# Si II autoionization and Fe II lines in the atmosphere of Bp star

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**Abstract.** The role of Si II autoionization lines around the $\lambda$520 nm depression is investigated using the curve of growth approach. While absorption of the Fe II ion decreases with increasing temperature, the absorption of the Si ion increases. However, absorption of the singly ionized Fe is still dominant in the depression. This is confirmed by consistent computations of synthetic spectra. The effect of atmosphere stratification in optical depths of silicon does not enhance the absorption in $\lambda$520 nm dominantly.

## 1. Introduction

About a decade ago Si II autoionization lines were considered as a possible explanation of continuum depressions observed in the spectra of a number of Ap stars. If the silicon abundance is enhanced to 100 times the solar abundance, it is possible to interpret the absorption observed at $\lambda$140 nm and partly at $\lambda$420 nm but not the continuum depression at $\lambda$520 nm. Adelman (1975) in his detailed spectrophotometric investigations and comparison of previous studies of normal and peculiar A stars observed that the presence of the $\lambda$420, 520, 630 nm broad continuum features was a quite common phenomenon in Ap stars. He found that of the peculiar A stars examined 58 per cent displayed the $\lambda$520 nm depression. If necessary, this statistics can be up-dated by the most recent research data,however, no comprehensive explanation of the $\lambda$520 nm feature has been reported yet.

An inconclusive explanation of the $\lambda$420 nm feature was given by Adelman and Wolken (1976) as due to Eu II bound-free discontinuities. In this contribution we will reexamine the role of the Si ion in the $\lambda$520 nm depression on the basis of synthetic spectra.

The depression is known to become more pronounced with increasing temperature. As concerns its variability with time, it was found in some cases to

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be roughly stable at central depths and halfwidths (e.g. HD 125248). However, the spectrophotometry of $\alpha^2$ CVn (Cohen 1970) indicates the variability of the depression.

## 2. Curve-of-growth approach

Maitzen and Muthsam (1980) found good agreement between the synthetic and observed spectra at $\lambda$520 nm for low temperatures ( 8000 K). At higher temperatures, while the $\lambda$520 nm feature is enhanced, the model depression decreases. They concluded that iron overabundance can be considered the main contributor to the opacity for cooler Ap stars, and that another source was needed to explain the growth of the feature toward higher temperatures.

In this section we shall attempt to estimate the contribution of Si II (normal and autoionization) and Fe II lines into the depression on the basis of classical curve-of-growth method (Mihalas 1978). Physically, the ratio of line and continuum opacities depends slightly on depth in the atmosphere of star. The total equivalent widths were determined for a set of Kurucz's (1979) LTE model atmospheres with $T_{eff}$ = 12000, 14000 and 15000 K and $log\ g = 2$ (SI). The value 14 000 K roughly corresponds to the one estimated for HD 34452 from the agreement between the observed UBV values and the synthetic flux distribution. This star's $\lambda$520 nm depression is well defined and can not be explained by line blocking.

While the Fe II absorption decreases with increasing temperature, both the Si II normal and autoionization line absorption increase. However, the increase of Si II absorption only amounts to a few percent, and the decisive impact on the depression is still due to the Fe II ion. The Fe II absorption behaviour is dominant mainly at 200-250 nm and 520 nm. If the stellar atmosphere is of typical peculiar composition (Muthsam 1979), the absorption of the Fe II ion increases in these wavelengths by a factor 0.8 and 4.0 respectively. The Kurucz and Peytremann (1975) line list was used these purposes. Si II autoionization lines were taken from Artru et al. (1981).

## 3. Atmosphere stratification - Equilibrium state of diffusion processes

The stratification of atmospheres of Ap stars is considered to occur as a consequence of the accumulation of atoms which could originate as a result of diffusive processes controlled by the radiative acceleration of atoms (e.g. Michaud 1970), To obtain a more realistic synthetic spectrum in the $\lambda$520 nm region, one should know the real stratification of the elements. The calculations of the depth- and time-dependent abundances is not easy. The atmospheric quantities used are known within an accuracy of a few percent, characteristic time of such processes is $10^3$ years and typical diffusion velosities are $\sim 0.01 m/s$. Perhaps the easier way would be finding a final state when balance would exist (it is no inevitable). Alecian and Artru (1988) calculated the stratification of Ga under the assumption of zero diffusion velocities everywhere. However, a more general equilibrium state can be reached, i.e. fluxes of particles of a certain element are constant in time and depth.

$$const. = \sum_i n_i(r)v_i(r) \tag{1}$$

where $n_i$ is the number density of ion $-i$, $v_i$ is its diffusion velocity, summation takes place over all important ions at depth $-r$. We can choose *const.* as the flux of the element at the bottom of the atmosphere with two free parameters, $n, \frac{\partial n}{\partial r}$. Including the diffusion equation (see Aller and Chapman, 1960) one can write (hereinafter all quantities are depth-dependent):

$$const. = \sum_i n_i D_i \Big[ -(1+\frac{D_T}{D_i})\frac{1}{c_i}\frac{\partial c_i}{\partial r} + \underbrace{+\frac{2W - Z_i - 1}{p}\frac{\partial p}{\partial r} + \frac{2.54Z_i^2 + 0.805(W - Z_i)}{T}\frac{\partial T}{\partial r}}_{TP_i} + \frac{m}{kT}g_i^{rad}(c_i)\Big] \tag{2}$$

where $c_i, W, Z_i, p, k, T, g_i^{rad}$ are the ion abundance, atom mass, the ion charge, presure, Boltzman constant, temperature and radiative acceleration of the ion respectively. The term $(1 + \frac{D_T}{D_i})$ takes into account turbulence, $D_T, D_i$ are turbulent and ion diffusion coefficients. After several simplifications, the equation for the element abundance $-c$ reads

$$\frac{\partial c}{\partial r} + c\underbrace{\frac{\sum_i (D_i + D_T)\frac{\partial f_i}{\partial r} - f_i D_i (TP_i + \frac{m}{kT}g_i^{rad}(c_i))}{\sum_i (D_i + D_T) f_i}}_{\alpha(c)} + \underbrace{\frac{const.}{n_H \sum_i (D_i + D_T) f_i}}_{\beta} = 0 \tag{3}$$

where $f_i = \frac{n_i}{n}$ ; $n, n_H$ are element and all atoms number densities. In a case where there are no saturated lines of the element, equation (3) can be simplified further because the abundance is independent of $g_i^{rad}$ and

$$\frac{\partial c(r)}{\partial r} + c(r)\alpha(r) + \beta(r) = 0 \tag{4}$$

The saturation effects can also be taken into account (Alecian and Grappin,1984) (or as results from the shape of the curve of growth) as $g_i^{rad} = g_{0i}^{rad}(1 + \frac{c}{c_{0i}})^{-\frac{1}{2}}$ ; $c_{0i}$ is the saturation abundance for the ion, $g_{0i}^{rad}$ is the radiative acceleration in unsaturated case.
However, the stability of the solution of these equations is very sensitive to the

atomic data, turbulence, model atmosphere.

## 4. Synthetic spectra

Fully consistent computations for an LTE model atmosphere with $T_{eff} = 14000K$ and *log g* = 2 (SI) are performed in this section. We used Hubeny's (1987) modified SYNSPEC code allowing to compute synthetic spectra under the assumption of a plane-parallel atmosphere with no macroscopic velocity fields and incident radiation. The synthetic spectra were computed in the wavelength interval $\lambda 500 - 570$ nm. In the first run the synthetic spectrum was computed with solar abundances, in the second run with abundances used in the model denoted "AB" in Muthsam's (1979) paper. These abundances are typical for an Ap star. In the third run the Fe,Si,Ca,Mn and Ni were considered stratified. Since the solution of the above mentioned equations is not known exactly, we put the elemental abundances around and beyond the optical depth equals to 1, to be 3 times larger than in the layers above ( AB abundances in Muthsam's 1979 paper) since we tried roughly to evaluate the influence of atmosphere stratification. The computations based on slight different stratification can be found in Zboril and Budaj (1992). Fig 1 gives the synthetic spectra computed in all runs.

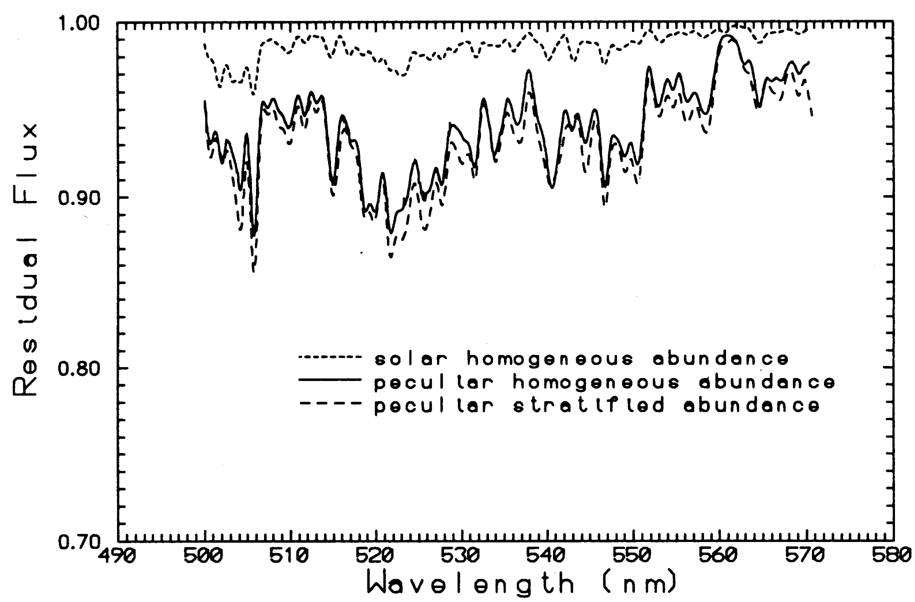


**Figure 1.** Synthetic spectra around 520 nm depression

## 5. Conclusions

The result of the curve-of-growth approach is the prominent absorption of the Fe II ion around $\lambda$520 nm under the assumption of a peculiar stellar atmosphere (i.e. with nonsolar abundances). Fully consistent computed synthetic spectra with Si II autoionization lines are unable to explain the depression as well as the stratification constructed by us was not found to be significant. Absorption due to the singly ionized Fe is still more decisive in comparison with Si. In considering the consistent computation of atmospheric stratification no optimal solution can be found at present and is a subject of subsequent investigations. To improve the procedure applied further steps should be taken: 1. Compute the synthetic spectra using the up-dated iron-peak and Si II autoionization line list 2. Find the solution describing the real atmospheric stratification (if present) 3. Deal with the correlation of He I line intensities and the variability of the $\lambda$520 nm, the case of HD 34452 (Shylaja and Babu 1986). 4.Deal with model atmosphere for CP stars with different $T-\tau$ relation.

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