A New Technique to Measure Magnetic Field Strength in Active Stars

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Abstract: We explore the use of the flux difference between the lines Fe I 5250 Å and Fe I 5247 Å as a technique to measure photospheric magnetic fields in late–type stars. The technique developed takes into account all the LTE physics of the problem, assuming a radial and homogeneous magnetic field distribution over the stellar surface. Some test calculations, in order to prove the feasibility of the method, are shown.

1. Introduction

Despite the advances achieved since the pioneer work of Robinson (1980), techniques to measure the magnetic field strength in stars still require improvement. The current methods resort to oversimplifications (see Hartmann, 1987) which can be summarized as: (i) An incomplete treatment of the radiative transfer in a magnetic medium which does not take into account line saturation or magneto-optical effects. (ii) An idealized magnetic model atmosphere, both in its thermodynamical properties and the distribution of magnetic zones over the stellar surface. In all cases magnetic and non-magnetic zones are assumed to be thermodynamically identical while in most cases magnetic zones are placed in a single position on the disk. This work presents a new technique which attempts to overcome some of these difficulties.

2. The method

Assume that we can observe two lines which are identical in every respect except for their Zeeman splittings. The difference between their profiles (flux difference versus wavelength) does not depend on the non-magnetic regions of the star (it is not even affected by a magnetically quiet unresolved companion of our problem star). This implies that if the magnetic field strength is derived by modelling the

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difference of the profiles, no hypothesis is needed about the regions of the star which do not contain magnetic fields.

We have developed a computer code which fits the difference between FeI 5250Å and FeI 5247Å by means of a non-linear least squares algorithm. It uses the Milne-Eddington solution of the radiative transfer equations integrated over the stellar disk (see Landolfi *et al.*, 1989). As we discuss in the next paragraph, these lines fulfil the requirements of being very nearly identical. The solutions of the radiative transfer equations take into account all the LTE physics of the problem (including magneto-optical effects), although they treat the thermodynamical properties of the atmosphere in a very simplified manner. Rotation is considered by direct integration of the specific intensity over the stellar disk, taking into account the local Doppler shift. Finally, the magnetic field is assumed to be uniformly spread over the star and radial. This magnetic field distribution (previously considered by other authors; see e.g. Basri and Marcy, 1988) resembles that of the Sun.

FeI 5250Å and FeI 5247Å have been chosen as the pair of *identical* lines, in the absence of a magnetic field, required by our method (Stenflo, 1973). Figure 1 shows the difference of specific intensity of these lines synthesized (LTE) in quiet and active solar regions. The synthesis takes into account the intrinsic difference between the lines. Note that the effect produced by the magnetic field is more pronounced in the core than in the wings. This fact is important because blends, which are sources of systematic errors, affect mainly the wings (Saar, 1988).

3. Observational and numerical tests

As a very preliminary observational test of our technique, we have applied the fitting procedure to an intensity (Stokes I) profile obtained over a facula close to the disk centre. The spectrum is described in detail by Stenflo *et al.* (1984), but it basically consists of a high signal-to-noise ratio, high spectral resolution, Stokes I and V profiles of a region partly covered by magnetic fields (10–15%). The Stokes V profile (circular polarization versus wavelength) allows an independent determination of the field strength of the region (Sánchez Almeida *et al.*, 1988), giving 1250 G. Figure 2 contains the observed data and the fitted subtraction $I_{FeI5250} - I_{FeI5247}$, which corresponds to a field strength of 1330 G.

A numerical test for the method has also been performed. We have simulated the difference of fluxes $F_{FeI5250}$ - $F_{FeI5247}$ for a star in which the line strengths are similar to those observed in the Sun, but which rotates with a velocity ($v \sin i$) of 5 km/s, has a macroturbulence of 7 km/s FWHM, and has a magnetic field of strength 2000 G covering 50% of its surface. Random noise has been added to the synthetic profiles to yield a signal-to-noise ratio 300 in the continuum. The values obtained from the fit for these parameters are within 20% of the *correct* values.

We infer that the method we propose seems to be a useful technique for measuring magnetic fields (and filling factors). It does not assume the same model

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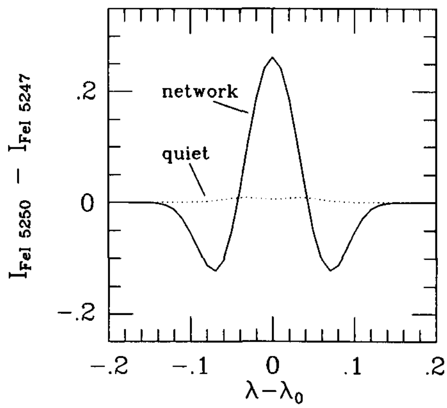

Fig. 1. Difference of specific intensity of the lines FeI 5250Å and FeI 5247Å synthesized in a quiet solar region without magnetic field, and a active region with a constant longitudinal magnetic field of 1300 G. Wavelengths (referred to the laboratory wavelengths of the lines, λ_0) are in Å.

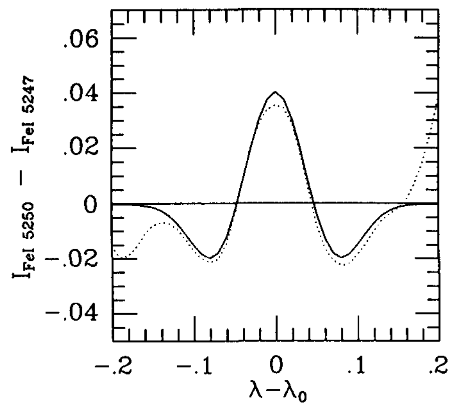

Fig. 2. The dotted line is the difference of specific intensity $I_{FeI5250}-I_{FeI5247}$ observed over a solar facula close to the disk centre. The solid line corresponds to the best fit provided by our method (without integration over the solar disk).

atmosphere for the parts of the star with and without magnetic fields and it includes complete polarized radiative transfer calculations.

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