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The nature of light variations in magnetic hot stars

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Abstract. Magnetic stars show several types of light variability which is modulated by the stellar rotation. In chemically peculiar stars, the redistribution of the flux in the surface regions with peculiar chemical composition leads to the light variability with a typical amplitude of the order of hundredths of magnitude. The most efficient processes that cause the flux redistribution are bound-bound (line) transitions of iron and bound-free (ionization) transitions of silicon. This type of light variability typically leads to a complex dependence of the amplitude on the wavelength and shows antiphase light curves in the far ultraviolet and visual regions. In hot magnetic stars, the modulation of the stellar wind by the magnetic field and the wind blanketing cause the light variability with a typical amplitude of the order of millimagnitudes. We predict the light variations in selected magnetic hot stars and compare the simulated light curves with light variations derived from observations.

Key words: stars: chemically peculiar – stars: early type – stars: variables – stars: winds, outflows – stars: mass-loss

1. Introduction

Rotational light variability of magnetic chemically peculiar stars is caused by inhomogeneous surface distribution of individual elements. The abundance inhomogeneities lead to the spatial variations of opacity due to bound-free (Peterson, 1970; Lanz et al., 1996) and bound-bound (Wolff & Wolff, 1971) transitions. Because the opacities depend on wavelength, the surface abundance variations cause the flux redistribution and the light variability. Detailed abundance maps combined with advanced model atmospheres enable us to predict the flux variability and to understand the mechanism of the light variability in detail (Krtička et al., 2007, 2015; Prvák et al., 2015).

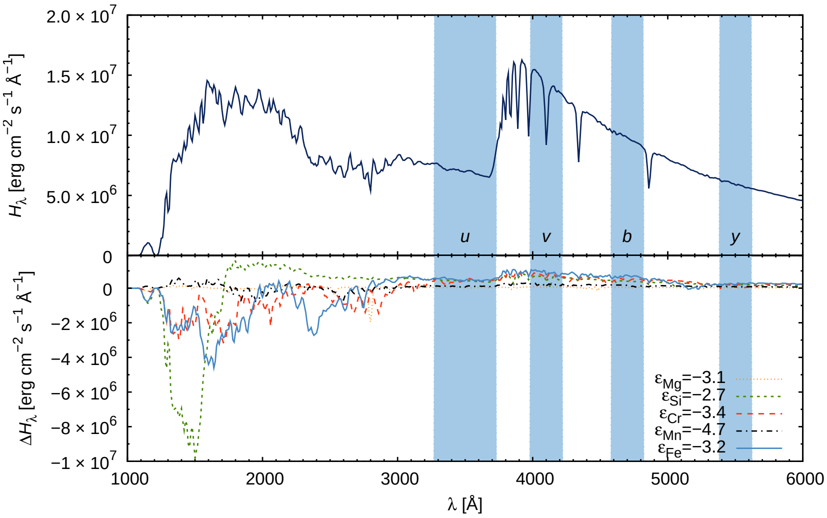

Figure 1. Influence of abundance variations on emergent flux. *Upper panel:* Emergent flux for the solar chemical comparison. *Lower panel:* Difference between the fluxes calculated for higher elemental abundances and the solar flux. The regions corresponding to the filters *uvby* of Strömgren photometric system are denoted in the graph.

2. Modelling of the flux variability

We assume constant effective temperature and surface gravity for the modelling of the flux. The abundance of individual elements $\{\epsilon_{\rm el}\}$ is taken from the Doppler maps. We calculate TLUSTY (Lanz & Hubeny, 2007) or ATLAS (Kurucz, 2005) model atmospheres with chemical composition from the maps and using the SYNSPEC code predict the specific intensities $I(\lambda, \theta, \{\epsilon_{\rm el}\})$. With the maps we therefore obtain the emergent intensities $I(\lambda, \theta, \Omega)$ as a function of the location on the stellar surface (with coordinates Ω). The specific intensities are integrated over the stellar surface to give the total phase-dependent emergent flux and magnitudes in individual photometric filters.

3. Chemically peculiar star θ Aur

For the modelling of chemically peculiar star θ Aur we used surface abundance maps of He, Si, Cr, and Fe derived from spectroscopy by Kuschnig (1998).

In the models with enhanced abundance, the flux is redistributed typically from far-UV region to the near-UV region and to the optical domain (Fig. 1). Consequently, the surface regions with enhanced abundance of heavier elements

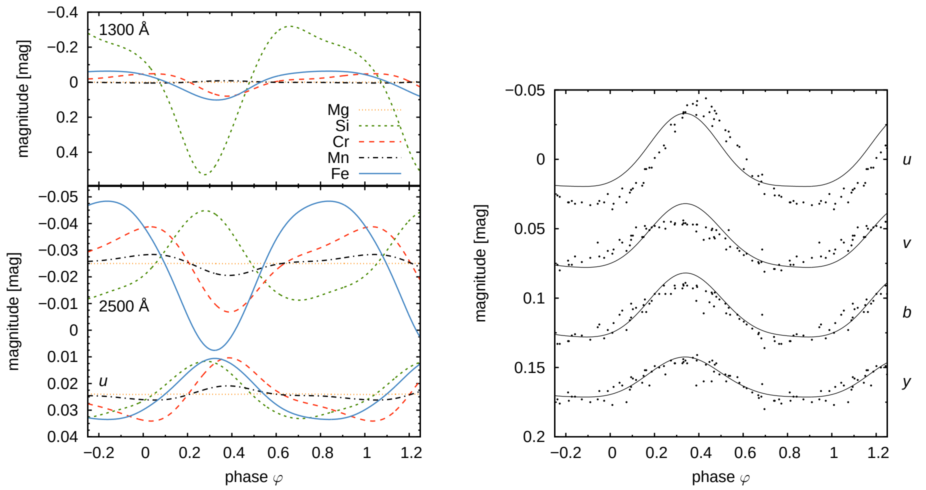

Figure 2. *Left*: Light variations of θ Aur in different wavelength regions calculated from the surface distribution of one element only. *Right:* Comparison of predicted light variations in the pass-bands of Strömgren photometric systems with observed variations (Adelman & Kaewkornmaung, 2005).

should be relatively bright in the optical region and relatively dark in the far-UV. This leads to the antiphase light curves in far-UV and in optical (see Fig. 2).

The predicted light variations due to individual elements (Fig. 2) show that mostly Si, Cr, and Fe contribute to the light variations of θ Aur (Krtička et al., 2015). Predicted and observed light variations nicely agree (Fig. 2). The remaining difference is likely caused by some missing element(s).

4. Chemically peculiar star a Cen

Modelling of the light variations of chemically peculiar star a Cen is based on He, N, O, Si, and Fe surface abundance maps derived from spectroscopy.

The modelling of the emergent flux and its variations nicely reproduces the UV flux and its variations observed by the IUE satellite (Fig. 3). Also the optical light curve observed by the BRITE satellite is nicely reproduced (Fig. 4).

5. Light variations due to wind blanketing in magnetic stars

Galactic O stars have strong winds that prevent the formation of surface layers with peculiar chemical composition. Therefore, we do not expect any rotationally modulated light variability in these stars. Despite this, Nazé (2004) found periodic light variations in magnetic O8fpe star HD 191612, which was

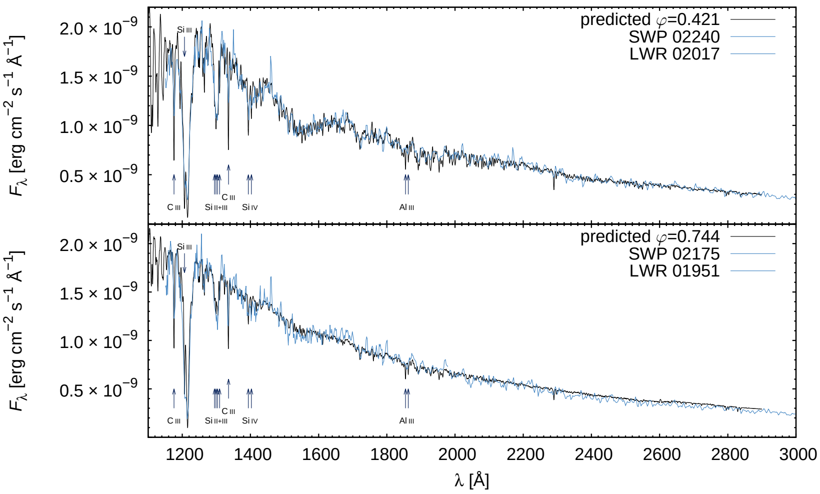

Figure 3. Comparison of predicted UV flux distribution of a Cen (black lines) with observed UV spectra (IUE, blue lines) for two rotational phases.

attributed to the light absorption in circumstellar magnetosphere (Wade et al., 2011).

In magnetic stars, the stellar wind is modulated by the magnetic field leading to the dependence of the wind mass-loss rate on the magnetic field tilt (Owocki & ud-Doula, 2004). This may cause additional light variability due to the wind blanketing, which scales with the wind mass-loss rate (Krtička, 2016). This effect explains part of the light variability of HD 191612 in Fig. 4.

6. Conclusions

Magnetic hot stars show several types of the light variability due to blanketing effects. In chemically peculiar stars, the rotational variability is caused by flux redistribution in the abundance spots due to bound-free (continuum, mainly He and Si) and bound-bound (lines, mainly Fe and Cr) transitions. In magnetic stars with winds, part of the light variability is caused by the wind blanketing modulated by the magnetic field.

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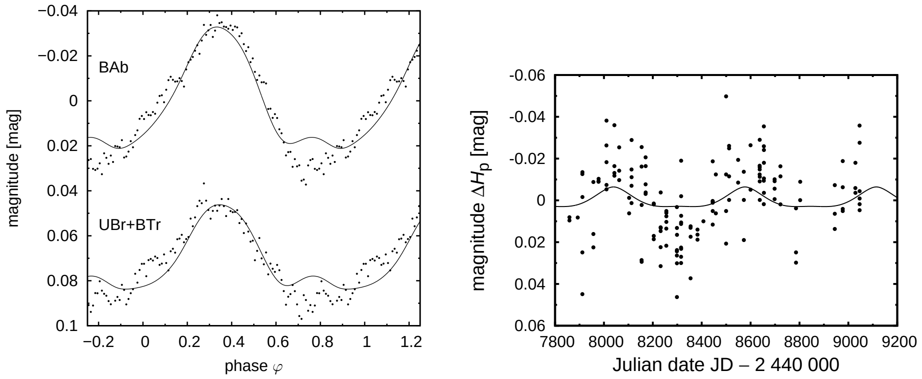

Figure 4. *Left*: Comparison of predicted optical light curve of a Cen with observations from BRITE satellite in the blue and red domains. *Right:* Light curve of HD 191612 due to wind blanketing in comparison with Hipparcos observations.

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