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THE (n-n')-MIXING PROCESSES IN STELLAR ATMOSPHERES

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Abstract. It is shown that the efficiency of the (n-n')-mixing processes in atom-Rydberg atoms collisions in weakly ionized layers of stellar atmospheres (Sun and DB white dwarfs) is larger or close to the efficiency of the concurrent electron-atom processes in the lower part of the block of atomic Rydberg's states. The presented results suggest the necessity of the including of the considered (n-n')-mixing processes in the models of the stellar atmospheres.

1. INTRODUCTION

In the previous papers (Mihajlov et al. 2004, 2008) it has been shown that the non-elastic processes in slow $A(n)+A$ collisions have a significant influence on the populations of atomic Rydberg states in the weakly ionized plasmas. In these papers have been investigated the (n-n')-mixing processes:

$$A^*(n)+A \rightarrow \begin{cases} A^*(n'=n+p)+A \\ A+A^*(n'=n+p) \end{cases} \tag{1}$$

$$A^*(n)+A \rightarrow \begin{cases} A^*(n'=n-p)+A \\ A+A^*(n'=n-p) \end{cases} \tag{2}$$

with $A=H,\ He$, where A and $A(n)$ denote the atoms in the ground and the excited states with the prncipal quantum number *n*. The processes (1) and (2) have been treated as the result of the mechanism of the resonant energy exchange within the electronic component of the atom - Rydberg atom collisional system, which is in further named the resonant mechanism.

Considering that the internuclear distance R satisfies the relation $R \ll r_n$, where r_n denotes the average radius of the Rydberg atom in the state with a principal quantum number $n \gg 1$, the processes (1) and (2) were treated as the result of the dipole interaction between the $A^*(n)$ atom's outer electron and the subsystem $A^+ + A$ (see Fig. 1).

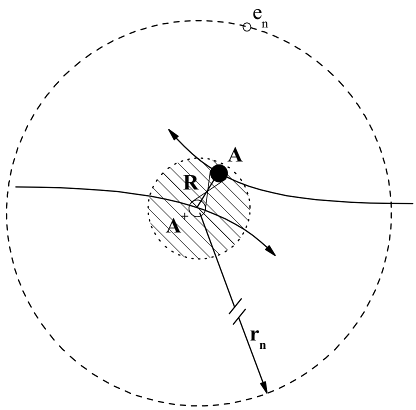

Figure 1: Schematic illustration of collision of Rydberg atom A*(n) with an atom A in the ground state. The region of R where the outer electron of atom A is collectivized is shaded.

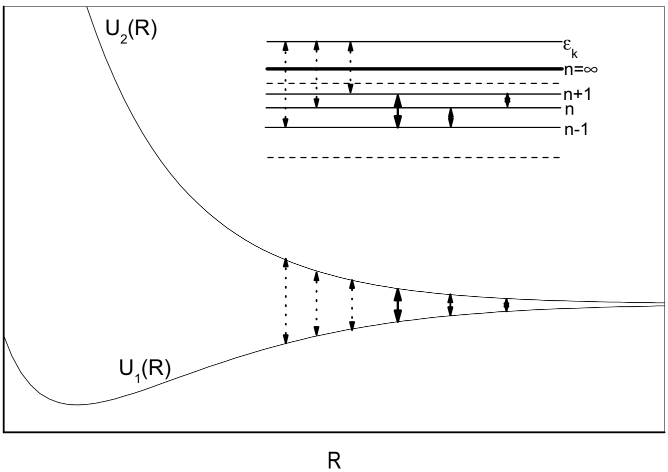

Figure 2: A diagram showing the resonant mechanism in chemi-ionization/recombination channels (dashed arrows), and *(n - n')*-mixing channels (full arrows).

The resonant character of the considered processes (1) and (2), as well as their connection with the chemi-ionization/recombination processes, namely

$$A^{*}(n)+A \Leftrightarrow \vec{e}_k + \begin{cases} A^{+}+A \\ A+A^{+} \end{cases}, \tag{3}$$

are illustrated in Fig. 2.

2. THEORETICAL REMARKS

Keeping in mind that the theory for description of these processes has already been published (see e.g. Mihajlov et al. 2004, 2008), here we will give only the final expressions for the excitation/deexcitation rate coefficients. The excitation rate coefficient $K_{n,n+p}(T_a)$ for the atomic temperature T_a is given by the relation

$$K_{n;n+p}(T_a)=\frac{2\pi}{3\sqrt{3}}\frac{(ea_0)^2}{\hbar}\cdot n^{-5}\int\limits_{R_{\min}(n,n+p)}^{R_{\max}(n,n+p)} X(R)\cdot\exp\left[-\frac{U_2(R)}{kT_a}\right]\frac{R^4 dR}{a_0^5} \tag{4}$$

where $X(R)$ is given by

$$X(R)=\frac{\Gamma(\frac{3}{2},\frac{-U_1(R)}{kT_a})}{\Gamma(\frac{3}{2})}, \tag{5}$$

while $U_1(R)$ and $U_2(R)$ are the corresponding adiabatic terms. The deexcitation rate coefficients are given by the relation

$$K_{n;n-p}(T_a)=K_{n-p;n}(T_a)\frac{(n-p)^2}{n^2}\cdot\exp\left(\frac{\varepsilon_{n-p;n}}{kT_a}\right) \tag{6}$$

where $\varepsilon_{n;n''}=\varepsilon_{n''}-\varepsilon_n$.

In order to estimate the real influence of the processes (1) and (2) to the populations of atomic Rydberg states in different stellar atmospheres we will compare the rate coefficients $K_{n,n+p}(T_a)$ with the rate coefficients of electron-atom (n-n')-mixing processes

$$\vec{e}_k + A^{*}(n) \Leftrightarrow \vec{e}_{k'} + A^{*}(n'),\quad n'=n\pm p, \tag{7}$$

which are denoted here by $\alpha_{n;n+p}(T_e)$. As a measure of their relative influence we will introduce the coefficient $F_{n,n+p}(T_a,T_e)$ which is defined by the relation

$$F_{n;n+p}(T_a,T_e)=\frac{K_{n;n+p}(T_a)}{\alpha_{n;n+p}(T_e)}\cdot\eta_{eA},\quad \eta_{eA}=\frac{N_A}{N_e}, \tag{8}$$

where N_A and N_e are the atomic and electron densities.

3. RESULTS AND DISCUSSION

The solar atmosphere (A=H). In Figs. 3 and 4 are presented the profiles of the temperature T and the ratio $1/\eta = N_e / N_H$ in the solar photosphere and lower chromosphere taken from Vernazza *et al* (1981).

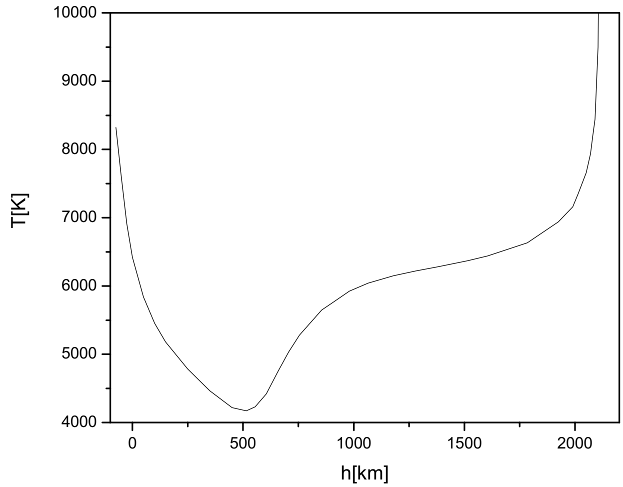

Figure 3: The temperature profile for Solar atmosphere model C of Vernazza et al. (1981).

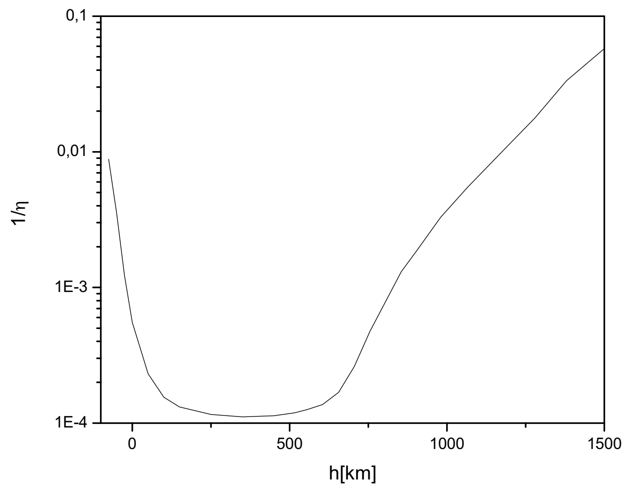

Figure 4: $1/\eta(h) = N_e / N_H$ for Solar atmosphere model C of Vernazza et al. (1981).

The comparison of Figs. 3 and 4 with the results presented in Mihajlov et al (2004) suggests that within significant part of the solar atmosphere the efficiency of the processes (1) and (2) is larger or at least comparable with the efficiency of the concurrent processes (7). This assumption is confirmed by Figs. 5, 6 and 7 which show the behavior of the parameter $F_{n,n+p}(h)$ for $n = 4-8$ and $p = 1-5$.

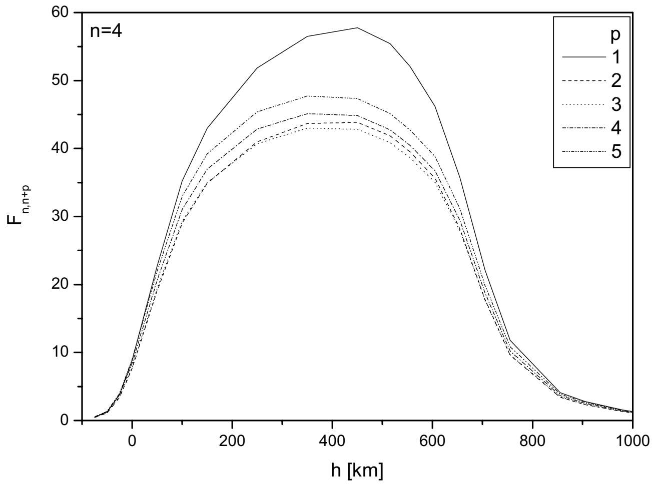

Figure 5: The parameter $F_{n,n+p}(h)$ for $n = 4$ and $p = 1-5$.

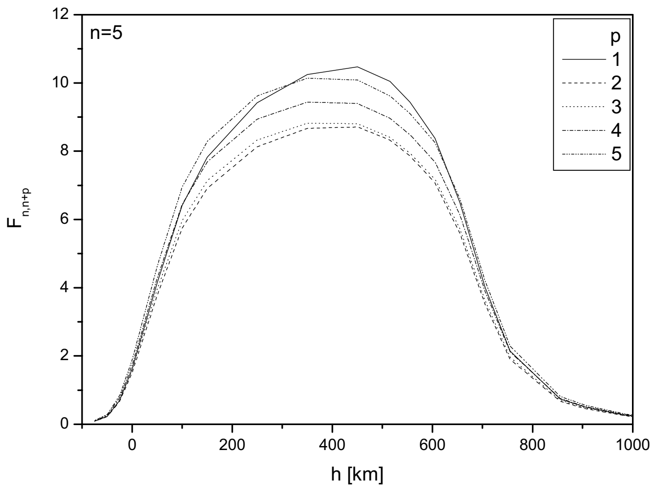

Figure 6: The parameter $F_{n,n+p}(h)$ for $n = 5$ and $p = 1-5$.

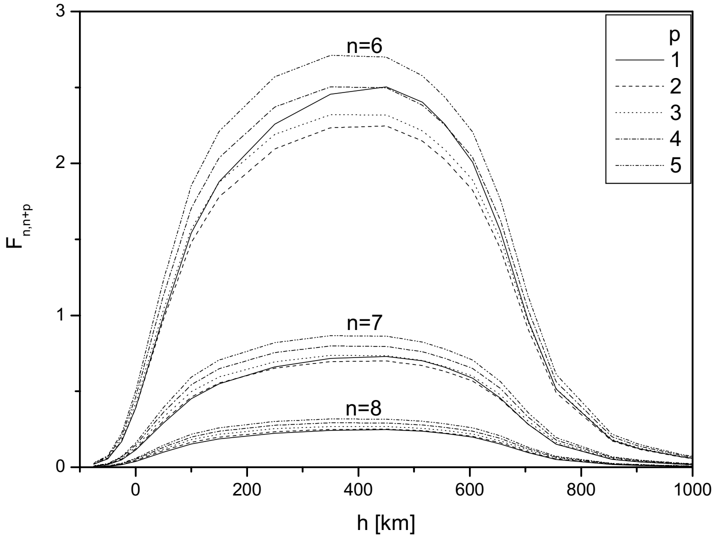

Figure 7: The parameter $F_{n,n+p}(h)$ for $n = 6-8$ and $p = 1-5$.

The atmospheres of DB white dwarfs (A=He). In Figs. 8 and 9 are presented the profiles of the temperature T and the ratio $1/\eta = N_e / N_{He}$ in the DB white dwarf atmosphere with $T_{eff} = 12000$ K and $\log g = 8$ taken from Koester (1980). The comparison of Figs. 8 and 9 with the results presented in Mihajlov et al (2008) suggests that within significant part of the considered DB white dwarf atmosphere the efficiency of the processes (1) and (2) also has to be larger or at least comparable with the efficiency of the concurrent processes (7). This is confirmed by Figs. 10, 11 and 12 which show the behavior of the parameter $F_{n,n+p}(\log \tau)$ for $n = 4-8$ and $p = 1-5$.

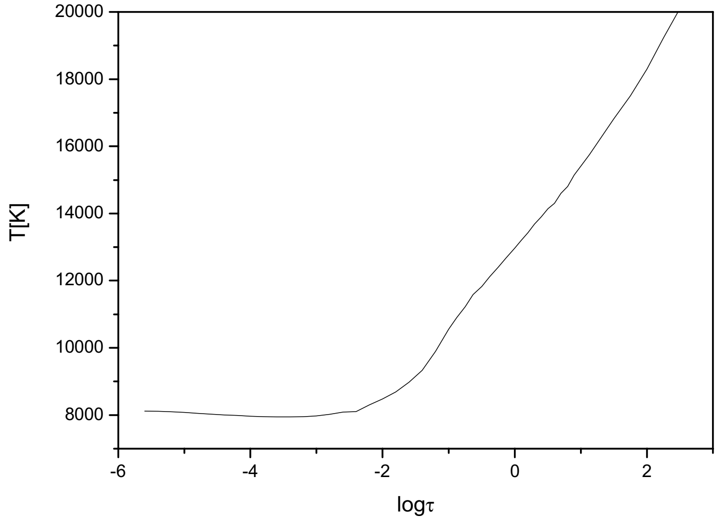

Figure 8: The temperature profile for DB white dwarf atmosphere with T_{eff} = 12000 K, log g = 8 from Koester (1980).

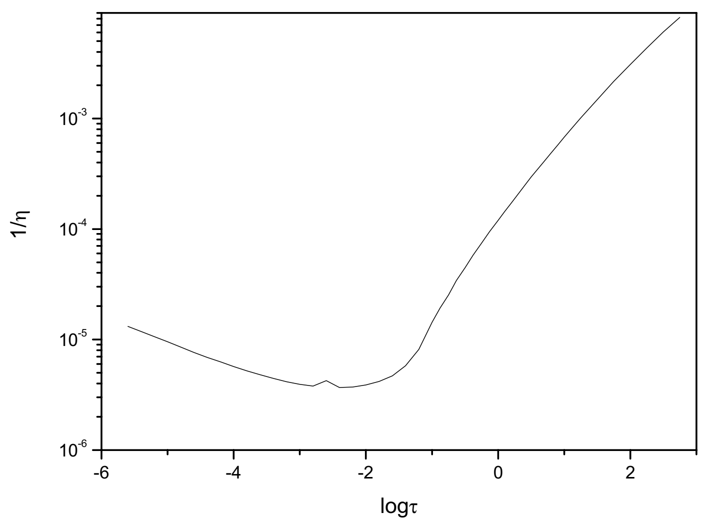

Figure 9: $1/\eta(\log\tau) = N_e / N_{He}$ for white dwarf atmosphere with T_{eff} = 12000 K, log g = 8 from Koester (1980).

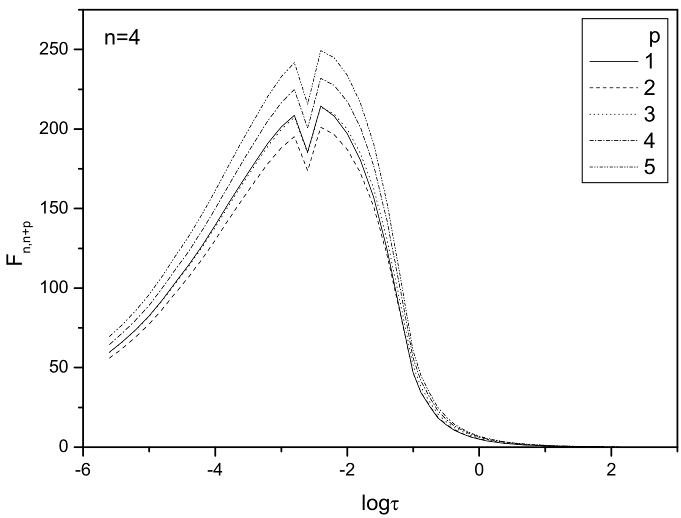

Figure 10: The parameter $F_{n,n+p}(\log\tau)$ for $n=4$ and $p=1-5$.

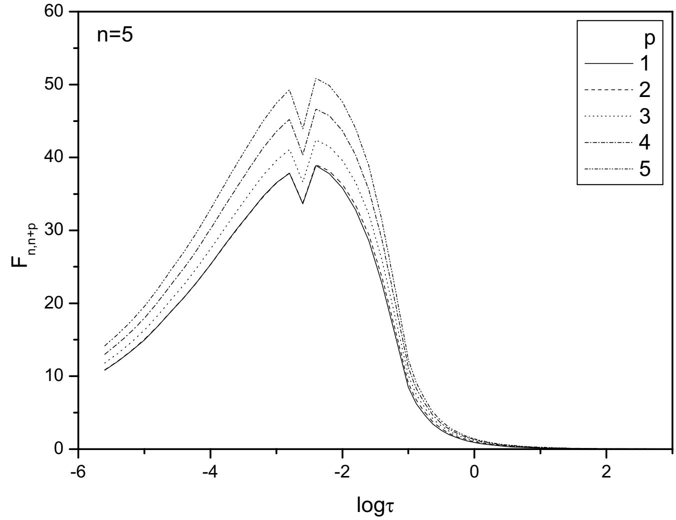

Figure 11: The parameter $F_{n,n+p}(\log\tau)$ for $n=5$ and $p=1-5$.

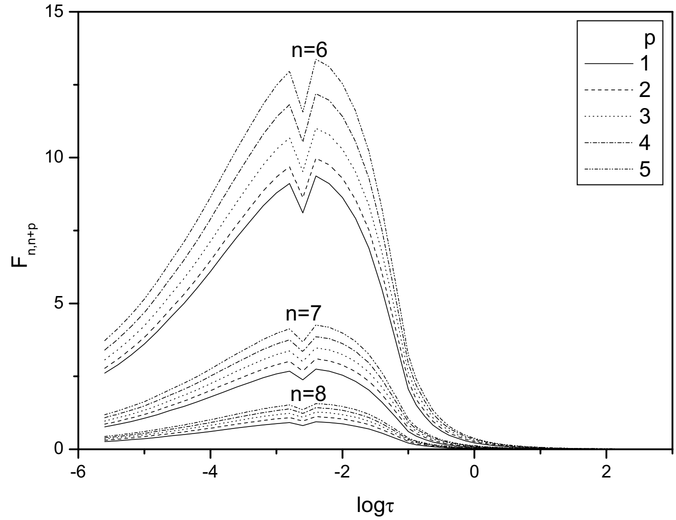

Figure 12: The parameter $F_{n,n+p}(\log\tau)$ for $n=6-8$ and $p=1-5$.

The Figs. 5-7 and Figs. 10-12 show that within the weakly ionized part of the considered solar or DB white dwarf atmospheres the efficiency of the (n-n')-mixing processes (1) and (2) in the atom-Rydberg atom collisions is larger or close to the efficiency of the concurrent electron-atom processes (7) in the region $4 \le n \le 8$. This is important since in the weakly ionized hydrogen and helium plasmas there is a distinct minimum ("bottleneck") in the lower part of Rydberg's block of states, just in the mentioned region of *n*. Consequently, the processes (1) and (2) have to essentially influence to the intensities of the ionization/recombination fluxes in the considered plasmas, and should be included into the models of the corresponding stellar atmospheres.

References

Koester, D.: 1980, *A&AS*, **39**, 401.

Mihajlov, A. A., Ignjatović, Lj. M., Djurić, Z. and Ljepojević, N. N.: 2004, *J.Phys. B*, **37**, 4493.

Mihajlov, A. A., Ignjatović, Lj. M., Srećković, V. and Djurić, Z.: 2008, *JQRST*, **109**, 853-862.

Vernazza, J. E., Avrett, E. H., Loeser, R.: 1981, *ApJS*, **45**, 635.