Light variability of white dwarfs and subdwarfs due to surface abundance spots

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Abstract

Classical main-sequence chemically peculiar stars show light variability that originates in surface abundance spots. In the spots, the flux redistribution due to line (bound-bound) and bound-free transitions is modulated by stellar rotation and leads to light variability. White dwarfs and hot subdwarfs may also have surface abundance spots either owing to the elemental diffusion or as a result of accretion of debris. We model the light variability of typical white dwarfs and hot subdwarfs that results from putative surface abundance spots. We show that the spots with radiatively supported iron overabundance may cause observable light variability of hot white dwarfs and subdwarfs. Accretion of debris material may lead to detectable light variability in warm white dwarfs. We apply our model to the helium star HD 144941 and conclude that the spot model is able to explain most of observed light variations of this star.

1 Motivation: Main-sequence Chemically Peculiar Stars

The current paradigm predicts that the photometric variability of main-sequence chemically peculiar stars is caused by the flux redistribution (blanketing) in surface abundance patches modulated by stellar rotation. The distribution of chemical elements over the surface of chemically peculiar stars is typically not uniform. The elements concentrate in vast persistent patches, partially governed by the magnetic field. The overabundance of elements leads to the flux redistribution from the far-UV to near-UV and visible domains due to the bound-bound (lines, mainly iron or chromium) and bound-free (ionization, mainly silicon and helium) transitions. Consequently, as a result of their rotation, CP stars show magnetic, spectral, and photometric variability (e.g., Krtička et al. 2012; Prvák et al. 2015).

The abundance anomalies in main-sequence chemically peculiar stars are caused by the radiative diffusion in quiet stellar atmospheres. The same processes can also be important in hot subdwarfs or in hot white dwarfs. Moreover, surface abundance spots in white dwarfs may be connected with the accretion of debris material. All these processes can lead to the photometric variability, which was detected in evolved compact stars (e.g., Dupuis et al. 2004; Kilic et al. 2013).

2 Model of Variability

We assume the existence of a spot with an overabundance of heavy elements on the stellar surface (Fig. 1). The spot has latitude $10^\circ \leq \vartheta \leq 70^\circ$ and longitude $180^\circ < \varphi < 270^\circ$. We model the influence of the spot on the emergent radiation using the TLUSTY code (Lanz & Hubeny, 2007).

Higher abundance of heavy elements causes stronger blocking of radiation in the UV. This leads to a redistribution of the radiative flux. Part of the redistributed flux appears in the optical region and causes brightening of the star, for example, in
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Figure 2: Emergent flux from model atmospheres with two different chemical compositions.

Figure 3: Calculated light curves of hot white dwarfs on the top of white dwarf cooling track.

Figure 4: Calculated light curves of hot white dwarf on the top of white dwarf cooling track with pure hydrogen atmosphere and solar metallicity spot.

Strömgren colours as shown in Fig. 2 for a hot white dwarf with $T_{\text{eff}} = 100231$ K and with overabundance of iron. The rotationally modulated brightening can be detected via optical photometry.

3 Hot White Dwarfs: Diffusion

For the calculation of light curves in Fig. 3 we assumed spots with an abundance of iron and silicon $10\times$ higher than the solar value. While the silicon spot does not cause any significant light variability, the iron spot leads to variability with amplitude of the order of 0.01 mag. Such variations could be easily detected from observations. The simulated light curves are nearly the same in all colours of the Strömgren photometric system. This happens because at such high temperatures the optical region lies in the Rayleigh-Jeans part of the flux distribution. Even stronger variability appears with solar metallicity spot on purely hydrogen surface mostly due to helium (Fig. 4).

4 Warm White Dwarfs: Accretion

The calculations of the light curves of a warm white dwarf assume a spot with a solar abundance of heavy elements while the rest of the surface is composed of pure hydrogen. Such a spot causes light variability with an amplitude of a few 0.01 mag, which decreases with increasing wavelength. These variations could be detected even from ground-based observations.

5 Hot Subdwarfs: Diffusion

For the calculation of light curves of a hot subdwarf we assumed spots with an abundance of iron and silicon $10\times$ higher than the solar value. The rest of the stellar surface has solar chemical composition. The silicon spot does not cause any significant light variability, whereas the iron spot causes light variability with an amplitude of the order of 0.01 mag. The variations due to the iron spot could be easily detected.

6 HD 144941: a test against reality

Jeffery & Ramsay (2018) attributed the light variability of helium star HD 144941 to surface spots. We
attempted to find a surface spot distribution that provides the best fit of the observed K2 light curve. We assumed maximum spot brightness variations of 7.5%. This can explain the main observed trends, while the remainder could be possibly caused by the light absorption in circumstellar clouds (Landstreet & Borra, 1978).

7 Conclusions

White dwarfs and hot subdwarfs may show rotationally modulated light variability due to flux redistribution in surface abundance spots. The spots may originate as a result of radiative diffusion in hot white dwarfs and subdwarfs or due to accretion in warm white dwarfs.

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