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ABSORPTION PROFILES OF THE POTASSIUM $4S-4P$ AND $4P-5S$ LINES PERTURBED BY HELIUM

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Abstract. An accurate determination of the complete profile including the extreme far wing is required to model the contribution of strong alkali resonance lines to brown dwarf spectra. A unified theory of collisional line profiles has been applied for the evaluation of the absorption coefficients of potassium perturbed by helium. Results are reported here from the optical range to the near-infrared.

Keywords: line: profiles - stars: low mass, brown dwarfs - stars: atmospheres

1 Introduction

Pressure broadening by molecular hydrogen and helium is one of the major broadening mechanism in the atmosphere of brown dwarfs. The optical spectra of L and T-type dwarfs exhibit a continuum dominated by the far wings of the absorption profiles of the Na $3s-3p$ and K $4s-4p$ doublet perturbed by molecular hydrogen and helium. Model atmosphere, synthetic spectra and color predictions rely on knowledge of the far wings of alkali resonance lines in the presence of high densities of H_2 and He (Allard et al. 2003, 2007a).

One of the improvements upon previous calculations of (Allard et al. 2003) is the use of *ab initio* K–He potentials instead of pseudo-potentials of Pascale (1983) which lead to a K–He line satellite at 6930 Å much too far to the blue. Laboratory spectra of K with He (Kielkopf & Allard 2008a,b) agree exceptionally well with the semi-classical profiles based on molecular potentials of Santra & Kirby (2005). The comparison with theoretical profiles establishes the accuracy of the interaction potentials, which are difficult to compute *a priori*. This work is now extended to the $4p-5s$ transitions. In theoretical spectra models of T dwarfs the KI doublet at 1.24/1.25 μm is seen for values of $T_{\rm eff}$ at 700 K and above. These lines of excited KI have been identified in T dwarfs (Strauss et al. 1999; Tsvetanov et al. 2000).

2 Theoretical spectra

In Allard et al. (2003) we presented the first application of the absorption profiles of sodium and potassium perturbed by helium and molecular hydrogen to the modeling of brown dwarfs. Line profiles were calculated in a unified line shape semi-classical theory (Allard et al. 1994, 1999) using pseudo-potentials of Pascale (1983) (hereafter labelled P83). For the specific study of the $D1$ ($P_{1/2}$) and $D2$ ($P_{3/2}$) components we need to take the spin-orbit coupling of the alkali into account. This is done using an atom-in-molecule intermediate spin-orbit coupling scheme, analogous to the one derived by Cohen & Schneider (1974). The degeneracy is partially split by the coupling and the distinction between $D1$ and $D2$ results.

Our approach requires accurate theoretical molecular potentials to describe the interaction between radiator and perturber. *Ab initio* calculations have now been reported by Santra & Kirby (2005) (hereafter labelled SK05). We compare in Fig. 1 potentials computed by Pascale (1983) and Santra & Kirby (2005) including spin-orbit coupling.

It is seen that the major difference with respect to SK05 is that Pascale's potentials are systematically less repulsive than theirs, the state mostly affected being state B which starts to deviate from SK05 as soon as

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$R < 5$ nm when decreasing the separation. This difference on the B state strongly affects the blue satellite position.

Blue satellite bands in alkali-He/H_2 profiles are correlated with maxima in the excited B state potentials and can be predicted from the maxima in the difference potentials ΔV for the B-X transition (Allard et al. (2003, 2005); Allard & Spiegelman (2006); Allard et al. (2007b); Zhu et al. (2005, 2006); Alioua & Bouledroua (2006); Alioua et al. (2008); Christova et al. (2008). The difference potential, $\Delta V(R)$, is given by

$$\Delta V(R) \equiv V_{e'e}[R(t)] = V_{e'}[R(t)] - V_e[R(t)] \, , \tag{2.1}$$

and represents the difference between the electronic energies of the quasi-molecular B-X transition.

New K-He semi-classical line absorption profiles have been done using these last potentials, they were presented in (Kielkopf & Allard 2008a,b).

The $P_{1/2}$ ($D1$) line is due to a simple isolated A $\Pi_{1/2}$ state, the line profile for the $D1$ line is totally asymmetric. Whereas the $P_{3/2}$ ($D2$) line comes from the A $\Pi_{3/2}$ and B $\Sigma_{1/2}$ adiabatic states arising from the $4p$ $P_{3/2}$ atomic state. The interaction potentials lead to far wing line profiles with a K-He satellite at about 700 nm on the blue side of the D-lines, and a monotonically decreasing wing on the red side. While the Pascale pseudopotentials overestimated the displacement of the He satellite from the line Allard et al. (2003), newer potentials of (Santra & Kirby 2005) predict a K-He satellite that matches the one observed in laboratory spectra of Kielkopf & Allard (2008a,b). Such comparisons provide a critical test of the calculated molecular potentials and the relevance of the theoretical approach which has been used. Opacity tables of alkali perturbed by He and molecular hydrogen can be obtained from *.

This work is now extended to the excited states. We had to use pseudo-potential of Pascale (1983) for the $4p - 5s$ transition as *ab initio* potentials are not available. The potential difference curves for the $4p - 5s$ transition are presented in Fig. 2. We report calculations done for the $4s - 4p$, $4p - 5s$ lines for $T_{\rm eff} = 1000$ K for a fixed helium density ($n_{\rm He}$=1×10^{21} cm^{-3}). They are presented in Fig. 3.

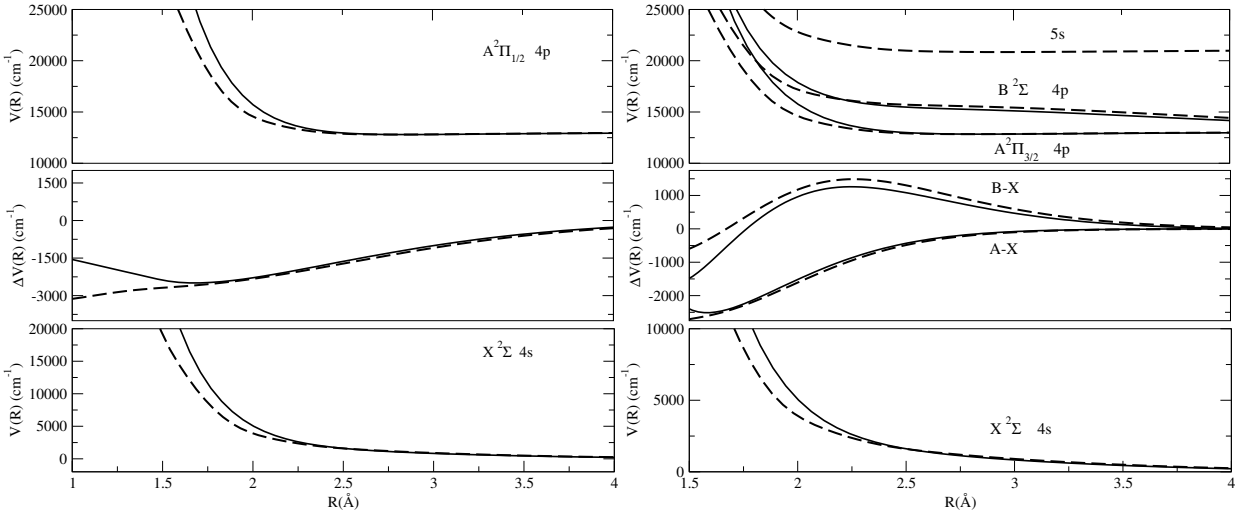

Fig. 1. Potential curves for the K-He molecule of P83 (dashed curves) compared to SK05 (full line).

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References

Alioua, K. & Bouledroua, M. 2006, Phys. Rev A, 74, 032711

Alioua, K., Bouledroua, M., Allouche, A. R., & Aubert-Frécon, M. 2008, J. Phys. B: At. Mol. Opt. Phys., 41, 175102

Allard, F., Allard, N. F., Homeier, D., et al. 2007a, A&A, 474, L21

*http://mygepi.obspm.fr/~allard/.

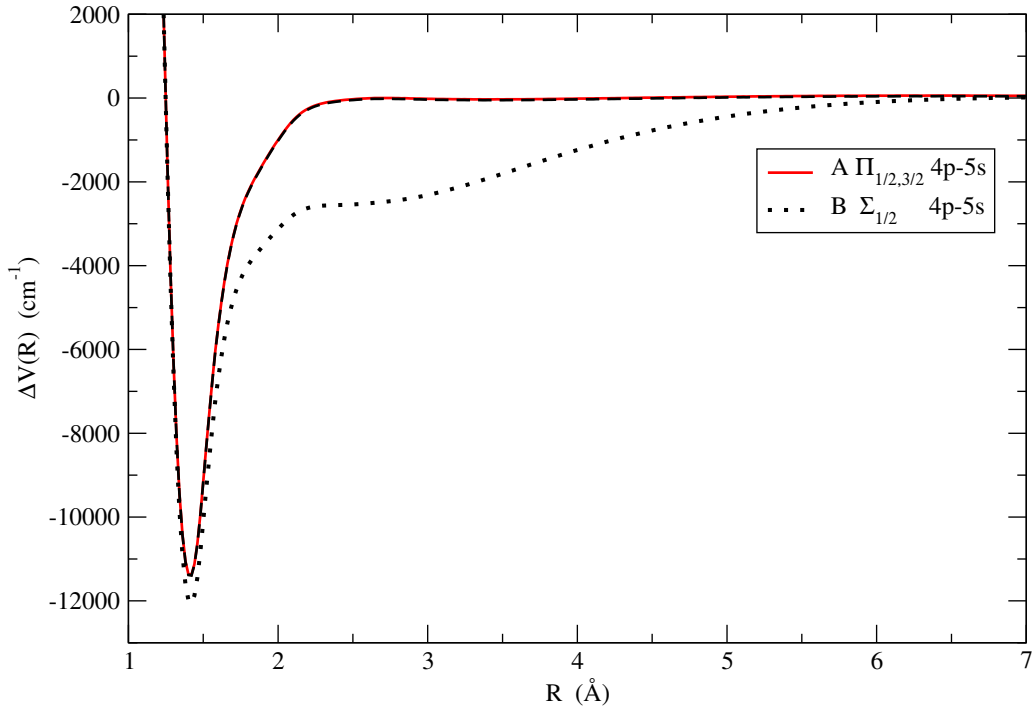

Fig. 2. Potential difference curves of the $4p-5s$ transition of the K-He molecule.

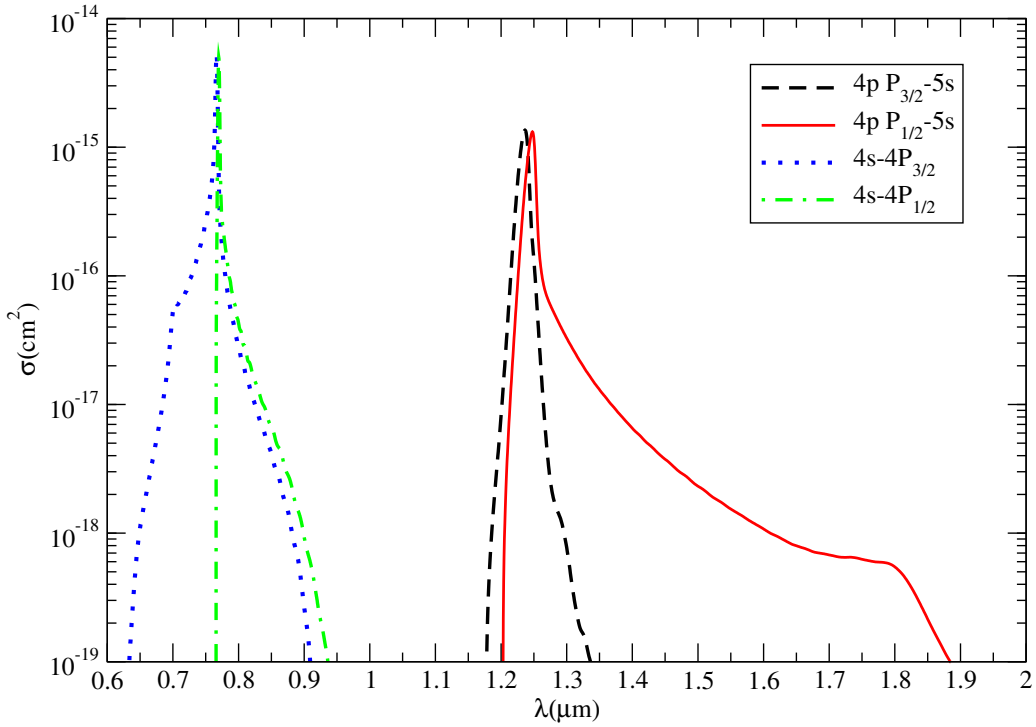

Fig. 3. Absorption cross section of the $4s-4p$, $4p-5s$ lines. (T= 1000K, n_{He}=1×10^{21} cm^{-3}).

Allard, N. F., Allard, F., Hauschildt, P. H., Kielkopf, J. F., & Machin, L. 2003, A&A, 411, 473
Allard, N. F., Allard, F., & Kielkopf, J. F. 2005, A&A, 440, 1195
Allard, N. F., Koester, D., Feautrier, N., & Spielfiedel, A. 1994, A&A Suppl., 200, 58
Allard, N. F., Royer, A., Kielkopf, J. F., & Feautrier, N. 1999, Phys. Rev. A, 60, 1021

Allard, N. F. & Spiegelman, F. 2006, A&A, 452, 351

Allard, N. F., Spiegelman, F., & Kielkopf, J. F. 2007b, A&A, 465, 1085

Christova, M., Allard, N. F., Kielkopf, J. F., Allard, F., & Homeier, D. 2008, in 19^{th} International Conference on Spectral Line Valladolid, Spain, June 16-20, 2008 (New York: AIP Conference Proceeding)

Cohen, J. S. & Schneider, B. 1974, J. Chem. Phys., 61, 3230

Kielkopf, J. F. & Allard, N. F. 2008a, Bull. Am. Astron. Soc., 40, 186

Kielkopf, J. F. & Allard, N. F. 2008b, in 19^{th} International Conference on Spectral Line Valladolid, Spain, June 16-20, 2008 (New York: AIP Conference Proceeding)

Pascale, J. 1983, Phys. Rev. A, 28, 632

Santra, R. & Kirby, K. 2005, J. Chem. Phys., 123, 214309

Strauss, M. A., Fan, X., & Gunn, J. E. 1999, ApJ, 522, L61

Tsvetanov, Z. I., Golimowski, D. A., & Zheng, W. 2000, ApJ, 531, L61

Zhu, C., Babb, J. F., & Dalgarno, A. 2005, Phys. Rev. A, 71, 052710

Zhu, C., Babb, J. F., & Dalgarno, A. 2006, Phys. Rev. A, 73, 012506