Inversion of 1.5 μm spectral data of a sunspot

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Abstract. Spectropolarimetric data of two neighboring infrared lines, Fe I 15648.5 Å and Fe I 15652.9 Å, recorded in a sunspot when it was near the solar limb ($\mu = 0.45$) and disk center ($\mu = 0.89$), are analyzed in order to understand the basic structure and the nature of Evershed flow. Here we discuss the inversion of the spectral data and present some initial results.

1. Introduction

The potential of the Fe I 15648.5 Å and Fe I 15652.9 Å lines in the IR H-band to diagnose the properties of solar magnetic features are described by Solanki *et al.* (1992). Using this combination of Lande $g = 3$ and $g_{eff} = 1.53$ lines it is possible to measure the field strength in solar magnetic features simply and with great accuracy. By forming the line ratio between the V profiles of these lines it is in principle possible to measure field strengths as low as 100 G. Due to the extremely high sensitivity of the $g = 3$ line one can follow the magnetic field and the associated Evershed effect beyond the visible sunspot. Using an inversion technique it is possible to determine the stratification of physical quantities in the solar photosphere from the spectral line profiles (Ruiz Cobo & Del Toro Iniesta 1992, Frutiger 2000, Frutiger *et al.* 2000, Westendrop Plaza *et al.* 2001). Recent inversion codes use response functions (RFs) to speed up the process of iterative fitting. In the following sections we discuss the inversion of the Stokes profiles of the above two lines observed in a sunspot.

2. Observational data

In this paper we use the observations of a symmetric sunspot obtained on 22nd ($\mu = 0.45$) and 27th ($\mu = 0.89$) Sep 99 with the Tenerife Infrared Polarimeter (TIP, Collados 1999). All four Stokes profiles were recorded over wavelength range which included the Fe I lines at 15648.5

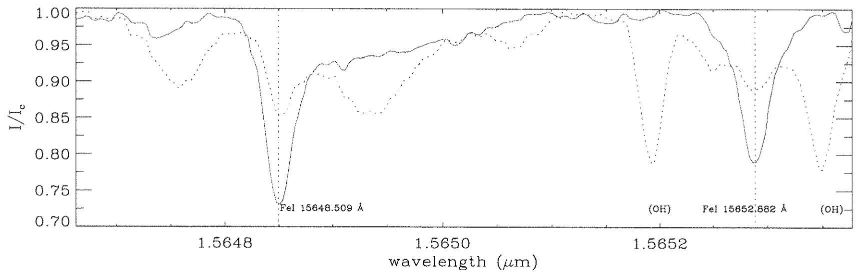

Figure 1. Sample Stokes I profiles for a quite sun (solid) and umbral(dotted) point. The umbral profile clearly shows the OH lines blending with the Fe I 15652.9 Å.

Å and 15652.9 Å. The data were corrected for flat field, dark current and instrumental polarization before running the inversions. Figure 1 shows sample Stokes *I* profiles for a quiet Sun and umbral point.

3. Method of analysis

The data were fitted using the code 'INVERT' described by Frutiger *et al.* (2000). The Stokes profiles were calculated in LTE through a two-component model atmosphere composed of a magnetic and non-magnetic part. In every pixel two atmospheric components are allowed for, one magnetic (with filling factor α) and one field-free (with filling factor $1-\alpha$). In sunspot the field free component describes stray light. The synthetic profiles were iteratively fitted with observed data using response functions (RFs) and the Levenberg-Marquardt algorithm that minimizes the merit function χ^2 (Ruiz Cobo & Del Toro Iniesta 1992, Frutiger 2000). The use of RFs considerably accelerates the iterative scheme, making it fully automatic. The relevant free parameters for the inversion are (depth dependent) magnetic field strength B, the inclination angle, line-of-sight velocity, field azimuth and the filling factor.

Telluric and molecular blends associated with the above lines (visible in Fig 1) introduced inaccuracies in the inversions if left unattended. We have removed the telluric blend from the Fe I 15648.5 Å line by fitting the averaged quiet Sun profile with a computed profile. The fitted profile is used to recover the blend and is subsequently removed from the intensity profiles. The two molecular OH blends present in Fe I 15652.9 Å line are also inverted, which improved the reliability of the deduced atmospheric parameters, in particular in the umbra where these blends are strong (Berdyugina *et al.* 2001).

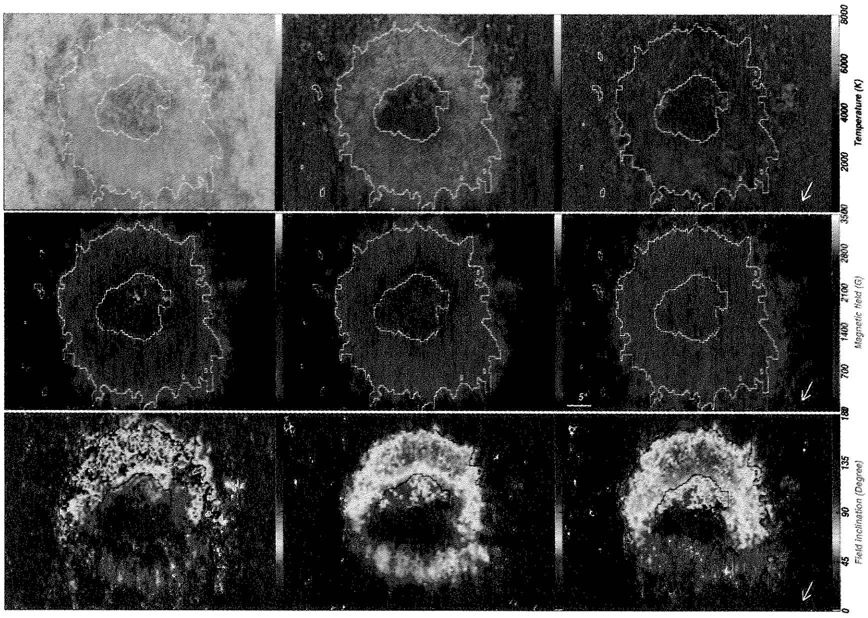

Figure 2. Temperature, field strength and field inclination at three different layers of the sunspot photosphere for 27th Sep 99. Contours indicate outer umbral and penumbral boundaries. Arrows are directed towards the Sun center.

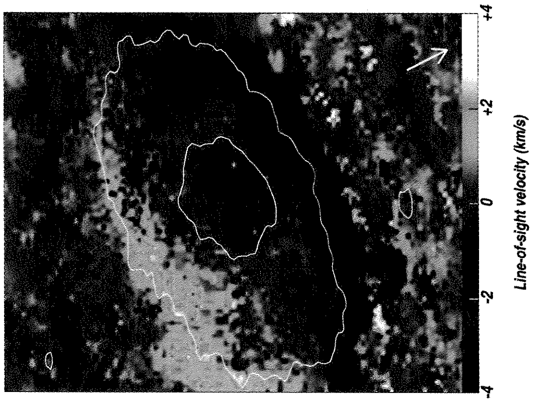

Figure 3. Velocity map for 21st Sep 99. Contours indicate outer umbral and penumbral boundaries and the arrow points towards the Sun center.

4. Preliminary results

Figure 2 shows the maps for temperature, magnetic field strength and magnetic field inclination for the magnetic component at three different logarithmic optical depths ($log[\tau] = 0, -1, -2$) for 27th Sep 99. The temperature structure is well constrained in the umbral and most of the penumbral regions, although the employed Fe I lines are only weakly temperature sensitive. It is mainly the OH lines which constrain the temperature. The quiet Sun temperature is better defined by the non-magnetic component, since $\alpha << 1$ there in general. In higher layers an increased signal for magnetic fields surrounding the sunspot beyond the outer continuum boundary is evident in the magnetic field map. This suggest the existence of a super penumbral canopy first suggested by Giovanelli & Jones (1982) and later confirmed by Solanki *et. al.* (1992). The inclination of the field vectors (γ) also increases at higher atmospheric layers. The derived velocity map for the 21st Sep99 is given Figure 3. Velocities ranging from 2 - 3 kms^{-1} are found in the outer penumbra, which is in agreement with earlier observations. An initial look at the velocity map shows that the Evershed flow continued beyond the visible penumbral boundary in the magnetic component.

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