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CrH molecule: New diagnostic tool for measuring magnetic fields of cool dwarfs

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Abstract. The quantum mechanical calculations for the $A^6\Sigma^+ - X^6\Sigma^+$ system of the CrH molecule were done in order to obtain its energy level structure and transition strenghts both in the absence and in the presence of a magnetic field. Employing this results and solving a set of the radiative transfer equations, we calculated the Stokes profiles for the entire 0-0 band for different magnetic field strengths and orientations. We show that the CrH lines produce a considerable polarization signal (up to 20%) at 0.5 − 10 kG. Furthermore, the polarization signal shows a significant asymmetry (*broad-band polarization*) that arises from the Paschen-Back effect in the individual CrH lines. An example of the signal, as it can be observed, is provided.

Keywords. brown dwarfs, stars: magnetic fields, techniques: polarimetric, radiative transfer

1. Calculations

The total Hamiltonian of the CrH molecule in the absence of an external magnetic field is (Brown & Milton (1976)):

$$\hat{H}_{\rm b} = \hat{H}_0 + \hat{V}, \tag{1.1}$$

where $\hat{V} = \hat{H}_{\rm rot} + \hat{H}_{\rm cd} + \hat{H}_{\rm so} + \hat{H}_{\rm sr} + \hat{H}_{\rm ss}$.

Following Ram *et al.* (1993), we express $\hat{H}_{\rm b}$ in the wave functions of case a, $|{\rm a}\rangle$:

$$\mathcal{H}_{\rm b} = \langle {\rm a}|\hat{H}_0|{\rm a}\rangle + \langle {\rm a}|\hat{V}|{\rm a}\rangle + \mathcal{O}\left(\langle {\rm a}|\hat{V}^2|{\rm a}\rangle\right) + \ldots . \tag{1.2}$$

The total Hamiltonian of the molecule in the presence of a magnetic field is (Berdyugina *et al.* (2005)):

$$\hat{H}_{\rm mag} = \hat{H}_{\rm b} + \hat{H}_H . \tag{1.3}$$

Expressing $\hat{H}_{\rm mag}$ in the wave functions of case b, $|b\rangle$, we obtain:

$$\mathcal{H}_{\rm mag} = \langle {\rm b}|\hat{H}_{\rm b}|{\rm b}\rangle + \langle {\rm b}|\hat{H}_H|{\rm b}\rangle. \tag{1.4}$$

For the amplitude of the transition between two states $|\Sigma' J'\rangle$ and $|\Sigma'' J''\rangle$ in case b we get (Schadee (1978), Berdyugina *et al.* (2005)):

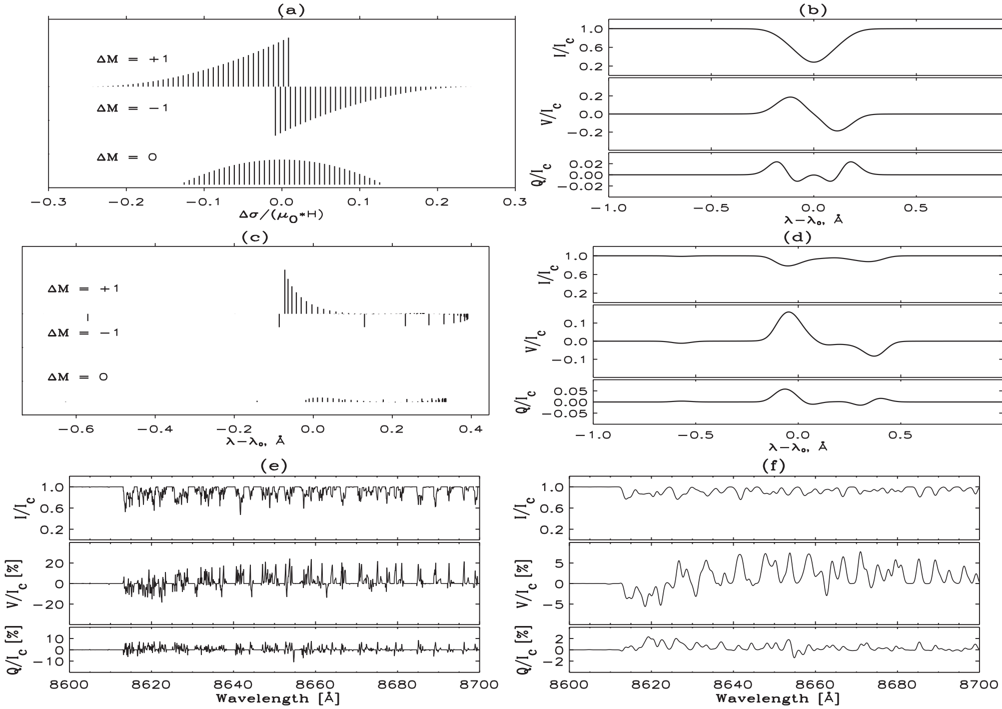
$$q^{\rm b}_{\Sigma'\Sigma'' J' J''} = \sum_i \sum_j C^{\rm T}_{\Sigma'_i J'}\, q^{\rm a}_{\Omega'\Omega'' J' J''}\, C_{\Sigma''_j J''}, \tag{1.5}$$

The transition amplitude between two magnetic levels $|\Sigma' J' M'\rangle$ and $|\Sigma'' J'' M''\rangle$ is:

$$q^{\rm mag}_{\Sigma'\Sigma'' J' J'' M' M''} = \sum_k \sum_l C^{\rm T}_{\Sigma'_k J' M'}\, q^{\rm b}_{\Sigma'\Sigma'' J' J''}\, q_{J' J'' M' M''}\, C_{\Sigma''_l J'' M''}. \tag{1.6}$$

We employed the code STOPRO (Solanki (1987)) for the calculation of the Stokes profiles presented in this paper.

2. Predictions for the CrH



We show here the Zeeman patterns and the corresponding Stokes profiles for a transition from the main spectroscopic branch R in the Zeeman regime (a,b) and in the Paschen-Back regime at 10 kG (c,d). Below we see the Stokes profiles of the 0-0 band ($\approx$ 300 lines) at 10 kG (e,f). The spectrum in the right bottom panel (f) is calculated for the instrumental broadening 0.8 Å and stellar rotation $v \sin i = 20$ km/s.
Further details can be found in the upcoming paper of Kuzmychov & Berdyugina (2013).

3. Conclusions

The Stokes V/I_c calculated for the entire 0-0 band shows a significant asymmetry at the magnetic field strengths $4 - 10$ kG, that arises from the Paschen-Back effect in the individual CrH lines. The asymmetric shape of the polarization signal is mainly the effect that allows us to measure the magnetic fields on cool dwarfs. The broad-band polarization allows detection of the observational signal, even if a polarimeter with low spectral resolution is employed. The asymmetry (or the shape) of the polarimetric signal is independent of the filling factor of a magnetic region, which merely reduces the strength of the signal.

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