Formation of optical spectra of L-dwarfs

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Abstract.
Problems of the formation of L-dwarf spectra are discussed. Only a weak remnants of TiO and VO bands are clearly seen in the spectra of the dwarfs with $T_{\text{eff}} < 2000 \ \text{K}$. In spectra of the coolest L-dwarfs VO and TiO dissapear completely due to the processes of depletion V and Ti into the dust. CrH bands appear in the red part of the spectrum of the coolest L-dwarfs. To fit the profiles of these bands, we suggest some depletion for Cr-contained species as well.

To fit the observed features in the optical spectra of the coolest objects with $T_{\text{eff}} < 2000 \ \text{K}$ we suggest that:

— There are extra depletions of molecular species absorbed in the optical part of the L-dwarf spectra.
— There are (a few) additional opacity $\kappa$ sources in their atmospheres.
— The additional opacity $\kappa$ depends on the wavelength.

In the frame of our model we determined the lithium abundance ($\log N(\text{Li}) \approx 2.5$) in the atmosphere of Kelu1.

1. Introduction

We intend to model the formation of the optical (6400–9100 Å) spectra of the very cool dwarfs recently discovered (see Rebolo 1998). In their spectra molecular bands of TiO and VO are very weak or even absent. The most striking feature in the observed spectra is well reproduced by our computations and it can be undoubtedly attributed to the KI and Na I resonance doublets (see also Pavlenko, 1998, Pavlenko et al. 1998, Tinney et al. 1998).

Pavlenko et al. (1998) found that the extra opacity can be described as a potential law in the form $a_0 \ (\nu/\nu_0)^N$, and it may be caused by dust scattering and/or absorption. However, for the case B models (i.e. models computed for the dynamical equilibrium of the dust-gas phase transition) we got the best fit only for large $N > 10$. Additionally, Pavlenko et al. (1998) showed that with densities of TiO and VO molecules given by the conventional chemical equilibrium, we are NOT able to reproduce any spectra of the objects cooler than Teide 1 (spectral type M8).
2. Procedure of computations

Instead of the paper Pavlenko et al. (1988) the author uses "dusty" C-model atmospheres of Tsuji (1998), i.e. computed for the case of the segregations of gas and dust particles. We consider the chemical equilibrium of 100 molecular species. Molecular spectra are computed in the frame of Just Overlapping Line Aproximation (JOLA). Profiles of absorption lines of atoms and molecules at each depth point of the L-dwarf atmosphere are described by Voigt function \( H(a, v) \), where damping constants \( a \) are computed in the frame of the classical approach (Unsold 1955). The computed spectra are normalized to the equal fluxes at \( \sim 850 \) nm and then compared with the observed spectra in the wide wavelengths range (\( \lambda \lambda 600-1000 \) nm). That procedure allows us to obtain several strong constrains on the parameters of the extra depletions \( R_d \), the additional opacity \( a_0 \) and \( N \), that are used in our computations.

We added to the conventional opacity source list (Pavlenko et al 1995) the opacities due to the CrH and CaH molecular bands absorption (Pavlenko 1999). CrH bands become observable in Kelul (\( T_{\text{eff}} \sim 2000 \) K) spectrum.

3. Results

3.1. L-dwarf spectra modeling

The overall shape of spectra of L-dwarfs is governed by the wings K I and Na I resonance lines + CrH band absorption (Fig. 1). Note, only assuming the strong Ti, V, and Cr EXTRA depletions into grains we can reasonably fit the shape of the observed spectra, even in the case of the coolest objects (\( T_{\text{eff}} \sim 1200 \)K), as shown in Fig.1.

The most striking feature in the observed spectra (pseudo-equivalent widths of roughly several thousands Å for the coolest L-dwarfs) is well mimic in our computations and it can be undoubtly attributed to the KI resonance doublet (see also Pavlenko, 1998, Pavlenko et al. 1998, Tinney et al. 1998). Other alkaline absorptions (Na, Rb and Cs) are also present.

The additional opacity has to be incorporated in the spectral synthesis procedure in order to fit the overall shape of spectra of objects cooler than M8 (Pavlenko et al. 1998, 1999). Otherwise, both blue and red wings of the KI lines cannot be modeled properly (Fig.2).

3.2. Lithium lines

Obviously, before the fitting of alkali lines in L-dwarf spectra one should reproduce an overall shape of the observed spectrum to dermine the parameters of the additional opacity \( a_0 \) and \( N \).

Lithium resonance doublet lines (\( \lambda \lambda 670.8 \) nm) are severely affected by the extra opacity. For larger opacities the lithium lines become more veiled, i.e more weak. Therefore, the weak lithium lines in L-dwarf spectra do not necessarily imply a depletion of this light element in their atmospheres.
Figure 1. Comparison of the observed spectrum of DBD J1228–1547 with synthetic spectra adopting Tsuji’s C-model atmosphere for $T_{\text{eff}} = 1600$ K, $\log g = 5$. Dotted line stands for a computation with complete depletion of Ti and V into grains. Note the poor fit to the spectra. Solid line denotes a computation incorporating an opacity source ($a_0 = 0.03$) and different depletion factors $R$ for molecules with respect to the chemical molecular equilibrium.

Figure 2. Comparison of the observed spectrum of Kelu 1 with synthetic spectra adopting Tsuji’s C-model atmosphere for $T_{\text{eff}} = 2000$ K, $\log g = 5$. Dotted line stands for a computation with complete depletion of Ti and V into grains. Note the poor fit to the spectra. Solid line denotes a computation incorporating an opacity source ($a_0 = 0.03$) and different depletion factors $R$ for molecules with respect to the chemical molecular equilibrium.
Figure 3. Fit to the 6708 doublet in Kelu 1 spectrum. The better fit is obtained for log N(Li) = 2.5 ± 0.5

In the Fig 2. we show the fits to the optical spectrum of Kelu1. Note, we obtained the "best fit" of the Li resonance doublet lines for log N(Li) = 2.5 ± 0.5 (Fig.3).

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References