Magnetic Fields throughout Stellar Evolution
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On the spectropolarimetric signature of FeH in the laboratory and in sunspots

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Résumé. Laboratory spectra showing Zeeman patterns in some FeH lines susceptible to be used as magnetic probes in cool stellar atmostpheres have been recorded in the laboratory, and molecular Landé factors obtained from analysis. These Landé factors have been used to model some lines recorded in Stokes V polarisation in sunspot spectra at the solar telescope THEMIS.

Keywords. electronic spectrum of FeH, molecular Landé factor, sunspot spectrum, Stokes V profile

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1. Laboratory determination of Landé factors

Zeeman-broadened lines in the near-IR bands of FeH have been suggested as a magnetic probe of cool stellar atmospheres (Afram *et al.*, (2008), but the Landé factors for these transitions are notoriously difficult to predict because of electronic configuration complexity in the FeH radical. Laser magnetic resonance spectroscopy (Brown *et al.* (2006))has established g_J values for the v = 0 in the X $^4\Delta_\Omega$ ground state. This work aimed to supply reliable g_J Landé factors for some electronically excited levels in the F $^4\Delta_\Omega$ state of FeH, refining estimates made by Harrison & Brown (2008) from Zeeman profiles of FeH transitions seen in the sunspot atlas of Wallace *et al* (1998). FeH is formed at $\sim$ 500 K in a hollow-cathode sputtering source described elsewhere, Vallon *et al.* (2009). Excitation spectra were recorded as total fluorescence signals, first in zero field, to secure the energy origins and Λ-doubling separations for each line of interest, and then at magnetic fields between 0.2 and 0.5 Tesla (calibrated against Ar I lines) provided by permanent magnets. Laser polarisation was selected to record either $\Delta M_J = 0$ or $\pm$ 1 transitions. In most cases the Zeeman profiles of the lines are only partially resolved (see below). Effective Landé factors g'_J have been determined from peak positions (when deconvolution is possible) or by profile fits, relying on literature values from Brown *et al.* (2006) for parameters in the ground electronic state, fitting measured wavenumbers to the expression

$$\nu \ = \ \nu_0 + \mu_B \ B \ (g'_J \ M'_J \ \text{-} \ g''_J \ M''_J),$$

where μ_B is the Bohr magneton (46.68645 $m^{-1}T^{-1}$) and B is the longitudinal magnetic field intensity. Fig. 1 illustrates the results, showing behaviour close to Hund's coupling case (b) for the ground state, but a very different trend (between limiting cases (a) and (b)) for rotational levels of F $^4\Delta_{7/2,\ 5/2}$, although both are nominally $^4\Delta$ electronic states, and could be expected to demonstrate similar angular momentum coupling.

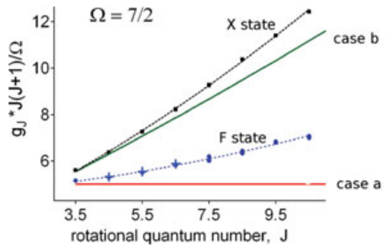

Fig. 1. Some electronic Landé factors in FeH. F $^4\Delta_\Omega$ v = 0, 1 data indicated by ∘ and +.

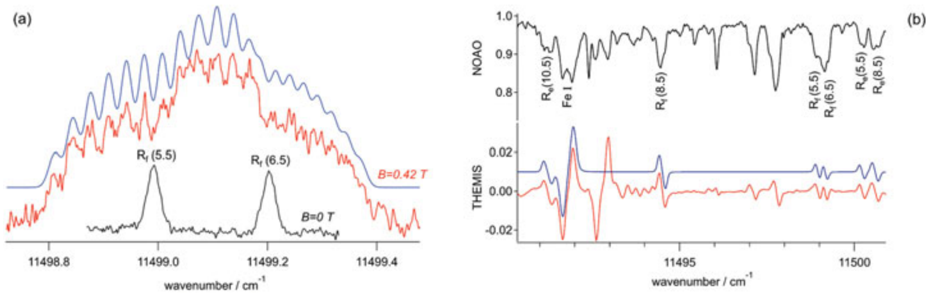

Fig. 2. a) Laboratory spectrum of overlapped $R_1(5.5)$ and $R_1(6.5)$ lines showing partially-resolved Zeeman structures. b) Sunspot (NOA0 11582) Stokes V spectrum from Themis with some calculated profiles drawn with vertical offset. Solar atlas absorption from Wallace *et al* (1998) is shown above for comparison, identifying the molecular transitions.

2. Determination of magnetic fields in sunspots

Polarimetric spectra have been recorded at the solar telescope THEMIS in Tenerife in the regions corresponding to the lines with best-resolved Zeeman structures in the laboratory. With a 0.5" slit and high order Echelle spectrograph, lines around 8730 Å in sunspot NOA0 11582 were recorded at a resolution of 90 mÅ. They are not the strongest contributions to the FeH bands in sunspot spectra, but the excellent S/N ratio ($\sim 10^4$) of the Stokes-V signals from THEMIS allows weak features to be examined and modeled. Our spectral simulations optimized linewidths to match effective instrumental resolution for six molecular transitions and one atomic line. Landé factors were constrained in these profile fits. Fig. 2 shows some lines in the F_2 F-X 1-0 band of ^{56}FeH. The laboratory spectrum shows the structure of two close-lying lines in this region corresponding to a blended feature in the solar absorption spectrum. Analysis of molecular line profiles leads to an average value for the longitudinal magentic field of -0.26(1)T. The profile of the Fe I line, however, leads to a larger value, -0.286 T. Atoms are assumed to be preferentially probed at deeper regions of the photosphere, where field lines are tighter. Molecular radicals become more abundant in cooler and higher-altitude regions of the sunspot.

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