# The dependence of energy distribution on the abundances of A-star atmosphere models


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Abstract: We calculate energy distribution of A-star atmospheres ($T_{\rm eff} = 10\,000$ K, $\log g = 4.0$) for large interval of abundances of silicon and other lighter chemical elements using adequate model atmospheres. We discuss the reasons and magnitudes of found departures of the stellar energy distribution and *uvby* magnitudes from the normal state.


## Introduction

It is known for many decades that magnetic chemically peculiar (mCP) stars exhibit periodical variations of their light and energy distributions which more or less differ from these ones of normal stars of the same effective temperature $T_{\rm eff}$ and surface gravity $g$. Observed light variations (the amplitude of which reaches typically several hundredths of magnitude) used to be explained by the presence of specific "photometric" spots with uneven energy distribution on the surface of rotating stars. It is believed that these hypothetical photometric spots are somehow connected with the "spectroscopic" spots of enhanced abundance of various chemical elements such as elements of the iron group, silicon, strontium, rare earth, manganese etc. While the location and detailed properties of these spots can be determined and mapped from the Doppler imaging profile analysis (e.g. Khokhlova et al. 1997), in the case of photometric spots such a tool is not in our disposal. The departures of energy distribution in spectra of CP stars are as a rule explained as the consequence of line blanketing caused by plenty of lines of overabundant elements namely in the UV region of stellar spectra (Peterson 1970, Molnar 1973). This general concept deserves a thorough quantitative verification by new tools of precise multicolor photometry and spectrophotometry and advanced stellar atmosphere modelling.

This paper presents first answers to question whether the above mentioned paradigm may be valid or it belongs only among astrophysical myths.

## Models

For the modelling of A star atmospheres we selected code TLUSTY (Hubeny & Lanz 1992, 1995, Lanz & Hubeny 2003). Using this code we calculate LTE plane-parallel model atmospheres for various abundances which are typical for chemically peculiar A stars. For our study we used the model of a main sequence A star with parameters $T_{\rm eff} = 10\,000$ K, $\log g = 4.0$, $\zeta_{\rm turb} = 2\,{\rm km\,s^{-1}}$. Elements and their ionization stages accounted for the model atmosphere calculation are given in the following table.

| Ion | Levels | Ion | Levels | Ion | Levels | Ion | Levels |
|---|---|---|---|---|---|---|---|
| H I | 9 | N I | 21 | Ne I | 15 | Si I | 16 |
| H II | 1 | N II | 26 | Ne II | 15 | Si II | 16 |
| He I | 14 | N III | 1 | Ne III | 1 | Si III | 12 |
| He II | 14 | O I | 12 | Mg I | 13 | Si IV | 1 |
| He III | 1 | O II | 13 | Mg II | 14 | | |
| C I | 26 | O III | 1 | Mg III | 14 | | |
| C II | 14 | | | Mg IV | 1 | | |
| C III | 1 | | | | | | |

The emergent radiative flux is afterwards calculated with spectrum synthesis program SYNSPEC. For the calculation of the emergent spectrum we include the line transitions of all atoms with atomic number $Z \leq 30$. Finally, with calculated spectral energy distribution it is possible to define departures of *uvby* magnitudes for the particular abundance $A$ of a selected element from the situation when its abundance is equal to the solar one

$$\Delta m_c(A) = -2.5 \log \left( \frac{H_c(A)}{H_c(A_\odot)} \right).$$

The fluxes $H_c(A)$, $H_c(A_\odot)$ in individual colors $c$ for model are given by the convolution of radiative flux $H_\lambda$ with Gauss function with peak at the central wavelengths of given colors $\lambda_c$, and dispersions $\sigma_c$ taken from Cox (2000).

## Dependence of calculated fluxes on the silicon abundance

In order to better understand the dependence of calculated magnitudes on elemental abundance we discuss the impact of variable abundance of silicon on radiative flux in the optical part of spectrum. In the following figure we plot calculated continuum radiative fluxes in the wavelength range studied for different abundances of Si.

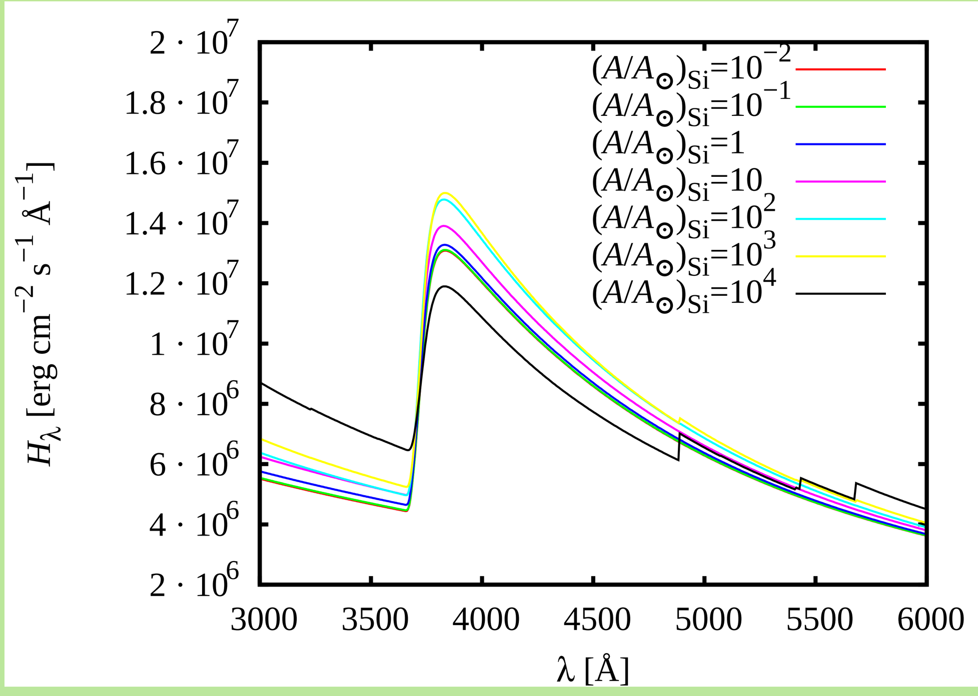


**Fig.** Continuum radiative flux for different abundances of Si

For the solar silicon abundance $(A/A_\odot)_{\rm Si} = 1$ model atmosphere the optical radiative flux is dominated by the Balmer jump and Paschen continuum. With increasing Si abundance the radiative flux in the wavelength domain studied increases. This is caused mainly by the photoionization of Si I from the ground and first excited levels which increases opacity in the UV region. The absorbed UV energy is then redistributed into near UV and optical regions. However, with increasing silicon overabundance the situation changes. The atmosphere becomes silicon dominated and the importance of hydrogen Balmer jump diminishes. Consequently, for the highest silicon abundances the emergent spectrum is given also by silicon bound-free transitions and jumps due to the photoionization of different Si levels occur.

The nature of influence of the eventual variation of Si abundances on the photometric variability can be well demonstrated by the ratio of radiative fluxes of the model with the Si abundance $A$ versus the fluxes of the model with solar abundance expressed in magnitudes (see following figure). We compared the model fluxes smoothed by the gaussian filter with a width $\sigma = 120$ Å.

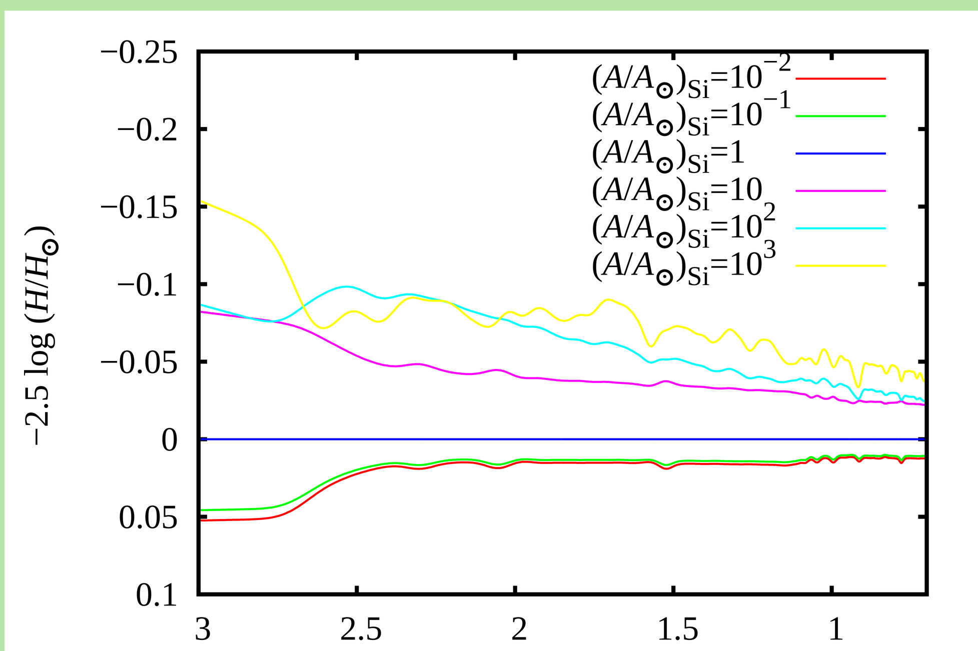


**Fig.** Smoothed ratio of radiative fluxes of the models with selected abundance relatively to the flux of the model with solar composition expressed in magnitudes

The advantage of this diagram is that the photometric variations can be easily deduced from it. As has been discussed in the previous paragraphs, the flux variations are dominated by the redistribution of the flux from the short-wavelength side of the spectrum to longer wavelengths due to the bound-free transitions. Hence, for lower overabundances the radiative flux increases in the displayed region and consequently the star is brighter in photometric colors. Apparently, the relative brightness increase is higher for shorter wavelengths, what is in accordance with the reality. However, for higher overabundances the star becomes silicon dominated and the photometric variations are more complicated. Anyway, it is remarkable that significant variations of observed magnitudes occur already for a relatively small departures from solar chemical composition.

For other elements than silicon the situation is similar. Detailed photometric variations are given mainly by the magnitude of bound-free cross-section of individual levels of ions and by the location of level ionization thresholds which are manifested in the occurrence of jumps.

## *uvby* variations

Abundance variations discussed in the previous section may cause photometric variations. Again, because the spectroscopic variations due to the elements studied are given mainly by the variations of bound-free absorption, the photometric variations can be also explained by the variations of bound-free absorption coefficient.

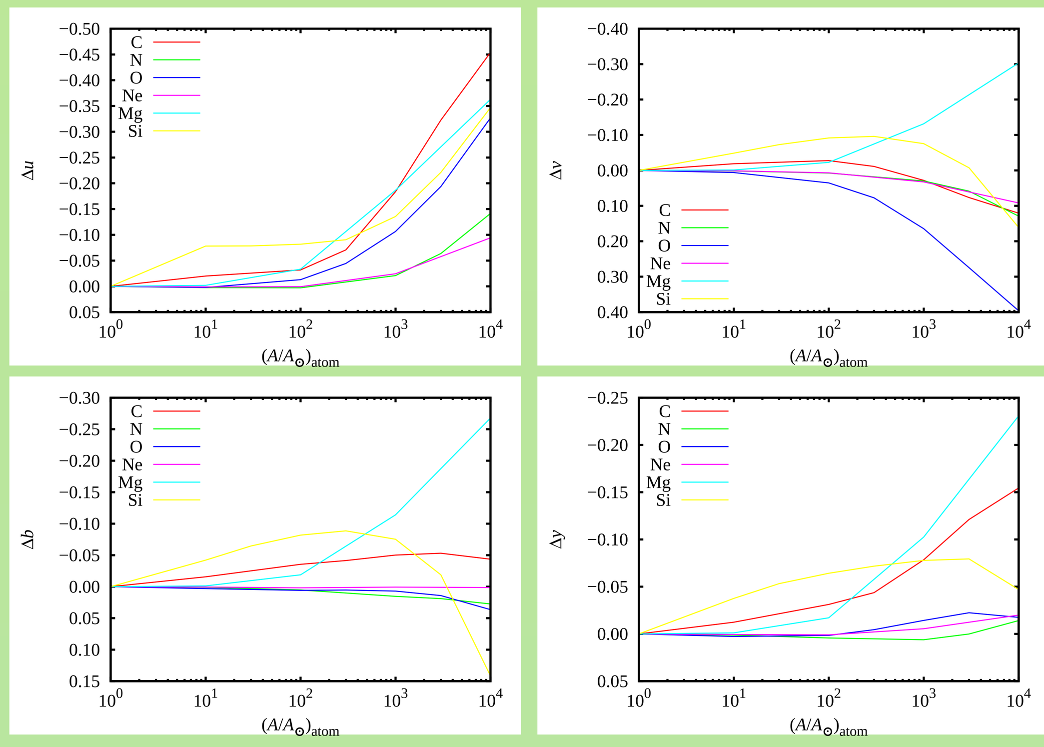

**Fig.** Photometric variations due to the different abundances

The photometric variations are dominated mainly by the discussed redistribution of radiative flux from the short-wavelength side of UV domain to near UV and optical domains and by the occurrence of jumps due to the different bound-free transitions of elements studied.

## Conclusions

We have shown that the theoretical spectral energy distribution significantly depends on the elemental abundances. Contrary to the common belief that flux and photometric variations are caused mainly by the line transitions we have shown that these variations are given mainly by bound-free transitions (at least for elements studied). For slightly increased elemental abundances the variations are dominated by the redistribution of flux from the short-wavelength side of UV domain to the near UV domain and optical domains. For very high overabundances the spectral energy distribution becomes dominated by the overabundant element and changes even more significantly.

Although our models are very simplified, since inclusion of further elements is necessary, it seems to be plausible that photometric variability of some CP stars (at least those with Si overabundance) might be explained by the deviations from solar chemical composition. The typical amplitude of photometric variability is of order several hundredths of magnitude. Taking into account that the spectroscopic spots occupy only a part of the stellar surface, already reasonable overabundance of individual elements (of order 10–100, especially that of silicon) may cause observed light variability.

The more detailed study of the problem will be published elsewhere.


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