NEW PHYSICS OF THE BROWN DWARF AND L–DWARF ATMOSPHERES

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Our main attention is paid for the formation of the spectra of the so-called objects of the Bottom of the Main Sequence. Substellar objects and brown dwarfs lie beyond the lower right end of the Main Sequence. Masses of the very red objects with the low-luminosity are too low for possible nuclear burning of the light elements (hydrogen, lithium or even deuterium) to stop their contraction.

INTRODUCTION

Spectral energy distributions of the recently discovered L-dwarfs are different from the conventional M-dwarfs. Ti and V atoms in atmospheres of M-dwarfs form oxygen molecules, which are the main absorbers governed the shapes of their SED's. Some atoms in atmospheres of L-dwarfs are significantly depleted into grain particles due to the low temperatures and high pressures regime. The differences in the observed SED's have prompted the use of a new spectral class for the coolest dwarfs [1, 2], first from the times of implementing classical MK classification. L-dwarfs are the low-mass objects, which occupy the part of the HR diagram with $1200 < T_{\rm eff} < 2200$ K.

INITIAL MASS FUNCTION

The observed mass distribution of LMS for Pleiades shows a slow positive slope toward lower masses [11]. The sample of the low-mass objects is the most populated in the Galaxy. Still, their contribution to the total barionic mass of the Galaxy is rather small (< 5 – 10%). Moreover, recent observations of σ Ori open cluster provides new sample of the low-mass objects with $M < 15M_J$, where M_J is the mass of Jupiter ($M_J = 0.001M_\odot$) [12].

L– AND M–DWARFS: OPTICAL SPECTRA

Speaking strictly, only M-dwarfs are the *conventional* objects yet. Their spectra are governed by the molecular bands of TiO and VO of the huge strengths (Fig. 1, see also [13, 14]). The spectral energy distribution in the spectrum of young Teide1 brown dwarf [15] – member of the Pleiades open cluster, is shown in Fig. 1. Rebolo *et al.* [16] observed strong Li I 6708 Å line in the Teide1 spectrum. This is evidence that the lithium has been preserved in the atmosphere of the brown dwarf, although more massive M-dwarfs burnt their lithium.

L-dwarf spectra show quite different picture (Fig. 2):
– TiO and VO molecular bands are weak or even absent there.
– A strong head of (O-O) band of CrH appears at 8600 Å [21].
– We see very strong alkali resonance doublets: Cs, Rb, Na, Li.
– The strongest features in L-dwarf spectra are formed by the lines of K I + Na I resonance doublets [5, 6].
– Perhaps, BRI0021-024 presents an intermediate (L — M) case.

ALGORITHM OF FORMATION OF L–DWARFS SPECTRA

The photospheres of L-dwarfs are moved toward high pressure regions due to the very low temperatures and low opacities (Fig. 4). Some specific physical conditions are realized there:
– Depletion of atoms into molecular species (Pavlenko *et al.*, 1995).
– Formation of the dust particles (see Tsuji *et al.* [19] and [6] for more details).
– The "dusty" opacities due to the absorption and/or scattering processes.

Invited paper.

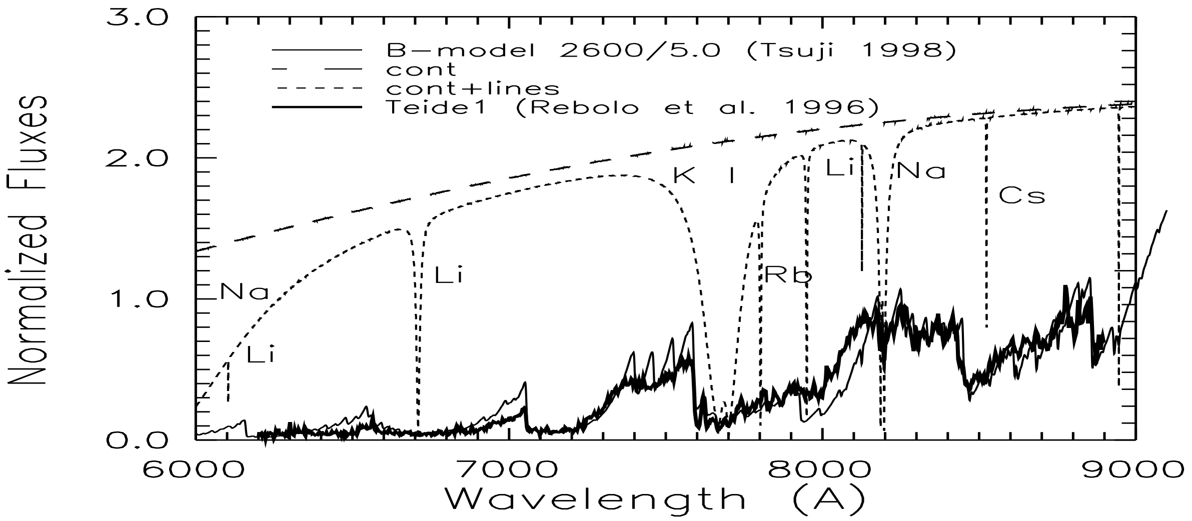

Figure 1: Comparison of the observed spectrum of Teide1 with theoretical spectra computed with use of the C-model atmosphere ($T_{\rm eff}$ = 2600 K, $\log g = 5.0$) by Tsuji [18]. Positions of the strongest atomic features which can be observed in M- and L- spectra are shown. The spectrum of Teide1 is clearly dominated by TiO and VO molecular bands whose abundances have been determined by chemical equilibrium. We have only considered the standard sources of opacities in these computations

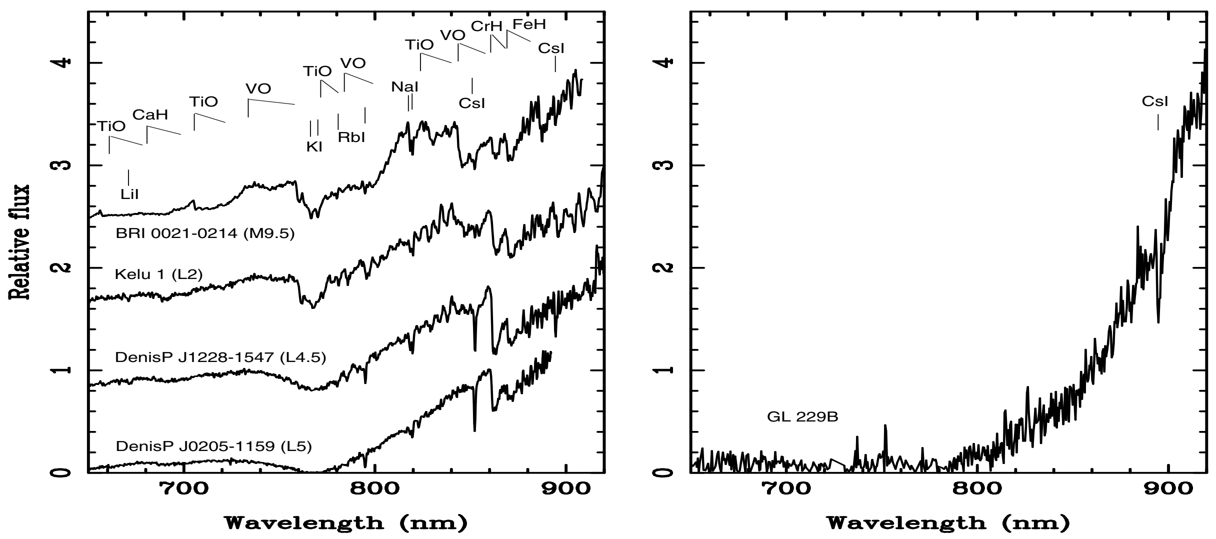

Figure 2: Far-red optical spectra for our sample. The observations are those of Kelu 1, DenisP J1228–1547 and DenisP J0205–1159 (KeckII spectrum). Data for BRI 0021-0214 and Gl 229B have been collected from Martín *et al.* [22] and from Schultz *et al.* [23], respectively. Spectral types for the L-dwarfs follow the classification by Martín *et al.* [1]. Spectra in the left panel have been shifted by 0.8 units for clarity. Identification of some atomic and molecular features is provided in the top of the figure (from PZR2000)

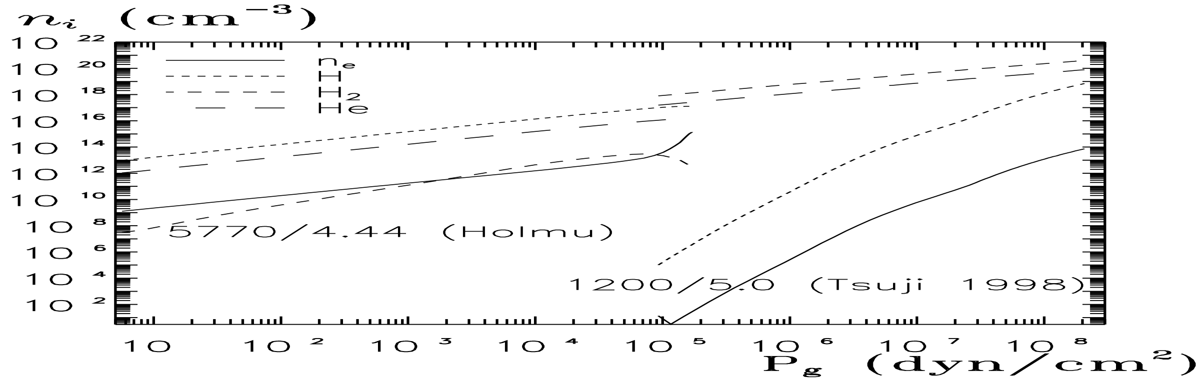

Figure 3: A comparison of the HOLMU solar model atmosphere [17] and 1400/5.0 C-type model atmosphere of L-dwarf [18]

DUST, MODEL ATMOSPHERES & SPECTRA

In the case of L-dwarfs we find a complicate case of the formation of the spectral energy distribution. Obviously, we have a temperature sequence of L-dwarf spectra [8]. Furthermore, following Tsuji (1998) we may suppose different cases of the impact of dusty opacities on model atmospheres: A-models are computed for the dusty-free media, physical conditions in B and C-models correspond to the dynamical equilibrium "dust-gas" phase transition, and the segregation of the dust and gas, respectively.

Equivalent widths of the resonance K I and Na I doublet lines are huge due to the broadening by atoms and molecules of hydrogen. Damping constants are of about $0.1-10.0$ instead of $0.005-0.1$ in the solar atmosphere. Residual fluxes of the lines of K I and Na I resonance doublets computed for the 1200/5.0 C-model by Tsuji [18] are shown in the Fig. 4. Formally, the computed equivalent widths of the doublets exceed 3 and 6 kÅ, respectively!

The comparison of the computed and observed spectra seems to be more interesting. In Fig. 5 we show the fit of the computed SED for a 1200/5.0 C-model atmosphere by Tsuji[18] to the observed spectrum of DenisP J0205-1159. We used a few additional suggestions to fit L-dwarf spectra [8]:

– there are some superdepletions of the molecular species in the atmospheres of L-dwarfs.

– there are some additional opacity (AdO) sources due to the additional absorption or scattering.

LITHIUM TEST

"Lithium test" was proposed by Rebolo *et al.* [24] to tell brown dwarfs from a sample of low luminosity dwarfs. Pavlenko *et al.* [25] shown that we could observe Li lines in spectra of young brown dwarfs which are "de-facto" the late-type M-dwarfs. Observations completed later confirmed the results [16, 26], see also [27].

"Lithium test" can be applied in the case of L-dwarfs. In that case, however, the main problem is not the molecular bands, but the huge wings of K I and Na I doublets and the "dusty" opacities. Furthermore, in some cases we can see the substellar meteorology effects – Li lines may by affects by the variable opacities provided by the dust clouds. Nevertheless, lithium lines should be detectable in the spectra of L-dwarfs or even T-dwarfs for $\log N(Li) \sim 3.0$ (*i.e.*, "cosmic value", see [8] for more details).

DEUTERIUM TEST

The "deuterium test" was proposed recently to tell brown dwarfs from a sample of low luminosity dwarfs. The problem here seems to be much more severe, than in the case of the "Lithium test". We may expect the appearance of the heavy water (HDO) bands in the IR part of cool dwarfs. However, there are strong bands of the "normal" water, *i.e.*, H_2O. Molecular bands of HDO and H_2O computed for Partrige & Schwenke line lists (*http://george.arc.nasa.gov/˜dschwenke*) and 1200/5.0 C-model by Tsuji (1998) are shown in Fig. 6. *In that case,* the bands of HDO for the normal "cosmic" deuterium abundance (D/H $\sim 10^{-5}$) should disappear under the bands of the more abundant H_2O.

SUMMARY (NEW PHYSICS)

New class of astrophysical objects discovered recently provides new challenges for the modern astrophysics. In fact, ultracool dwarf's family consists of various population, where substellar objects/brown dwarfs, low-mass

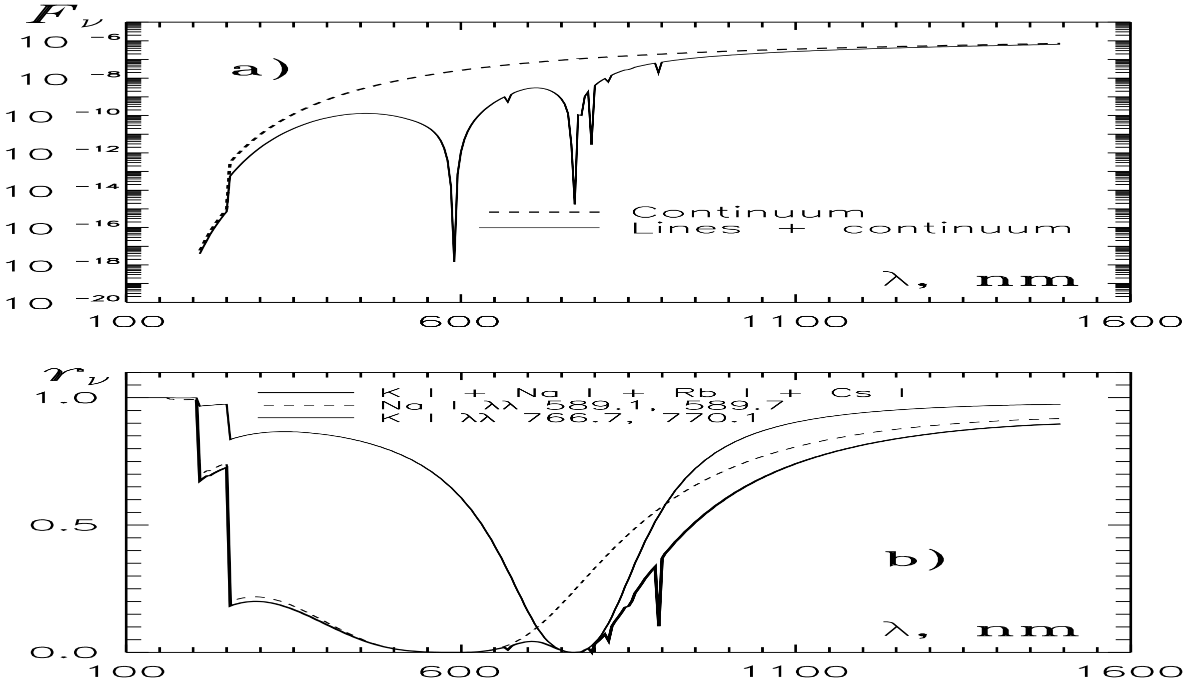

Figure 4: Theoretical fluxes and profiles of K I and Na I resonance doublet lines computed for the 1200/5.0 C-model atmosphere by Tsuji [18]

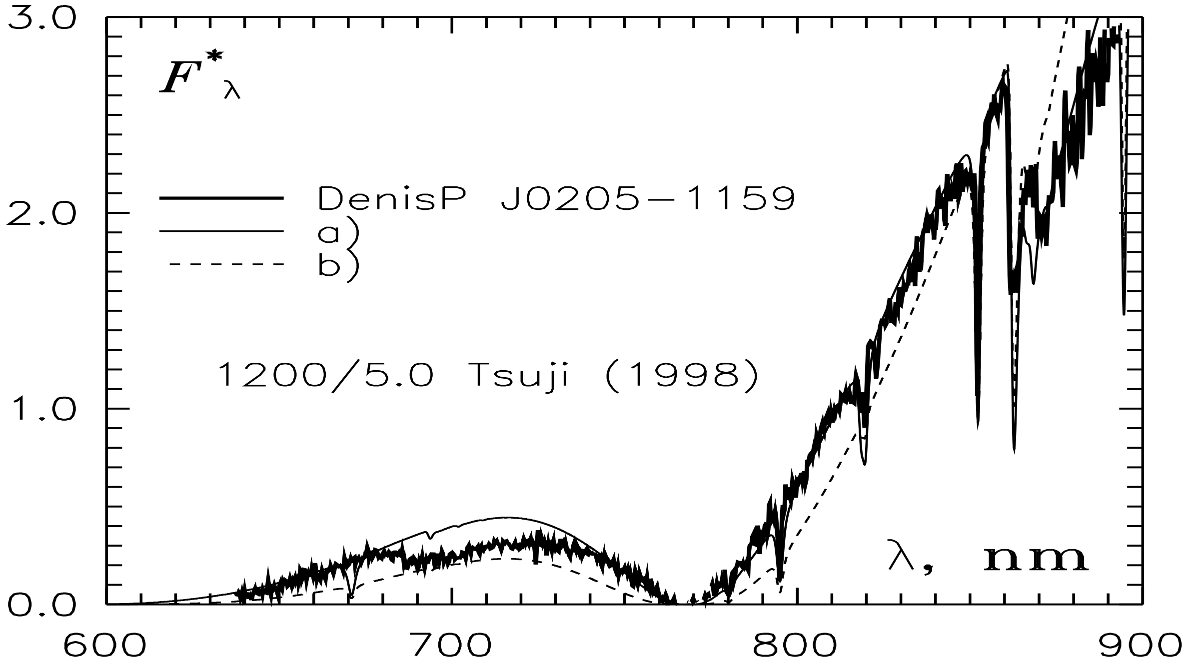

Figure 5: Fit to DenisP J0205-1159 spectra

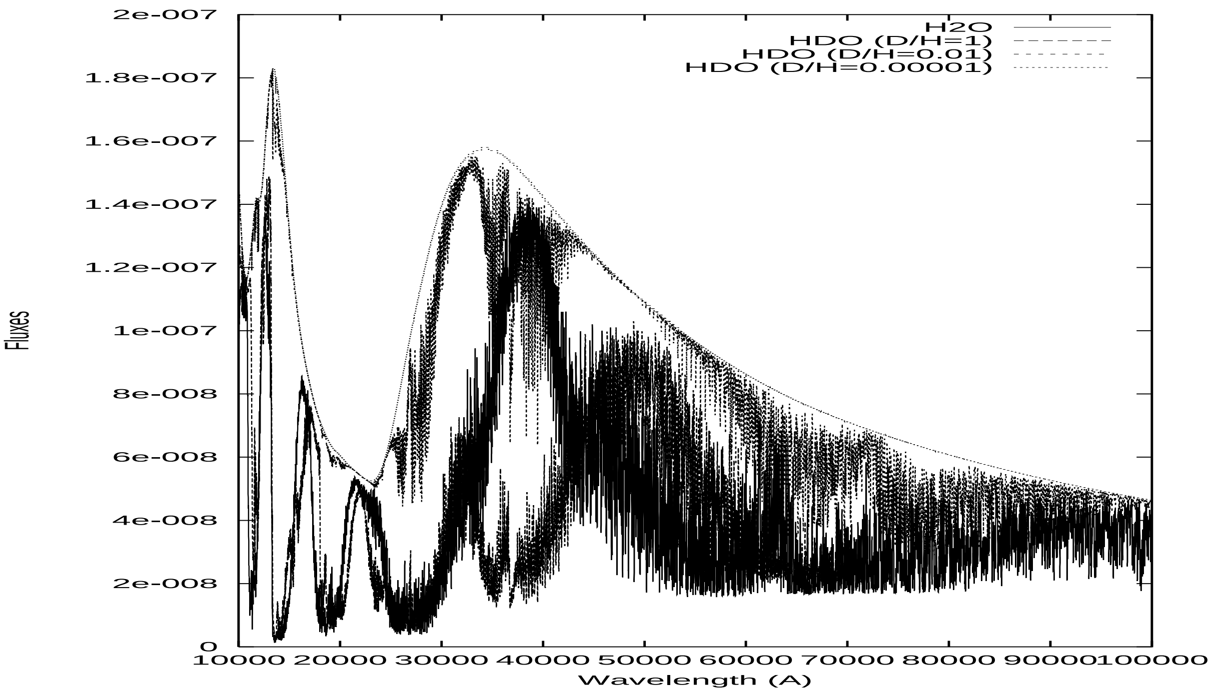

Figure 6: Bands of H_2O and HDO computed for 1200/5.0 C-model by Tsuji (1998)

dwarfs/stars and big (superbig?) planets can be found. Being the M-dwarfs at the beginning of their evolution, these objects then move to the L-dwarfs region. Time scale of the evolution depends on some parameters – masses, initial abundances, rotation, binarity, *etc.*

The situation with their emitted radiation regions (photospheres) is very specific. Indeed, we work in the boundary region between classical stellar astrophysics and canonical planetary science. Plasma of the atmospheres of the ultracool dwarfs exists in the low temperatures as well high pressures regime. Our knowledge about the physical process in the cool dense plasma is far from being perfect. Optical spectra of the coolest dwarfs are governed by the wings of K I and Na I doublets. Their profiles are pressure broadened. Moreover, to describe their shape we should use non-conventional methods for calculating the parameters of their broadening. In this case the micro and macro physics meet in L-dwarfs atmospheres.

Bands of TiO and VO spectra are weak or even disappear in L-dwarfs spectra. Obviously, Ti and V atoms should be depleted into dust particles, still the mechanisms of the dust formation cannot be modeled in detail. Then, dusty particles may provide original opacity.

No doubts, these effects should affect the temperature structure of atmospheres of L-dwarfs.

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