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THE INFLUENCE OF CHEMICAL IONIZATION AND CHEMICAL RECOMBINATION PROCESSES ON THE PLASMA PARAMETERS IN LOW-TEMPERATURE LAYERS OF STELLAR ATMOSPHERES

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In this paper we have presented some of our preliminary results illustrating the influence of a group of symmetrical chemical ionization and chemical recombination processes on the populations of hydrogen-atom Rydberg states in low-temperature layers of stellar photospheres and a part of chromospheres. These processes are $H^*(n) + H(1s) \rightarrow H_2^+ + e / H(1s) + H^+ + e$ and $H_2^+ + e \rightarrow H^*(n) + H(1s)$, $H(1s) + H^+ + e \rightarrow H^*(n) + H(1s)$, where $H^*(n)$ is the hydrogen atom in a Rydberg state with the principal quantum number $n \gg 1$, and H_2^+ is the hydrogen molecular ion in a weakly bound rovibrational state. The mentioned processes have been considered within the framework of the semiclassical approximation, developed in several previous papers. Their influence on the populations of hydrogen-atom Rydberg states has been investigated by direct inclusion in a computer code for stellar atmosphere modelling. Here we present some of our preliminary results for the M dwarf atmospheres. Our results show that the influence of these processes is significant for the considered stellar atmospheres, so that they should be taken into account for their modelling.

Keywords: Stellar plasma; Collisional processes; Chemical ionization; Chemical recombination

1 INTRODUCTION

In previous papers (Mihaljov and Ljepojević, 1982; Mihajlov et al., 1992; 1996) a group of the chemical ionization and chemical recombination collisional processes, namely

$$H^*(n) + H(1s) \rightarrow H_2^+ + e, \tag{1a}$$

$$H^*(n) + H(1s) \rightarrow H(1s) + H^+ + e, \tag{1b}$$

$$H_2^+ + e \rightarrow H^*(n) + H(1s), \tag{2a}$$

$$H(1s) + H^+ + e \rightarrow H^*(n) + H(1s), \tag{2b}$$

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have been considered as possible factors influencing the populations of the hydrogen-atom Rydberg states in weakly ionized gas plasmas. Here, H*(n) is the hydrogen atom in a state with the principal quantum number $n \gg 1$, and H_2^+ is the hydrogen molecular ion in a weakly bound rovibrational state belonging to the its ground electronic state. The rate coefficients of the processes (1a), (1b), (2a) and (2b) have been determined within the semiclassical theory as described in detail in Mihajlov et al. (1996).

Mihajlov et al. (1996) drew attention to the fact that, since stellar atmospheres often have weakly ionized layers, it is very interesting to investigate the role of processes (1a), (1b), (2a) and (2b) in the plasma of such atmospheric layers. Consequently, we have compared the rate coefficients of processes (1a), (1b), (2a) and (2b) with the corresponding rate coefficients of other relevant ionization and recombination processes, by using the data on the temperature, electron density and the populations of the hydrogen atomic states from the work of Vernazza et al. (1981). The results of such a comparison show that processes (1a), (1b), (2a) and (2b) should be important for the Solar photosphere and the lower parts of the chromosphere (Mihajlov et al., 1997; 1998). These, as well as the other results of our investigations suggested that it would be useful to undertake a systematic research of the role of processes (1a), (1b), (2a) and (2b) in the low-temperature layers of stellar atmospheres. We report here research on the influence of processes (1a), (1b), (2a) and (2b) on the populations of hydrogen-atom Rydberg states by direct inclusion in a computer code for stellar atmosphere modelling. We start here such investigations with the case of M dwarfs, that is stars with $T_{eff} < 4000$ K.

2 RESULTS AND DISCUSSION

Calculations of the stellar plasma characteristics have been made using the PHOENIX computer code (Hauschildt et al., 1994, 1997; Allard and Hauschildt, 1995; Baron and Hauschildt, 1998). In this paper, preliminary results concerning a M red-dwarf atmosphere with $T_{eff} = 3800$ K are presented. In Figure 1, the behaviour of the electron density and temperature, characterizing the M red-dwarf atmosphere model considered here, is shown.

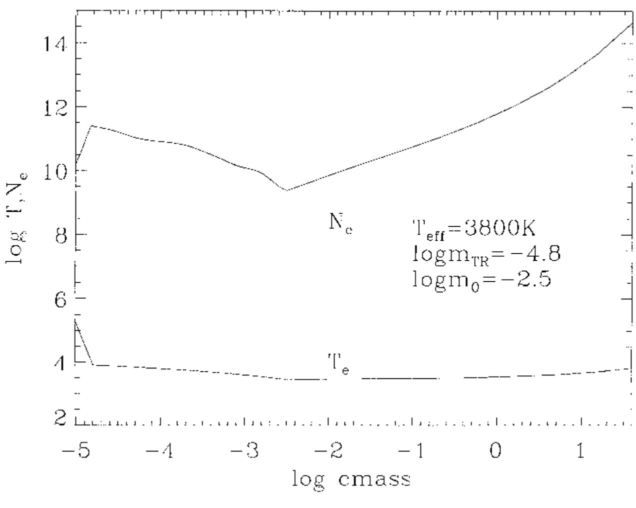

FIGURE 1 The behaviour of the electron density and temperature in the considered M red-dwarf atmosphere as functions of log c_{mass}.

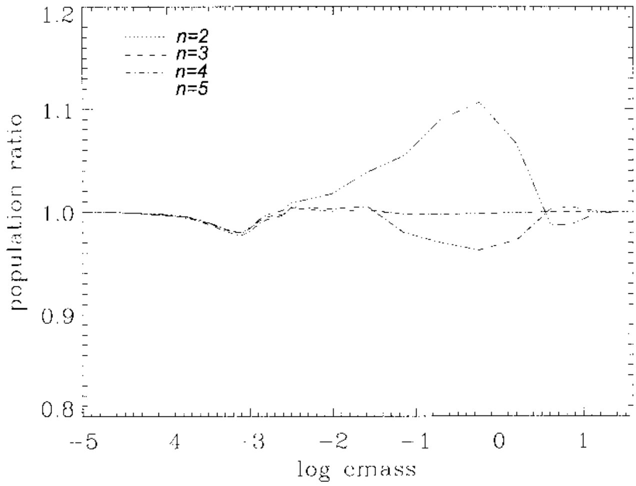

FIGURE 2 The ratio of the population of excited hydrogen-atom states determined with and without processes (1a), (1b), (2a) and (2b) for $n \leq 5$, as functions of log c_{mass}.

As in our previous papers, processes (1a), (1b), (2a) and (2b) for $n > 4$ have been taken into account directly here. However, as a difference from previous work we have not limited the principal quantum number range here to $n = 8$ (as in our previous papers (Mihajlov et al., 1996; 1997)); this range has been extended to $n = 15$. In Figures 2–4, the behaviour of the ratio of population of $H^*(n)$ excited hydrogen-atom states determined with and without processes (1a), (1b), (2a) and (2b) is shown.

In order to check the influence of the considered processes on the $n = 1$, 2 and 3 hydrogen-atom state populations, in Figure 2, the corresponding curves are shown together with the curves for $n = 4$ and 5. It should be noted that these curves are almost equal to unity for $n = 1$, close to unity for $n = 2$ and 3 and start to deviate for $n = 4$ and 5. For $n = 5$ the maximum deviation has already increased to around 10%.

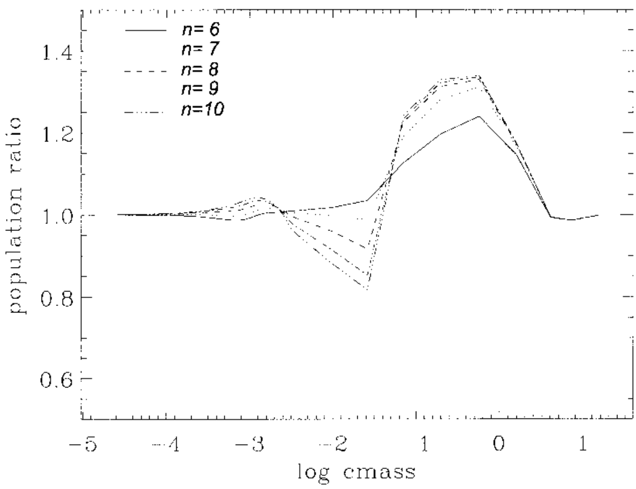

FIGURE 3 Same as Figure 2 but for $6 \leq n \leq 10$.

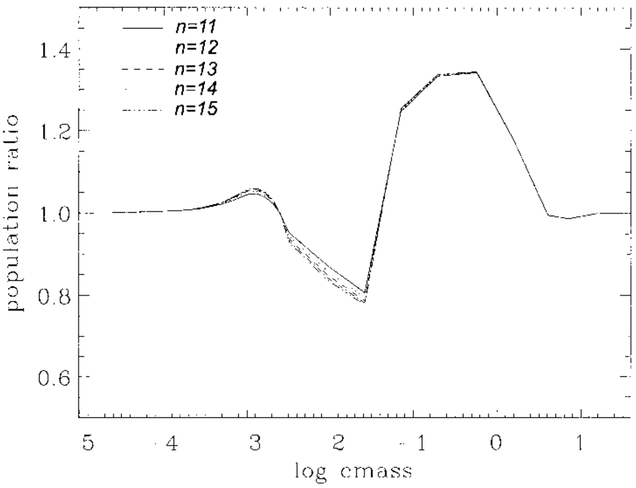

FIGURE 4 Same as Figure 2 but for $11 \leq n \leq 15$.

In Figure 3 the behaviour of the corresponding ratios for $6 \leq n \leq 10$ is shown. This figure demonstrates that, within this principal quantum number range, in accordance with our expectations (based on our previous results), layers exist within the considered atmosphere where the examined ratios for $n > 5$ deviate significantly from unity. The maximal deviation varies from 25 to 35%. The real importance of these deviations may be understood if we take into account that they should cause large differences in the intensity of processes where excited atoms $H^*(n)$ are involved (e.g. radiative processes of population and depopulation and recombination to the ground state). Moreover, one should take into account that processes (1a), (1b), (2a) and (2b) have been until now neglected factors which very effectively contribute to establish local thermodynamic equilibrium. Also, we supposed earlier that the maximal values of the considered ratios are within the range $6 < n < 10$. However, Figure 3 demonstrates that the influence of processes (1a), (1b), (2a) and (2b) does not decrease when n approaches 10 but continues to increase, and the maximal deviation (around 35%) is just for $n = 10$.

Figure 4, where the behaviour of considered ratios for $11 \leq n \leq 15$ is given, shows that the influence of processes (1a), (1b), (2a) and (2b) remains equally significant up to the upper limit of the principal quantum number range considered, namely $n = 15$. Consequently, processes (1a), (1b), (2a) and (2b) must be significant for more of the principal quantum number region $n > 15$. This indicates the need for further investigations of the influence of processes (1a), (1b), (2a) and (2b) on the $H^*(n)$ state populations within a wider principal quantum number region.

Taking into account the obtained results we plan to continue these investigations for atmospheres of other different stellar spectral types. We shall study stars with higher effective temperatures, since our preliminary results show that for these stars, processes (1a), (1b), (2a) and (2b) should influence not only the hydrogen excited atomic state populations but also the electron density.

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