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Schuster-Schwarzchild model: On the study of Stellar Atmospheres

Report - Radiative Processes in Astrophysics

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ABSTRACT

Aims. We aim to develop an algorithm that implements the fundamental equations that describe the physics of stellar atmospheres, using the Schuster-Schwarzchild two layer model.

Methods. For the case of a sunlike star, we studied spectral lines of several elements, considering only two ionization states. We estimated their Voigt profiles, taking $a = 0.01$ and $\epsilon_{mic} = 2km/s$, and calculated their equivalent widths. We then studied how varying these parameters changes the lines' profiles. Lastly, for the Ca I line, we took into account other stars, verifying how the stellar characteristics changes its behaviour.

Results. A method for the study of spectral lines was developed. We verified that higher values for both a and e_{mic} broadens the lines' profiles, generally resulting in a larger equivalent width, but not always, as was the case for the Si II line. We also verified that, for the Ca I line, the equivalent width is dependent on the stellar temperature and its type, hotter, smaller stars having sharper lines.

Key words. stellar atmospheres – spectra – schuster-schwarzchild

1. Algorithm

The program is divided in three files, "read_files", "general_functions" and "test_file".

- "read_files" processes the dat files that contains the data. It reads them into four separate *pandas*: pd_lines, $pd\_abundances$, pd_atomic and pd_model, carrying all information which will be used. It also carries a function called $split\_coefs$ which is later used to further process data found on the atomic.dat file, namely the coefficients used to approximate the partition function.
- "general_functions" carries all the functions that apply the physical equations that are used to complete our goals. It follows step by step the resolution of the problem, calculating:
  - *Abundance* using f_logN_A;
  - *Ionized fraction*, by estimating the partition function using *particc*, $log(n_A)$ using *saha*, and finally N_{AII} and N_{AI} using $fracc$.
  - *Number of absorbing particles*, using *particc*.
  - *Voigt profile* of the line, with *voigt*. Limits of where the lines start and finish were estimated by hand.
  - *Optical depth*, using *espessura*.
  - *Equivalent width*, through *eq_width*, where the same limits are used.
- "$test\_file$" is used to test the functions above, calculating equivalent widths and plotting spectral lines. It is sectioned to allow the quick access to information:
  - Firstly tests are done for a sunlike star, with fixed a and ϵ_{mic}. Plotting all profiles simultaneously or separately is allowed, as well as printing their equivalent widths.
  - Next, there are tests for varying a, followed by tests for varying ϵ_{mic}. Both parts allow for plots of lines with these changing quantities, and printing equivalent widths for all lines.
  - Lastly, there is a Ca I test for different stellar parameters.

2. Results

The algorithm was initially tested for a sunlike star, with input parameters $T_{cont} = 5800, T_{layer} = 5000, log(n_H) = 12, log(N_H) = 24, log(n_e) = 12$. We determined each elements' profiles as stated, resulting in the lines in figure 1. Their equivalent width was calculated, as is shown in table 1.

Table 1. Equivalent width determined using the values $a = 0.01$ and $\epsilon_{mic} = 2km/s$. Next to the element, its ionization state is stated, I referring to the atomic state and II to the first ionized state.

Element	λ(Å)	EW (mÅ)
Na I	5895	263.17
K I	7699	131.92
Ca I	6162	47.75
Fe I	4957	16.96
Fe II	5316	2.61
Fe I	5615	13.32
Mg I	8806	28.78
Ca II	8927	1.17
Si II	6347	0.14

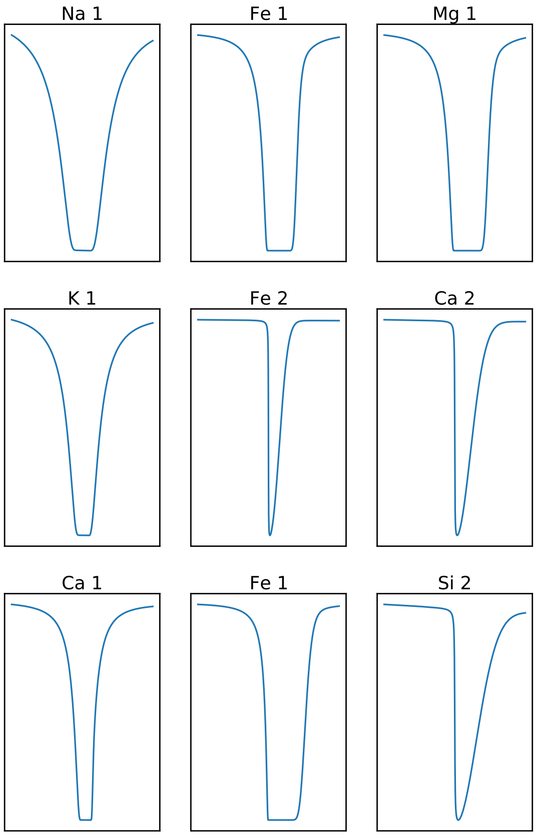

Fig. 1. Profiles of all lines studied, for the case of a sunlike star and parameters a of 0.01 and $\epsilon_{mic} = 2km/s$.

2.1. Varying a

We firstly fixed the parameter $\epsilon_{mic} = 2km/s$, testing for three orders of magnitude of a. It is relevant to note that, for values lower than 0.001, the algorithm took long to converge. In general, the lines showed a broader profile for larger a values. The results for $a = 0.8$ can be seen in table 2. Broader profiles usually lead to higher equivalent width, as is the case of the Na I line, shown in figure 2. However, some had a smaller result, namely Si II, whose change in profile is shown in figure 3.

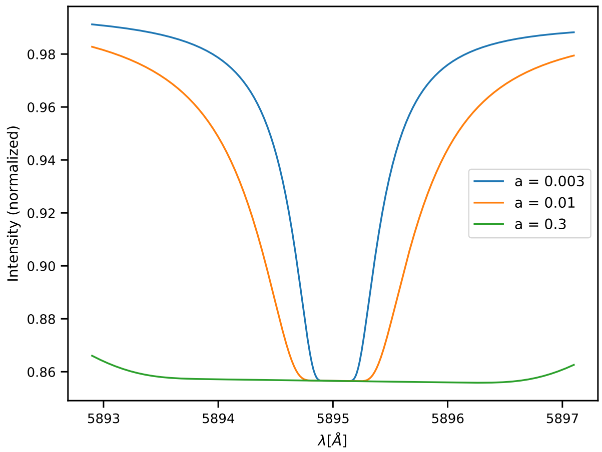

Fig. 2. Profile of the Na I line, for a fixed ϵ_{mic} of 2 km/s but for different a values. F or this line, the highest this parameter, the broader the profile, leading to higher equivalent widths.

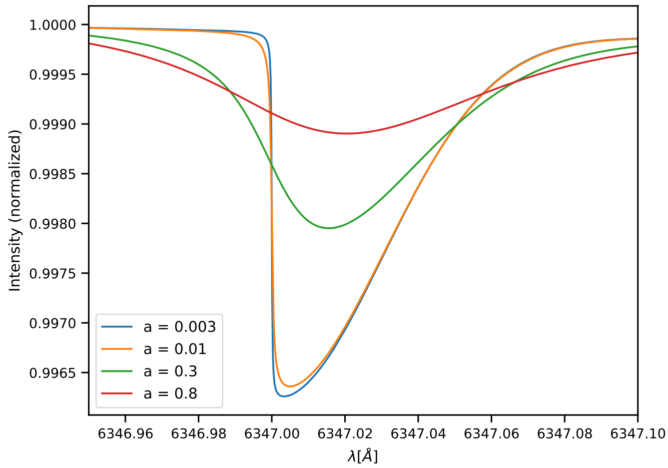

Fig. 3. Profile of the Si II line, for fixed ϵ of 2km/s and varying a.

Table 2. Equivalent width determined using the values $a = 0.8$ and $\epsilon_{mic} = 2km/s$. Most elements showed a higher equivalent widths, while some the opposite behaviour, namely Si II and Ca II.

Element	λ(Å)	EW (mÅ)
Na I	5895	579.29
K I	7699	412.01
Ca I	6162	207.75
Fe I	4957	52.78
Fe I	5316	2.82
Fe II	5615	35.82
Mg I	8806	80.40
Ca II	8927	1.03
Si II	6347	0.11

2.2. Varying ϵ_{mic}

We then fixed a to 0.01, and tested for several values of ϵ_{mic}. Likewise, higher values lead to broader lines. For the Na I line, results can be seen in figure 4. Overall, the results are similar. Higher values lead to broader lines, thus higher equivalent widths, with some exceptions, namely Fe I for $\lambda = 5316$Å, Si II and Ca II, as seen in table 3. This effect can be seen in figure 5, for the case of the Si II line.

Table 3. Equivalent width determined using the values $a = 0.01$ and $\epsilon_{mic} = 20km/s$.

Element	λ(Å)	EW (mÅ)
Na I	5895	524.79
K I	7699	334.19
Ca I	6162	153.40
Fe I	4957	35.20
Fe I	5316	1.83
Fe II	5615	23.40
Mg I	8806	53.31
Ca II	8927	0.45
Si II	6347	0.04

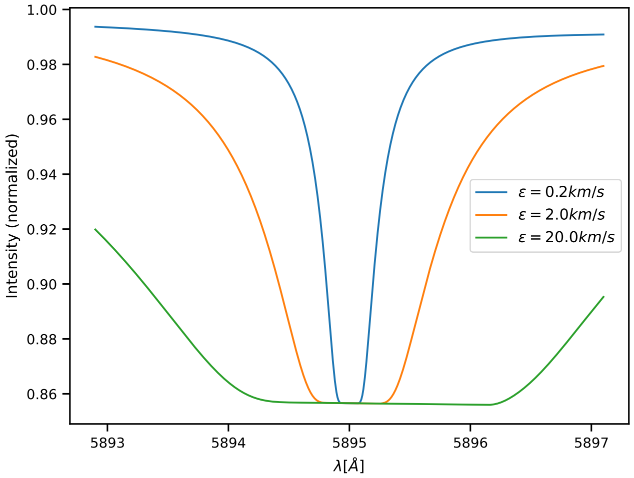

Fig. 4. Profile of the Na I line, for a fixed a of 0.01, but for different ϵ_{mic}. For this line, like the previous parameter, the highest this value, the broader the line.

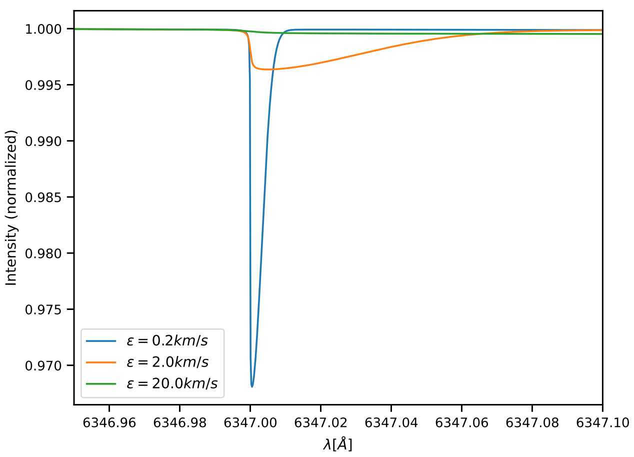

Fig. 5. Profile of the Si II line, for fixed a of 0.01 and varying ϵ_{mic}.

2.3. The Ca I line under different stellar characteristics

Lastly, we fixed $a = 0.01$ and $\epsilon_{mic} = 2km/s$, testing for different stellar characteristics: T_{cont}, T_{layer},n_H,N_H and n_e. We aimed to observe how these parameters influence the profile of the line. It is important to note that here, the solar parameters used are different than the sunlike ones used in the previous tests. The results are shown in figure 6.

Taking as reference that the sun's effective temperature is around 5800 K, we can see from figure 6 that hotter stars have sharper Ca I lines, with higher equivalent widths, as in the figure they're ordered in terms of effective temperature. Comparing the stellar types, stars with $logg \geq 4$ are considered dwarves, and the others giants. It seems from this figure that giants have lower equivalent widths in comparison to smaller stars, as one can notice looking at the red and green lines, both for $T_{eff} = 4000K$, but the first one being a giant, and the second a dwarf. Other examples include both stars with $T_{eff} = 5740$, where the same happens. For higher effective temperatures, the stellar type did not seem to pose much of a difference, as can be seen in the bottom two lines, for $T_{eff} = 8000K$.

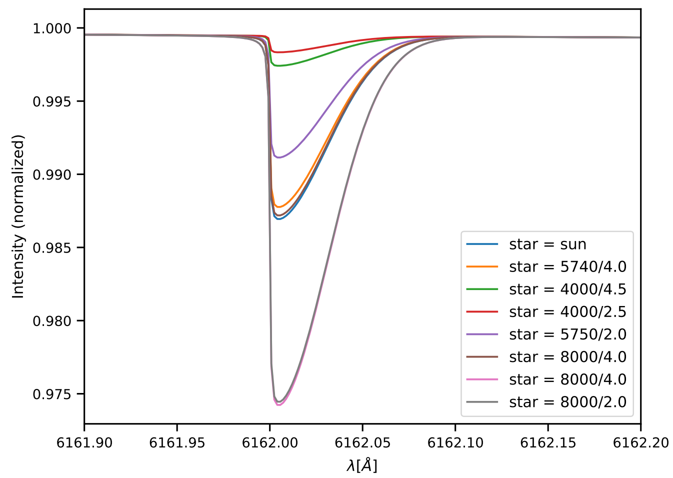

Fig. 6. Profile of the Ca I line, for fixed a of 0.01 and ϵ_{mic} of 2km/s, but for different stellar types. In the legend, values shown are $T_{eff}/logg$.

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3. Conclusions

A method for the study of spectral lines was developed, using a simplified two layer model. Using parameters for a sunlike star, we started by determining several lines' Voigt profiles and calculated their equivalent widths. We then varied two parameters, a and ϵ_{mic} and verified that, for both of them, higher values lead to broader lines. This meant a higher equivalent width for most cases, with a few exceptions. Lastly, with fixed a and ϵ_{mic} values, we studied how stellar characteristics changed the Ca I line's profile. We concluded that hotter stars are correlated with sharper lines, with higher equivalent widths. We also noticed that there is a dependence on the stellar type, with giants having lower equivalent widths in comparison to dwarves.