

Formation of the optical spectra of the coolest M- and L-dwarfs and lithium abundances in their atmospheres

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Abstract. Theoretical aspects of modeling of spectra of late M- and L-dwarfs are discussed. We show, that the processes of formation of spectra of M- and L-dwarfs are basically different. Instead of the case of M-dwarfs, atoms of Ti and VO should be depleted into grains in the atmospheres of L-dwarfs. Overall shape of the L-dwarf spectra is governed by the K I + Na I resonance line wings of the huge strength. To fit lithium lines observed in spectra of the coolest dwarfs we used two additional suggestions: a) there are some *extra* depletions of molecular species absorbed in the optical spectra of L-dwarfs; b) there may be (a few?) additional (“dusty”?) opacity sources in their atmospheres. Problems of lithium line formation and the “natural” limitation of their use for the “lithium test” for the case of L-dwarfs are discussed.

1. Introduction

A few definitions of the “unconventional” spectral classification of low mass stars and substellar objects are used in this paper:

M-dwarfs are objects (stars + young brown dwarfs) with $4000 > T_{\text{eff}} > 2200$ K. Their spectra are governed by molecular bands of TiO and VO (in the optical part of the spectrum) , H₂O (in the red).

L-dwarfs are objects (brown dwarfs + stars) with $1000 < T_{\text{eff}} < 2200$ K (cf. Martin et al. 1997). Optical spectra of L-dwarfs are governed by the K I + Na I lines and molecular bands of CrH + FeH (in the optical spectrum), H₂O (in the red).

T-dwarfs are super-giant, planet-like objects (big Jupiters?) with $T_{\text{eff}} < 1000$ K. Their spectra are formed by the “dusty opacities” and methane + H₂O + ...? absorption (Strauss et al. 1999, Burgasser et al. 1999)

For the time being most of the known brown dwarfs are actually recognized by the detection of the Li I resonance doublet in their spectra (Rebolo et al. 1996, Martín et al. 1997a, Kirkpatrick et al. 1999). Indeed, temperatures in the interiors of brown dwarfs are not high enough to burn lithium (Rebolo et al. 1992).

2. Procedure

The computations of synthetical spectra of M- and L-dwarfs are carried out by program WITA5, which is a modified version of the program WITA31 used by Pavlenko (1997). The modifications were aimed to incorporate “dusty effects” that affect the chemical equilibrium and radiative transfer processes in very cool atmospheres.

We have used the set of Tsuji’s (1999) “dusty” (C-type) LTE model atmospheres. These models were computed for the case of segregation phase of dust and gas.

Chemical equilibrium was computed for the mix of ≈ 100 molecular species. To take into account the effect of the oversaturation, we reduced the abundances of those molecular species down to the equilibrium values (Pavlenko 1998).

In L-dwarf atmospheres the additional opacity (AdO) could appear due to molecular and/or dust absorption and/or scattering. We have modelled the additional opacity with a simple law of the form $a_o (\nu/\nu_o)^N$, with $N = 1 - 4$ (see Pavlenko, Zapatero Osorio & Rebolo 2000 for more details).

3. M-dwarf spectra

Lithium lines observed in spectra of the late M-dwarfs are well known tracers of their evolution. Completely convective M-dwarfs are very effective lithium destroyers, therefore cool pre-main sequence (PMS) stars are expected to preserve their initial lithium only during their first few million’s years (Fig.3, see also Magazzu, Rebolo & Pavlenko 1992, Oppenheimer et al. 1997, Pavlenko (1997, 1997a), Pavlenko & Oppenheimer 1998).

Lithium lines in spectra of M-dwarfs are formed at the background of mighty TiO bands (Fig.1). Only cores of the saturated Li lines may be observed in the real spectra (Pavlenko et al. 1995). To estimate of the abundance of lithium one may use “pseudoequivalent widths” of lithium lines, i.e. W_λ measured in respect to the local pseudocontinuum formed by molecular bands around Li lines (see also Pavlenko 1997a).

Sure, the better way of the quantitatively determination $\log N(\text{Li})$ is the use of synthetical spectra (Fig. 2).

4. L-dwarf spectra

Due to depletion of the Ti and VO into grains a structure of the optical spectra of L-dwarfs becomes more simple in comparison with M-dwarfs. The overall spectral energy distribution (SED) is governed by absorption of resonance doublets of K I and Na I which have pressure broadened wings extended up to thousands Å (Fig.3). Furthermore, Pavlenko et al. (2000) showed that L-dwarf optical spectra are affected by the additional (“dusty”) absorption and/or scattering.

Our computations show that lithium lines are very sensitive to the additional absorption (AdO) that we need to incorporate in the spectral synthesis if we want to explain the observed broad spectral energy distribution (Fig.4). In Table 1 we give the predicted equivalent widths W_λ of the Li I resonance doublet at 670.8 nm for L-dwarf’s model atmospheres (2000–1000 K) considered in this

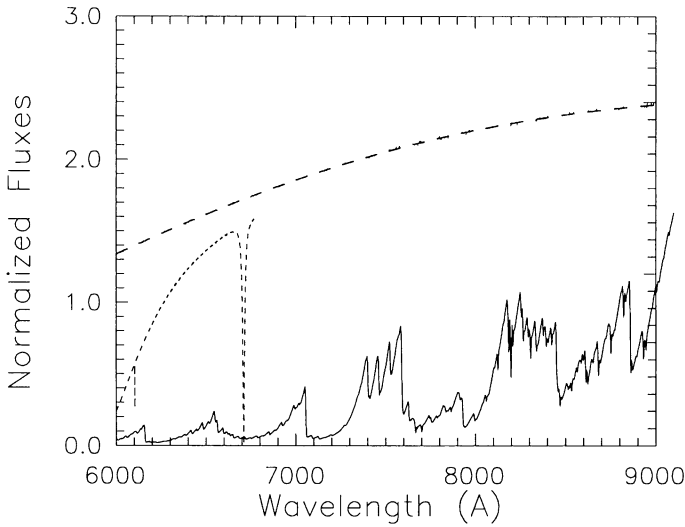


Figure 1. Comparison of the observed spectrum of the Pleiade's young brown dwarf Teidel (Rebolo et al. 1996) with theoretical spectra computed using C-model atmosphere ($T_{\text{eff}}=2600$ K, $\log g = 5.0$) of Tsuji (1999). The strongest atomic lines which may be observed in M- and L- spectra and the real (theoretical) continuum are shown.

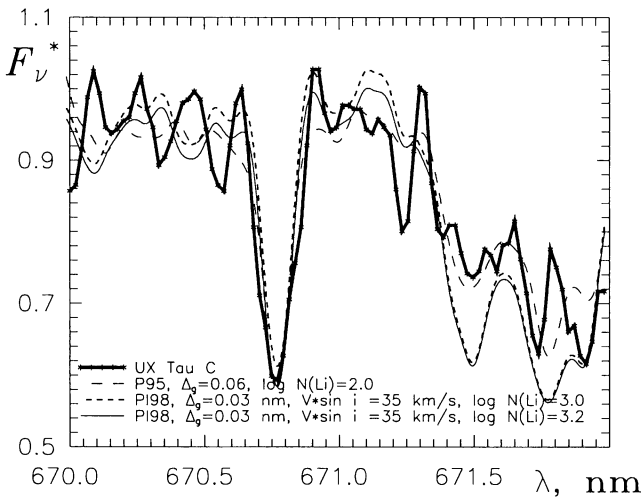


Figure 2. Fit to the observed Li I resonance doublet in UX Tau C spectrum (Magazzu et al. 1991) with the list of TiO lines of Plez (1998) and model atmosphere 3100/4.5 (Allard & Hauschildt 1995)

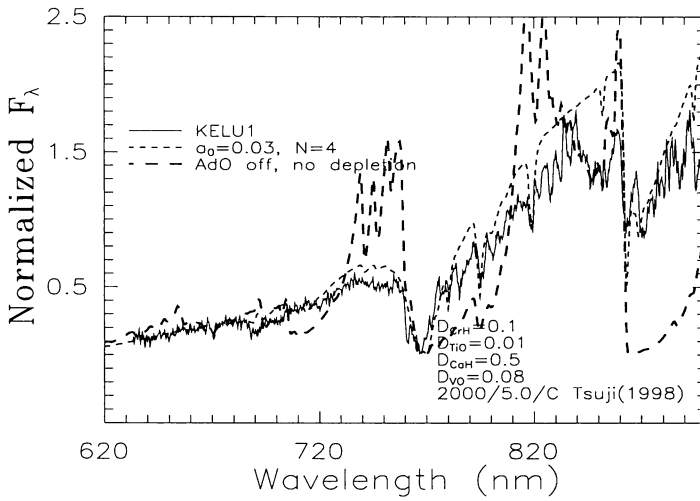


Figure 3. Fit of theoretical SED's computed for C-model atmosphere 2000/5.0 (Tsuji 1999) to Kelu1 spectrum. D factors showed in the Fig. are used to simulate the *extra* depletion of several species into grains.

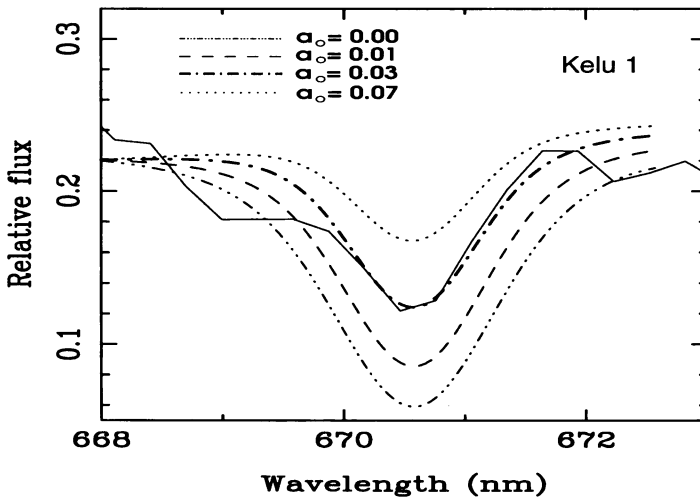


Figure 4. Fit to Li I λ 6708 nm resonance doublet in Kelu1 spectrum. Computations were carried out for $\log N(\text{Li}) = 3.0$ and different parameters of the AdO

work. We found:

– In the AdO-free case (second column in the table), we would expect for the “cosmic” values of $\log N(\text{Li})$ rather strong neutral Li resonance lines in the spectra of objects as cool as DenisP J0205–1159 and Gl 229B.

– The chemical equilibrium of Li-contained species still allow a sufficient number of Li atoms to produce a rather strong resonance feature.

– Our computations indicate that L-dwarfs with moderate dust opacities should show the Li I resonance doublet if they had preserved this element from nuclear burning, and consequently the lithium test can still be applied.

– Temporal variations of the dusty opacities may originate some kind of “meteorological” phenomena occurring in these cool atmospheres. Lithium lines (as well other lines) may be severely affected by the effect (see Pavlenko et al. 2000 for more details).

Table 1. Equivalent widths of the Li I resonance doublet at 670.8 nm computed for the C-type Tsuji’s (1999) model atmospheres, cosmic Li abundance ($\log N(\text{Li}) = 3.2$) and gravity $\log g = 5.0$.

T_{eff}	a_{\circ}		
	0.00	0.01	0.10
(K)	$W_{\lambda}(\text{\AA})$		
1000	17	8	0.6
1200	30	12	0.7
1400	42	21	0.9
1600	40	24	1.6
2000	23	16	3.6

5. Conclusions

Finally, we have arrived to the following conclusions:

- Processes of formation of Li lines in L- and M-spectra differ significantly:
 - for M-dwarfs the main problem to be solved is blending of lithium lines by molecular lines,
 - in the case of L-dwarfs we deal with a menagerie of different processes: depletion of lithium atoms into molecules and grains, “dusty effects”, meteorological phenomena, stratification effects, etc...
- We can fit the optical spectra of L-dwarfs in the frame of our simple model.
- Using our model we may perform a numerical analysis of the L-dwarf spectra (at least in the sense of the Li abundance determination).

- The basic algorithm of the “lithium test” may be used even for the assessment of the coolest L-dwarfs.

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