Non-LTE LINE FORMATION FOR S I

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ABSTRACT. A comprehensive model atom for non-LTE line formation calculations for neutral sulfur in the spectra of F-K stars is presented. All the calculations were made using the 65-level atomic model of S I and Kurucz's atmosphere models with $T_{\rm eff} = 5000 \div 6500$ K, log $g = 2 \div 4$ and $[Fe/H] = -4 \div 0$. It was found that the lines of different multiplets are differently sensitive to the NLTE effects. The NLTE corrections themselves are quite small (about –0.1 dex) for the lines 6543-6557 Å, they increase up to –0.26 dex for 8694 Å line, and achieve −1.1 dex for IR triplet 9212-9237 Å. The atomic model adequacy was checked by modeling of the sulfur lines that belong to the investigated multiplets in the solar spectrum, as well as in the spectra of two main sequence and two giant stars. Good fit between calculated and observed profiles is obtained. It was showed that the rather high sulfur overabundance found in some metal-deficient stars can be explained as a result of neglecting of the strong NLTE effects.

Key words: atomic data - line: formation - star: abundances

1. Introduction

At present time it is not clear whether we have correct knowledge about the sulfur abundance in galactic halo stars. In some works (Nissen et al. 2004, 2007, Ryde and Lambert 2004) it was reported that the stars with metallicity $-3 <$[Fe/H]< -1 sulfur shows systematical overabundance at the level of 0.3 dex, and this is in a good agreement with predictions of the galactic chemodynamical models. The main source of the metals in early Galaxy is SNeII. The ration [S/Fe] decreases at [Fe/H]>–1 because of the iron abundance increase due to SNeIa, At the same time some investigators (Israelian and Rebolo 2001) find the larger sulfur overabundances (up to +0.8 dex) in the stars with [Fe/H]=–2. There is an attempt to explain such overabundances by the shorter time of the mixing, or by the hypernovae explosions.

The sulfur abundance in metal-poor stars is based on an analysis of 8694 Å and 9212-9237 Å lines. As it was showed by Takeda et al. (2005) all these lines are subject of NLTE effects. Authors used photoionization cross sections found in hydrogen-like approximation. Oscillator strengths were taken from incomplete list of Kurucz.

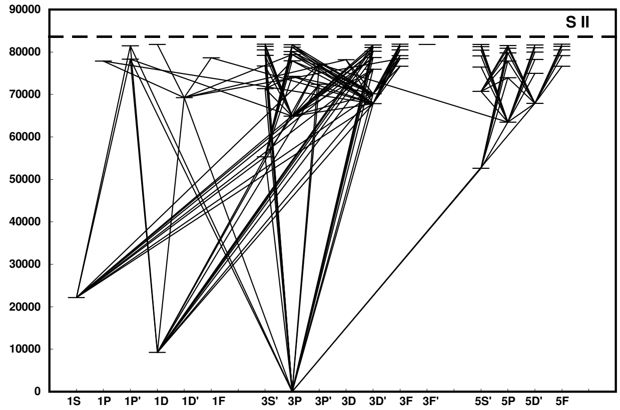

Figure 1: Grotrian diagrams for S I.

2. The S I model atom

In our calculations we used modified program MULTI (Carlsson 1986). The sulfur atomic model consists of 64 lower singlet, triplet and quintet systems of SI and the ground level of SII (Fig. 1). The radiative photoionization rates for all considered levels were calculated using the detailed photoionization cross-sections listed in OP TopBASE. The detailed consideration comprises 137 radiative b-b transitions (allowed and inter-combination transitions). The radiative rates of the other 200 very weak radiative transitions were adopted to be constant and they were calculated in LTE. Oscillator strengths are from OP TopBASE.

In the visual and near IR parts of the spectrum of metal-poor stars there are only a few sulfur lines which are appropriate for the abundance determination. Among them there multiplet 1 (9212-9237 Å), 6 (8694 Å) and 8 (6743-6757 Å). The rest of the lines are very weak or blended.

To check the model we calculated the line profiles for

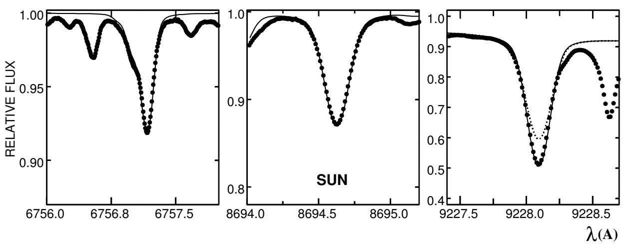

Figure 2: Comparison of the calculated and observed profiles of sulfur lines in a spectrum the Sun. The dotted lines show the LTE and solid lines - nonLTE profiles.

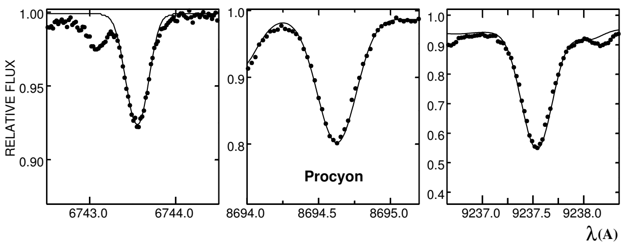

Figure 3: Comparison of the calculated and observed profiles of sulfur lines for Procion.

the different multiplets in the solar spectrum. For the lines of 1st multiplets that are situated in the wing of the hydrogen line we have first calculated with MULTI b-factors and then used these factors in the LTE synthetic spectrum code STARSP (Tsymbal 1996). Thus we calculated LTE synthetic spectrum in vicinity of the sulfur lines, while their own profiles were calculated with NLTE source function.

There is a goof agreement with observed profiles (Fig. 2). The dashed line represents LTE profiles. It is seen that there is significant difference between LTE and NLTE profiles for the lines of 1st multiplet, while the lines of 6^{th} and 8^{th} multiplets are not suffered from NLTE effects. The same test has been performed for the two main sequence stars and two supergiants. Again, a good agreement is seen in Fig. 3.

3. NLTE effects for sulfur lines

We have calculated profiles and equivalent widths of the spectral lines for the grid of the atmosphere models in the range of effective temperatures 5000-6000 K with [Fe/H] from 0.0 to –4.0 and log g from 2 to 4. For the metal-poor stars we have performed calculations with [S/Fe] = +0.3, since in these stars some the alpha-elements have increased abundance. In all the cases LTE abundances of sulfur were larger than those found within the NLTE approximation (Fig 4.).

Table 1: Atomic data of used spectral lines.

λ (Å)	log gf	Γ_{rad}	Γ_{wv}
8694.626	0.08	7.62	-6.98
9212.863	0.42	7.47	-7.37
9228.093	0.26	7.46	-7.37
9237.538	0.04	7.46	-7.37
6743.440	-1.200	7.58	-7.12
6743.531	-0.850	7.58	-7.12
6743.640	-0.950	7.58	-7.12
6748.573	-1.320	7.58	-7.12
6748.682	-0.730	7.58	-7.12
6748.837	-0.530	7.58	-7.12
6756.851	-1.670	7.59	-7.12
6757.007	-0.830	7.59	-7.12
6757.171	-0.240	7.59	-7.12

As one can see the lines of 8^{th} multiplet practically are not affected by NLTE effects, but these lines become very weak to be used at [Fe/H] < –1.5. The same picture is seen for 8694 Å, but this line is much more sensitive to the departure from LTE.

The lines of the 1^{st} multiplet are strongly influenced. There is significant dependence of the NLTE corrections upon log g and $T_{\rm eff}$. Corrections become larger with metallicity increase, achieving maximum value of about 1.1 dex at [Fe/H] = –2, then corrections decrease.

NLTE corrections for the lines of considered multiplets are qualitatively the same but with different values. Fig. 5 shows this difference as a function of $T_{\rm eff}$ for log g = 2 and 4, and [Fe/H] = –2. Fig. 6 shows a dependence of the NLTE corrections as a function of V_t for 1^{st} and 6^{th} multiplets. One can note apparently complicated form of this dependence.

Summarizing one can make a conclusion that calculated grid of the NLTE corrections should be used with a caution, taking into account an influence from the microturbulent velocity, metallicity, temperature, luminosity and individual characteristics of the certain sulfur line. For the more precise determination one needs to perform a direct NLTE calculation of the sulfur line profiles.

References

M. Carlsson: 1986, *Uppsala Obs. Rep.* **33**, 1.
Israelian G., Rebolo R.: 2001, *Astrophys.J.* **557**, 43.
Nissen P.E., Chen Y.Q., Asplund M., Pettini M.: 2004, *Astron. Astrophys.*, **415**, 993.
Nissen P.E., Akerman C., Asplund M. et al.: 2007, *Astron. Astrophys.*, **469**, 319.
Ryde N., Lambert D.L.: 2004, *Astron. Astrophys.*, **415**, 559.
Takeda Y., Hashimoto O., Taguchi H., et al.: 2005, *PASJ*, **57**, 751.
Tsymbal V.V.: 1996, *ASP Conf. Ser.*, **108**, 198.

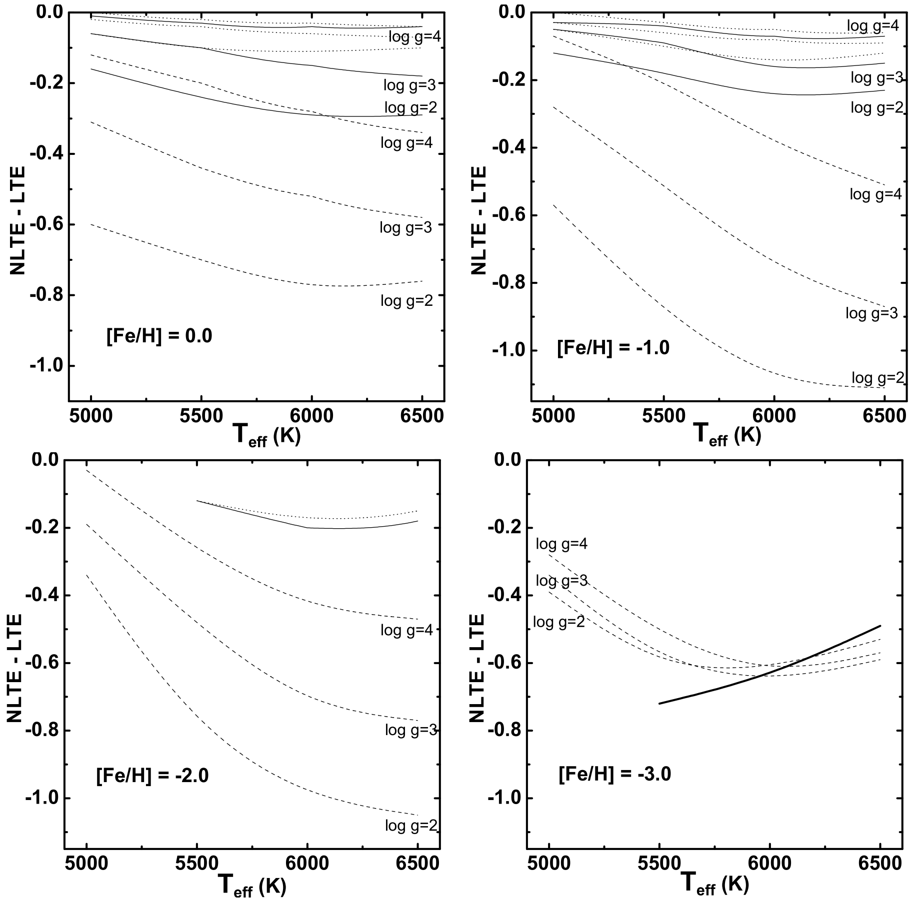

Figure 4: NLTE corrections computed as a function of the temperature and the metallicity of the model. NLTE corrections for lines 9212 Å show dashed lines; for lines 8694 Å - solid lines; and for lines of the eighth multiplets - dotted lines.

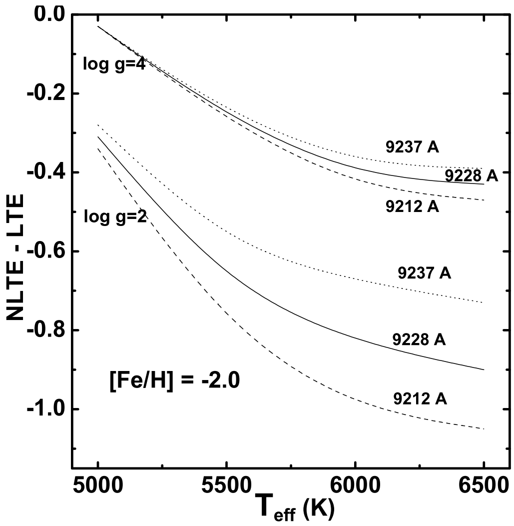

Figure 5: NLTE corrections for three lines of the first multiplets for model atmospheres with log $g = 2$ and 4 and [Fe/H]$= -2$.

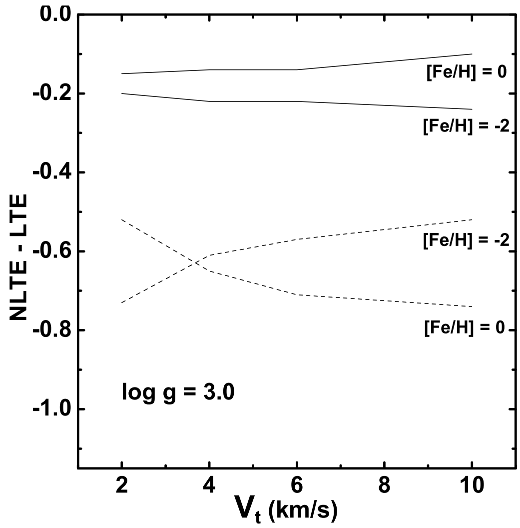

Figure 6: NLTE corrections computed as a function of the $V_{\rm t}$ for lines of the first and the sixth multiplets ($T_{\rm eff} = 6000$ K, log $g = 3$, $[Fe/H] = -2.0$).