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Grid of NLTE corrections for sulfur lines in the atmospheres of A–K stars

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Abstract. A correction grid is presented to take into account the influence of departures from local thermodynamic equilibrium on sulfur lines in the atmospheres of stars in the range of spectral classes from A to K. The correction grid was obtained using the atomic model of sulfur that takes into account the most modern atomic data on collision rates with electrons and hydrogen. The influence of NLTE effects on lines in both the optical and IR regions, including lines in the H-band, is considered. For some lines of neutral sulfur, which are practically not subject to NLTE effects, the wavelengths and oscillator strengths in the solar spectrum have been refined. The modified atomic model of sulfur, used to determine the sulfur abundance from the spectra of stars of different metallicities, has shown its reliability and adequacy. All sulfur lines are well described by similar element contents, regardless of their sensitivity to the influence of NLTE effects.

Keywords: line: formation, profiles; stars: abundances; Sun: abundances

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1 Introduction

The sulfur abundance of stars has been of increasing interest when modeling the chemical evolution of the galaxy. There is still no consensus on the nature of the behavior of the [S/Fe] ratio on metallicity in stars with low metal abundance. A major problem in the accuracy of determining sulfur abundance is the influence of departures from LTE for S I lines. In the optical range, sulfur abundance is usually determined by three groups of lines: 6046–6052 Å (multiplet 10), 6743–6757 Å (multiplet 8) and 8694 Å (multiplet 6). In the near-infrared range, two IR triplets are used: 9212–9237 Å and 10 455–10 459Å. High-resolution IR spectrographs allow the addition of lines in the H-band to the study: 15 400–15 422 Å 15 469–15 478 Å and 22 507–22 707Å. As shown in papers of Takeda et al. (2005) and Korotin (2009), many sulfur lines are, to one degree or another, influenced by departures from LTE in stellar atmospheres. Since new atomic data concerning neutral and ionized sulfur have appeared since these calculations, we have carried out work to modernize the atomic model of sulfur by Korotin (2009) taking into account the most modern atomic data and checking it against the spectra of well-studied stars.

2 Modified atomic model of the sulfur and grid of NLTE corrections for S I lines

The modified `MULTI` software package was used for calculations. The new model of the sulfur atom includes 64 S I levels, 81 S II levels, and the main S III level (Fig. 1). Radiative photoionization rates for all levels considered were calculated using detailed photoionization cross sections from OP TopBASE. For detailed consideration 775 radiative bound-bound and 146 bound-free transitions were selected. Photoionization cross sections and oscillator strengths are taken from OP TopBASE. Unlike the 2009 model, instead of approximation formulas to take into account collision rates with electrons and hydrogen, detailed quantum mechanical calculations from the ADAS database and the work of Belyaev & Voronov (2020) were used. Modernization of the atomic model made it possible to expand the range of effective temperatures of stellar photospheres in the NLTE correction grid to $T_{\rm eff} = 10\,000$ K.

The effects of departures from LTE have different values for various S I lines. The two IR triplets experience the greatest departures. The atomic model was tested to determine the sulfur abundance of 13 stars and showed its adequacy in a wide range of fundamental stellar parameters ($T_{\rm eff}$ from 4850 K to 9600 K, $\log g$ from 2.9 to 4.5, [Fe/H] from -2.0 to $+0.25$). In the spectra of all test stars, the sulfur lines are described by similar abundances of the element, regardless of the degree of influence of departures from LTE on a specific spectral line.

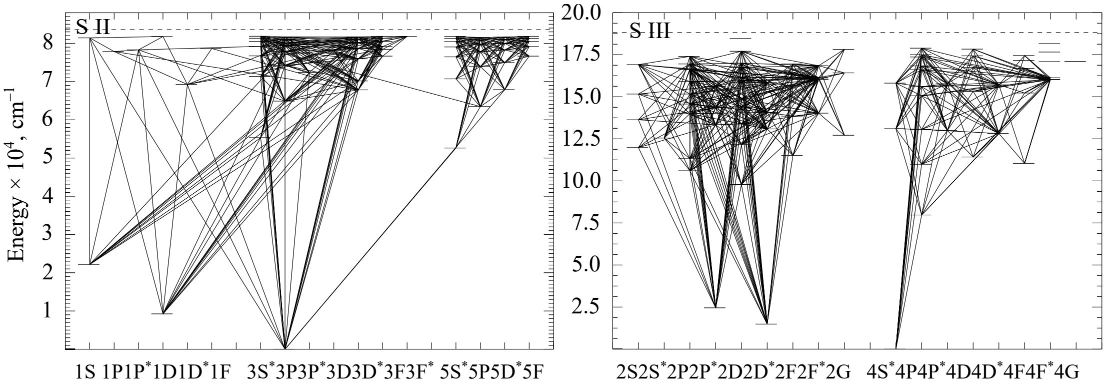

Fig. 1. The Grotrian diagram for atomic model.

The parameters of sulfur lines observed in the optical range have been determined through theoretical calculations and can vary greatly among different authors. When used to calculate a synthetic spectrum with wavelengths and oscillator strengths from the VALD or NIST databases, the lines cannot be described accurately. At the same time, NLTE effects do not influence the lines of the sixth, eighth, and tenth multiplets in the solar atmosphere. Therefore, assuming the sulfur abundance is equal to the meteorite abundance, which is confirmed by the abundance determined from IR triplets, we refined the wavelengths and oscillator strengths of the S I lines in the optical spectrum. The list of recommended sulfur lines for determining abundance is presented in Table 1.

Table 1. Parameters lines of S I.

Wavelength Å	E eV	$\log gf$	Γ_{vw}	Wavelength Å	E eV	$\log gf$	Γ_{vw}	Wavelength Å	E eV	$\log gf$	Γ_{vw}
6052.53	7.87	−1.99	−6.55	8693.16	7.87	−1.29	−6.98	15422.20	8.70	−1.84	−7.00
6052.59	7.87	−1.15	−6.55	8693.95	7.87	−0.45	−6.98	15422.26	8.70	−0.30	−7.00
6052.69	7.87	−0.56	−6.55	8694.64	7.87	0.14	−6.98	15422.28	8.70	0.77	−7.00
6743.47	7.87	−1.24	−6.65	9212.87	6.53	0.39	−7.37	15469.82	8.05	−0.17	−6.90
6743.54	7.87	−0.88	−6.65	9228.09	6.53	0.25	−7.37	15478.48	8.05	0.06	−6.90
6743.65	7.87	−0.94	−6.65	9237.54	6.53	0.02	−7.37	22507.56	7.87	−0.48	−7.44
6748.61	7.87	−1.36	−6.65	10455.45	6.86	0.25	−7.32	22519.07	7.87	−0.25	−7.44
6748.71	7.87	−0.77	−6.65	10456.76	6.86	−0.45	−7.32	22552.57	7.87	−0.04	−7.44
6748.85	7.87	−0.56	−6.65	10459.41	6.86	0.03	−7.32	22563.83	7.87	−0.26	−7.44
6756.86	7.87	−1.71	−6.65	15400.08	8.70	0.43	−7.00	22575.39	7.87	−0.73	−7.44
6757.03	7.87	−0.86	−6.65	15403.72	8.70	−0.30	−7.00	22644.06	7.87	−0.34	−7.44
6757.18	7.87	−0.28	−6.65	15403.79	8.70	0.61	−7.00	22707.74	7.87	0.44	−7.44

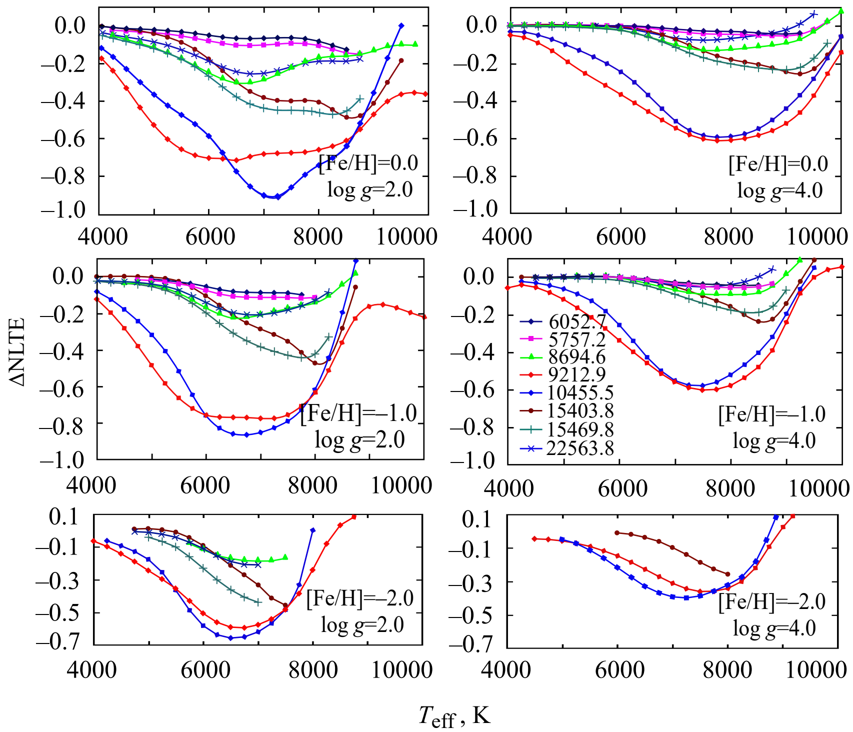

Fig. 2. The grid of non-LTE corrections for S I lines.

The grid of NLTE corrections is calculated for $T_{\rm eff}$ from 4000 K to 10 000 K, $\log g$ from 0 to 5, [Fe/H] from -2.0 to 0.0 and [S/Fe] from 0.0 to +0.8 dex at $V_t = 2$ km/s (Fig. 2). The absolute value of the corrections increases when moving from dwarf stars to giants, since the less dense atmosphere of giants reduces the influence of collisional processes. The lines of the eighth (6743–6757 Å) and tenth (6046–6052 Å) multiplets in dwarf stars have the least corrections and can be used in LTE analysis. The influence of NLTE effects on these lines is significant only for giant stars. The same conclusion can be drawn for all lines from the H-band. The lines of the sixth (8694 Å) multiplet are slightly more sensitive to departures from LTE, and the lines of two IR triplets can only be used if NLTE corrections are taken into account.

References

Belyaev A.K. and Voronov Y.V., 2020, Astrophysical Journal, 893, 1, id. 59

Korotin S.A., 2009, Astronomy Reports, 53, 7, p. 651

Takeda Y., Hashimoto O., Taguchi H., et al., 2005, Publications of the Astronomical Society of Japan, 57, p. 751