Paschen-Back effect in the CrH molecule
New diagnostic tool for measuring magnetic fields in ultra-cool dwarfs

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Warsaw
May 08, 2012
Today’s program

Why we study CrH

How we study CrH

Simulations with STOPRO
   Individual lines
   0 – 0 band

Outlook
Why CrH?

Fig. from http://www.stsci.edu/~inr/ldwarf1.html
Objectives

- linelist for CrH,
- line strengths (in the absence/presence of a mag. field),
- simulation of a CrH spectra (Stokes I, Q and V),
- observations.
Hamiltonian for $^6\Sigma$ el. state

$$\hat{H} = \hat{H}_{\text{int}} + \hat{H}_{\text{rot}} + \hat{H}_{\text{so}} + \hat{H}_{\text{sr}} + \ldots + \hat{H}_H$$

- eigenvalues,
- eigenvectors.
Intensity

\[ I_{n''}^{n'} \propto A_{n''}^{n'} \propto \sum |R_{n''}^{n'}|^2, \]

where

\[ \sum_{M'M''} |R_{n''}^{n'}|^2 = f_e \times q_{v'v''} \times \sum_{M'M''} q_{\Omega'\Omega''J'J''M'M''}^2 \]

\( \text{line strength} \)
Amplitudes

\[ q_{\Omega'\Omega'' J' J'' M' M''} = q_{\Omega'\Omega'' J' J''} \times q_{J' J'' M' M''} \]

\[ q^{(b)}_{\Omega_i' \Omega_j' J_k' J_l'} = \sum_{\Omega_i'} \sum_{\Omega_j'} C^{*}_{\Omega_i' J_k'} q^{(a)}_{\Omega_i' \Omega_j' J_k' J_l'} C_{\Omega_j' J_l'} \]

\[ q^{pb}_{\Omega_k' \Omega_l' J_k' J_l' M' M''} = \sum_{M_k'} \sum_{M_l'} C^{*}_{J_k' M_k'} q^{(b)}_{\Omega_k' \Omega_l' J_k' J_l'} q_{J_k' J_l' M_k' M''} C_{J_l' M_l''} \]

Indices:

\[ i, j = -5/2, -3/2, \ldots, 5/2 \quad \text{case (a)} \]
\[ k, l = -5/2, -3/2, \ldots, 5/2 \quad \text{case (b)} \]
\[ m, n = -J, -J + 1, \ldots, J \quad \text{both cases} \]
Recipe for simulations with STOPRO\textsuperscript{2}

- linelist
  - energies of transitions
  - strengths of transitions
- spectroscopic data:
  - damping constants, FC factor, ...
- atmospheric model ($T = 2500$ K, $\log g = 4.5$)
- strength of the mag. field
- orientation of the mag. field ($\chi = 0^\circ$, $\gamma = 45^\circ$)

\textsuperscript{2}Solanki 1987 and Solanki et al. 1992
Zeeman regime

\[ \Delta E = g \mu_0 MH \]
Paschen-Back regime

(a) 0.001 kG

\[ \Delta M = +1 \]

\[ \Delta M = -1 \]

\[ \Delta M = 0 \]

(b) 0.001 kG

\[ \frac{V}{V_c} \]

\[ \frac{Q}{Q_c} \]
Paschen-Back regime

\[ \Delta M = +1 \]

\[ \Delta M = -1 \]

\[ \Delta M = 0 \]
Paschen-Back regime

\[ \Delta M = +1 \]

\[ \Delta M = -1 \]

\[ \Delta M = 0 \]
Paschen-Back regime

\[ \Delta M = +1 \]
\[ \Delta M = -1 \]
\[ \Delta M = 0 \]
Paschen-Back regime

\[ \Delta M = +1 \]
\[ \Delta M = -1 \]
\[ \Delta M = 0 \]
Simulations with STOPRO $0 - 0$ band

\[ \text{crh00}_05\text{kG}_\chi=0\_\text{gam}=45 \]

\[ \frac{I}{I_c}, \frac{V}{I_c}, \frac{Q}{I_c} \]

\[ \lambda - \lambda_0, \text{Å} \]
Simulations with STOPRO 0–0 band

\[ \text{crh00\_1kG\_chi=0\_gam=45} \]

\[ \frac{I}{I_c}, \frac{V}{I_c}, \frac{Q}{I_c} \]

\[ \lambda - \lambda_0, \ \text{Å} \]
Simulations with STOPRO $0 - 0$ band

$crh00\_3kG\_chi=0\_gam=45$

$I/I_c$

$V/I_c$

$Q/I_c$

$\lambda - \lambda_0$, Å
Simulations with STOPRO $0 \rightarrow 0$ band

crh00_6kG_chi=0_gam=45

$I/I_c$

$V/I_c$

$Q/I_c$

$\lambda - \lambda_0$, Å

8600 8620 8640 8660 8680 8700
Simulations with STOPRO 0−0 band

O. Kuzmychov, S.V. Berdyugina () Paschen-Back effect in the CrH molecule Warsaw May 08, 2012 19 / 20
Summary & Outlook

- promising potential of the CrH,
- observing campaign is pursued,
- if success $\Rightarrow$ first mag. field maps for L-dwarfs.