The effects of new Na I D line profiles in cool atmospheres  
(Research Note)

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Received 10 January 2007 / Accepted 31 January 2007

ABSTRACT

Aims. New Na I D line profiles and their effects on synthetic spectra of cool dwarfs computed with PHOENIX are studied. Sodium is the most abundant alkali in cool dwarf atmospheres and mostly responsible for the shape of the optical spectrum.  

Methods. In previous work we have pointed out the importance of atomic hydrogen as a perturber. Here, broadening due to collisions with atomic hydrogen as well as fully quantum mechanically calculated profiles for perturbations by helium are introduced for the Na I resonance line profiles. Furthermore, the effects of the new line profiles are compared to already existing line profile calculations.  

Results. We have calculated a number of “GAIA-cond” class model atmospheres and synthetic spectra for effective temperatures from 1100 K to 3000 K considering a gravity of 4.5. The line formation process has been analyzed with the flux contribution function. Due to changes in atmospheric structure, the effects of the line profiles on the synthetic spectra become larger for smaller effective temperatures. The influence of hydrogen as perturber is visible at higher effective temperatures although at the same time the strength of molecular bands increases. Furthermore, the newly introduced fully quantum mechanically calculated He I broadened profiles change the synthetic spectra by reducing the flux and the depths of the sodium absorption lines.

Key words. stars: atmospheres – line: profiles – stars: low-mass, brown dwarfs

1. Introduction

In 1995, the first brown dwarf Gliese 229b was discovered (Nakajima et al. 1995). Since then there has been tremendous progress in the search for and identification of such cool objects. As a result of this work the spectral types L and T have been introduced. We have calculated a number of “GAIA-cond” class model atmospheres and synthetic spectra for effective temperatures from 1100 K to 3000 K considering a gravity of 4.5. The line formation process has been analyzed with the flux contribution function. Due to changes in atmospheric structure, the effects of the line profiles on the synthetic spectra become larger for smaller effective temperatures. The influence of hydrogen as perturber is visible at higher effective temperatures although at the same time the strength of molecular bands increases. Furthermore, the newly introduced fully quantum mechanically calculated He I broadened profiles change the synthetic spectra by reducing the flux and the depths of the sodium absorption lines.

2. Profiles

In addition to the van der Waals profiles in the impact approximation (hereafter, impact) (Schweitzer et al. 1996) and modern and detailed calculations (hereafter, modern1), described in (Johnas et al. 2006) and references therein, in which molecular hydrogen in the symmetries C₂, and C₈, as well as neutral helium have been considered as perturbers, we will discuss the following specific line profiles: line widths and shifts of a Lorentzian profile for atomic hydrogen perturbers of Na I in the impact approximation (Leininger et al. 2000) are added to modern1 resulting in the model type “modern2”. In “modern3” we have substituted the helium broadened Na I, K I, and Li I line profile data of modern2 with the results of Mullamphy et al. (2006). These have been obtained by using the fully quantum mechanical theory of Baranger (1958). In this theory the perturbers are treated quantum mechanically. Thus inelastic collisions, degeneracy and overlapping lines are taken into account. Furthermore the impact approximation is used. Although concentrating on the sodium D...
3. Analysis of the different line profiles in the synthetic spectrum

Figure 1 displays synthetic spectra for $T_{\text{eff}} = 1100$–$3000$ K and $\log(g) = 4.5$ at a reduced resolution of 10 000 around the sodium resonance doublet. The original calculated resolution of the synthetic spectra is $3 \times 10^5$. All wavelengths are given in vacuo. In Fig. 1, for effective temperatures of 1100 K, 1500 K, and 2000 K, large differences between the different model types are obvious, especially “impact” versus “modern1-3”. At $T_{\text{eff}} = 2500$ K and 3000 K, molecular bands, such as TiO, VO, CaH, and FeH, become predominant and overwhelm the effect of the different line profiles on the emitted spectrum. A close up of the sodium doublet in Fig. 1 is shown in Fig. 2. It shows the differences in more detail at the full computed resolution. The contribution of sodium broadened by neutral hydrogen (modern2) is most visible in the near wings at $T_{\text{eff}} = 3000$ K, as predicted by Johnas et al. (2006) and depicted in Fig. 2. Under these atmospheric conditions, atomic hydrogen is the most prominent species at the optical depths where the line wing forms. At this effective temperature, there are differences of up to 50%.

If not otherwise mentioned, the comparison refers to a wavelength range between 5850 Å and 5950 Å.
between the modern1 and modern2 spectra for the sodium D lines. The differences between modern1 and modern2 spectra decrease rapidly with decreasing effective temperature, so that at \( T_{\text{eff}} = 2500 \, \text{K} \), the difference is at the most about 10%. At even lower effective temperatures, the differences are only in the range of one-tenth of a percent due to decreasing concentration of atomic hydrogen in the atmosphere.

When comparing the impact spectra with modern2 spectra, the differences in the near wing and core regions are already 60% at \( T_{\text{eff}} = 3000 \, \text{K} \). For lower effective temperatures starting at \( T_{\text{eff}} = 2000 \, \text{K} \), the influence in the line wings (at 5800 Å) is even greater, decreasing from 90% to 75% at \( T_{\text{eff}} = 1500 \, \text{K} \) and 60% at \( T_{\text{eff}} = 1100 \, \text{K} \). The wing–core regions are affected by 70%, 50% and 45% respectively for these effective temperatures. The changes at the core wavelengths of the two sodium D absorption lines reach up to 400%. This is expected, however, as there are substantial differences between the impact and modern1–3 line profiles.

Due to the similar characteristics of the modern3 and modern2 spectra at \( T_{\text{eff}} = 3000 \, \text{K} \), the difference between the two is at the most 4%. The comparison between the modern1 and modern3 spectra gives similar results. In contrast, at \( T_{\text{eff}} = 2500 \, \text{K} \) the difference between modern2 and modern3 spectra reaches up to 35%, as between modern1 and modern3. As mentioned before, because of the evanescent differences between the spectra calculated with the modern1 and modern2 profiles at effective temperatures \( \leq 2000 \, \text{K} \), the differences between the modern1 and modern3 spectra are similar, namely 25% at \( T_{\text{eff}} = 2000 \, \text{K} \), 20% at \( T_{\text{eff}} = 1500 \, \text{K} \), and 29% at \( T_{\text{eff}} = 1100 \, \text{K} \). Following the discussion above, comparing with the spectra of the impact setup, the differences between the impact and modern3 spectra are again of the same order of magnitude and the changes increase in the wings towards lower effective temperatures as can be seen in Fig. 1.

With the flux contribution function \( \mathcal{C}_F \) as introduced in Magain (1986) and Fuhrmeister et al. (2006) and applied in Johnas et al. (2006), the differences around 5891 Å seen in Figs. 1 and 2 between the different model types can be interpreted. The maximum of \( \mathcal{C}_F \) indicates the layers where the line forms in the atmosphere at a specific wavelength. The wavelength 5891 Å has been chosen to represent the near wing region in which the changes in the setups are significant. For each effective temperature slightly different locations of the line forming region in the atmosphere for each model type are found, as shown in Fig. 3. This causes the differences in the emergent flux of the synthetic spectra. Further analyses of the flux contribution function and the gas pressure of each model type for each effective temperature have shown that the locations of the maxima of the flux contribution functions are consistent with the theoretical predictions. Moving closer to the line core, the maxima are positioned at higher and hence cooler regions of the atmosphere.

On the other hand, moving further into the line wings of the Na D lines, the flux contribution originates in deeper and hotter layers of the atmosphere.

4. Conclusions

We have demonstrated the effect of different line profiles of the Na D lines on the emitted spectra. Although only small changes in the intrinsic line profiles were applied when introducing modern2 and modern3, concerning the data of the near wings, the synthetic spectra show visible changes. Despite of the presence of strong molecular bands at higher effective temperatures, the inclusion of neutral hydrogen perturbers for the sodium D line profile data is significant for computing synthetic spectra.

There is an obvious need for extending the modern2 profiles especially to potassium and lithium lines, due to their prominence in brown dwarf spectra. It is crucial to improve the NaI and K I line profiles as they are also essential for the modeling of the other strong alkali doublets, i.e. Li I, Rb I, and Cs I. Furthermore, far wing calculations for both modern2 and modern3 should be done in order to produce complete sets of line profiles, from the line core to the farthest wing. In a subsequent paper the dependence of the equivalent widths on the different models will be discussed. Finally, it is very important to compare the results for the different profile types with low and high resolution observations of L and T dwarfs for conclusions of the quality of each profile type.

Acknowledgements. The authors would like to thank Steve Gibson for computational assistance with the quantum mechanical calculations.

References

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