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The light variations of HD 37776 as a result of the uneven surface distribution of helium and silicon

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Abstract.
We calculate the *uvby* light curves of the helium-strong chemically peculiar (CP) star HD 37776. Assuming that the chemical peculiarity influences the monochromatic radiative flux due to mainly the bound-free processes and using the model of the surface distribution of helium and silicon on HD 37776, as derived from spectroscopy, we calculate the emergent fluxes for a series of its rotational phases. We show that it is possible to consistently simulate light curves of a chemically peculiar star and that the basic properties of variability of helium CP stars can be understood in terms of the model of spots with a peculiar chemical composition.

Key words: stars: chemically peculiar – stars: early-type – stars: variables: other – stars: atmospheres

1 Introduction

The periodic light variations are a common feature among the magnetic CP stars. It is believed that most of these variations are caused by the rotational modulation of the observed radiative flux due to spots of a different peculiar chemical composition present on the stellar surface. In Krtička et al. (2004) we investigated the effect of the uneven surface distribution of helium on the monochromatic emergent flux and showed that the distribution of the flux may be changed by the bound-free processes. In this work we calculate the light curves of the helium-strong CP star HD 37776 using the spectroscopically derived surface distribution of helium and silicon by Khokhlova et al. (2000). To study the influence of the chemical peculiarity on the observed light variability besides helium, we selected silicon as: (i) it is overabundant for a large group of chemically peculiar stars that show light variations (e.g., Si, He-weak, and He-strong stars), and these stars form a photometrically homogeneous group; (ii) a large overabundance of silicon is observed on the HD 37776 surface.

2 Atmosphere models of HD 37776

Given the map of the helium and silicon surface distribution, we computed the emergent flux for every surface element, sized $1^\circ \times 1^\circ$, and then integrated over all visible surface. The fluxes were computed using SYNSPEC, the code for spectrum synthesis, for 8×10 LTE models computed with TLUSTY (Hubeny & Lanz 1995) for different silicon and helium abundance from the grid $[\mathrm{Si/H}] = -3, -2, -1, 0, 1, 2, 2.5, 3$ and $[\mathrm{He/H}] = -5, -4, -3, -2, -1, 0, 1, 2, 2.5, 3$ to cover the extent of values given by Khokhlova et al. (2000). The effective temperature T_{eff} and surface gravity $\log g$ of the models are the same (see Tab. 1). The atomic species and the number of their energy levels included in the model atmosphere calculations are listed in Tab. 2.

Table 1: Parameters of HD 37776

T_{eff}	22 000 K	Groote & Kaufmann(1982)
$\log g$	4.0	Groote & Kaufmann(1982)
inclination i	45°	Khokhlova et al. (2000)
spots parameters		Khokhlova et al. (2000)

Table 2: The atomic species and the number of their energy levels included in the model atmosphere calculations

Ion	Levels	Ion	Levels	Ion	Levels	Ion	Levels
H I	9	N I	21	Ne I	15	Si II	40
H II	1	N II	26	Ne II	15	Si III	30
He I	24	N III	32	Ne III	14	Si IV	23
He II	20	N IV	1	Ne IV	1	Si V	1
He III	1	O I	12	Mg I	13	S II	14
C I	26	O II	13	Mg II	14	S III	10
C II	14	O III	29	Mg III	14	S IV	15
C III	12	O IV	1	Mg IV	1	S V	1
C IV	1						

We calculate the flux from the model atmosphere for given silicon and helium abundances $H(\lambda, [\text{He/H}], [\text{Si/H}])$. The flux $H_c([\text{He/H}], [\text{Si/H}])$ in the color c is obtained as a convolution of $H(\lambda, [\text{He/H}],[\text{Si/H}])$ with a Gauss profile peaked at the central wavelength of the color λ_c, with dispersion σ_c. The radiative flux in the color c from individual surface elements $H_c(\Omega)$ (Ω are spherical coordinates on the stellar surface) is obtained by interpolation of fluxes from the model grid. Finally, the total observed radiative flux is calculated as the integral over all the visible surface elements

$$H_c = \int H_c(\Omega)\, u(\theta) \cos\theta \,\mathrm{d}\Omega \qquad (1)$$

(θ is the angle between the normal to the surface element and the line of sight, and $u(\theta)$ describes the adopted linear limb darkening) and the observed magnitude difference is then

$$\Delta m_c = -2.5 \log \left(\frac{H_c}{H_c^{\text{ref}}} \right), \qquad (2)$$

where H_c^{ref} is a reference flux. This was performed for 36 rotational phases (some of them are shown in Fig. 2).

3 The origin of light variations

The plot of the radiative flux calculated for different values of the silicon abundance (Fig. 1) shows that the stellar surface in silicon rich regions is brighter in the *uvby* colors than in the silicon poor

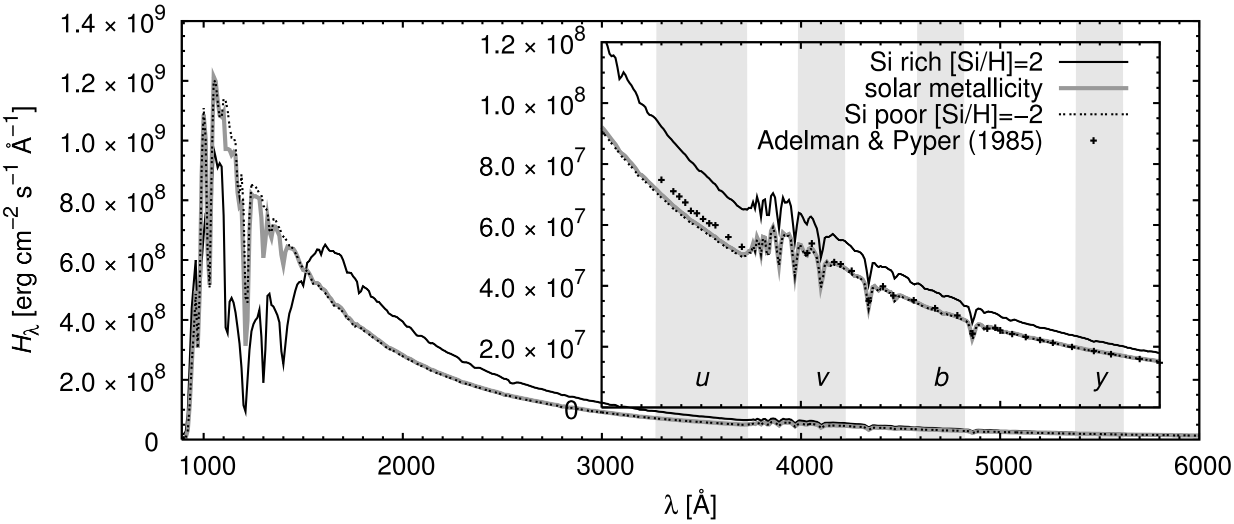

Figure 1: The radiative fluxes from the HD 37776 atmosphere calculated with different silicon abundances and the observed averaged dereddened flux distribution according to Adelman & Pyper (1985). The radiative flux was smoothed to better demonstrate the light separation. In the *uvby* colors, the silicon spots are evidently brighter than the regions with low silicon abundance. Silicon abundances lower than the solar do not significantly change the radiative flux.

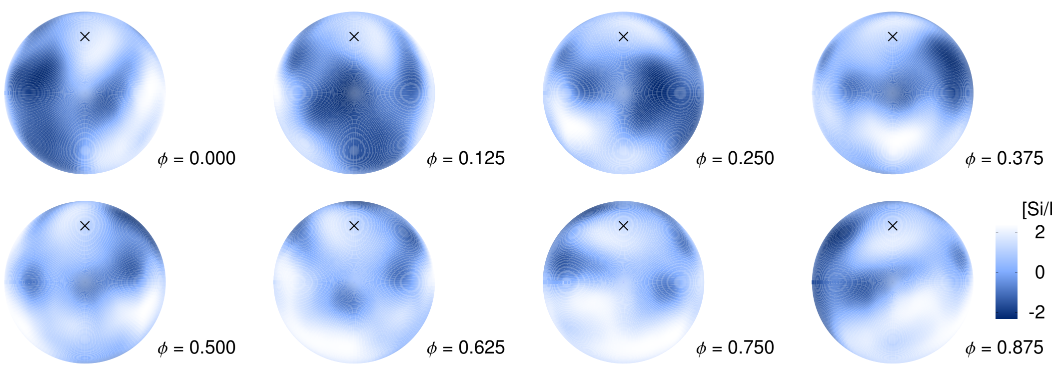

Figure 2: Variation of the silicon abundance on the surface of HD 37776 derived from spectroscopy by Khokhlova et al. (2000), smoothed for different rotational phases. The Si overabundant regions are bright on the stellar surface (see Fig. 1) and white on the graph; the Si underabundant regions are dark on the stellar surface and blue (dark) on the graph.

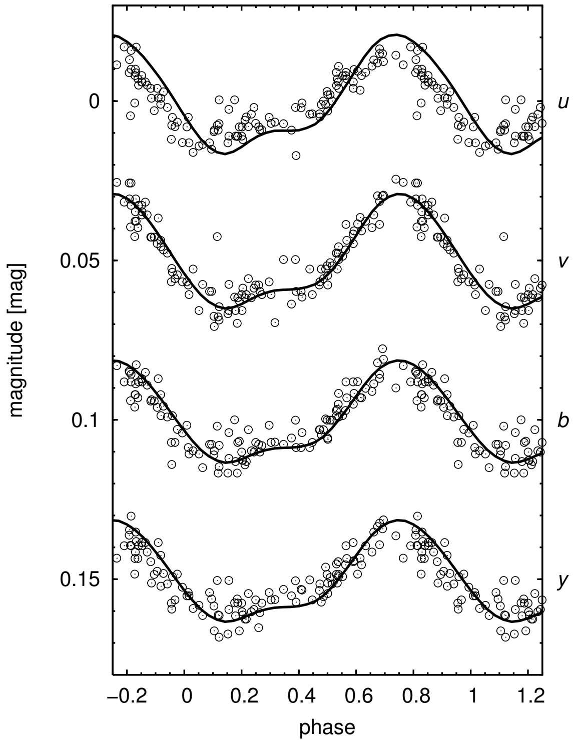

Figure 3: The predicted light variations of HD 37776 calculated using the silicon and helium surface distribution after Khokhlova et al. (2000) and compared with the observed ones (empty circles).

ones. The increase of the flux in the optical domain is caused by the flux redistribution from the far UV region mainly due to the enhanced silicon bound-free absorption.

4 Elemental surface distribution

At different rotational phases, surface elements with different silicon abundance are seen on the stellar disc. During the light maximum around the phase $\phi = 0.75$ (see also Fig. 3) the Si rich regions are seen, which have large flux in the *uvby* (see Fig. 1). During the light minimum around the phase $\phi = 0.1$ the Si poor regions are seen on the stellar disc, which have lower flux in the *uvby*.

5 Predicted light variations

Due to the uneven surface distribution of silicon (and partly also due to helium) the emergent monochromatic flux varies with the location on the visible disc. As shown in Fig. 1, the Si rich regions are brighter in the *uvby* colors (the brightness temperature is higher), whereas Si poor regions are darker.

Using the model atmosphere fluxes derived for the different helium and silicon abundances, we calculated the theoretical light curves (see Fig. 3) and compared them with the observed ones. The observed light variations can be explained as alternation of the emergent flux due to the uneven surface distribution of silicon and helium.

6 Conclusions

We are able to simulate the light variations of the He-strong CP star HD 37776 assuming that the light variations are due to the uneven surface distribution of silicon and helium. The silicon and helium spots modify the emergent flux mainly due to bound-free transitions. The predicted light curves reproduce the observed ones very well in their overall shape and amplitude. We stress that the theoretical light curves were obtained from the spectroscopical silicon surface distribution without using any free parameter. We were able for the first time (to our knowledge) to simulate the light curve of a CP star. Due to the satisfactorily good agreement between the observed and predicted light variations, we conclude that this modelling is a very promising way towards the explanation of the light variations of chemically peculiar stars.

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