1σ confidence interval of the data inversion results.

tative of quiet Sun regions (QS) and of large-scale dark magnetic features in penumbral (PEN) and umbral (UM) regions. Each analysed subFOV represents a $\approx 6\times6$ arcsec^2 region on the solar disc.

Figure **1** shows examples of the photospheric and chromospheric observations analysed in our study. We show the continuum intensity measured in the Fe I 617.3 nm line (panel a), and the intensity map measured at the core of the Ca II line (panel c). We also show the circular polarization maps computed from the Fe I 617.3 nm line data (panel b).

We performed full-Stokes spectropolarimetric non-LTE (NLTE) inversions of the selected subFOVs with the NICOLE code [13]. We applied the NICOLE code to measurements of both sampled lines simultaneously. We performed the data inversion by considering the individual Stokes measurements in each pixel of the analysed subFOV and then spatially averaging the results of the subFOV. Find more details about the input parameters employed to invert the data in [10].

Finally, for the purpose of discussing the results derived from the analysed observations, we considered some sets of 1D atmosphere models presented in the literature. Find more details in the following.

3. – Results

We compared the stratification of the average temperature with respect to the optical depth (T(τ), hereafter) obtained from the data inversion of the various studied subFOV with those described by a few 1D models presented in the literature.

Figure 2 shows this comparison for the atmospheres derived from the QS, PEN, and

UM data. Colored lines correspond to the results from the data inversion and the 1D models employed for comparison, specifically the HOT and COOL models by [14] and the M model by [15]. All these reference models are representative of umbral regions. The T(τ) derived from the inversion of the various observed regions agree well with those in compared models, both qualitatively and quantitatively, and in particular within the range log τ = [-1,-4]. The atmosphere models derived from the observations of the QS and PEN regions exhibit higher plasma temperatures at almost all the atmospheric heights than those represented by all the models considered for comparison.

4. – Conclusions

We derived atmosphere models of various solar features (QS, UM, and PEN regions) from inversion of spectropolarimetric observations that sample the solar atmosphere from the low photosphere to the middle chromosphere. We found that the average temperature stratification obtained from the inversion of the umbral data is in very good agreement with that represented by the reference umbral models considered for comparison. However, it is worth noting that the reference models employed in our study consider lower plasma temperatures than those of models assumed in some current SI reconstructions, e.g. the S model by [16], see Figure 10 by [6].

The results presented above encourage us to continue our study of observation-based atmosphere models for inclusion in SI reconstructions. Future work will aim at achieving atmosphere models from photospheric and chromospheric observations representative of other solar regions than considered in the present study, in particular of network and plage regions, and at performing NLTE spectral syntheses calculations on our observation-based atmospheres.

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