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NLTE Model Atmospheres of Irradiated Stars in B Binaries

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Abstract. Model atmospheres of B stars irradiated by their companion are calculated using our model atmosphere computer code under the assumption of hydrostatic, radiative, and statistical equilibrium (NLTE). The external source of radiation (a hot white dwarf) is able to change the temperature structure of the outer atmospheric layers of B stars significantly. The changes of the temperature structure cause changes in the profiles of some lines, especially in those of hydrogen.

1. Introduction

Mutual irradiation of stars in binaries may be an important mechanism of heating the stellar atmospheres for some combination of stellar parameters. Individual stars in a binary system absorb radiation that comes from the other star. However, if the incoming radiation is much fainter than the emergent radiation, the effect of incoming radiation is negligible and model atmospheres may be considered exactly the same as for single stars. However, it may happen that some stars are emitting such an amount of radiation that is able to change the atmospheric structure of the other star. An example is a binary consisting of a relatively cool star (e.g. of a B-type or even cooler) and a very hot star like a hot white dwarf.

Model atmospheres of irradiated components in binaries have been calculated by a number of authors. Reflection effects for model atmospheres of cool stars were calculated for convective grey model atmospheres by Vaz & Nordlund (1985) and for non-grey models by Nordlund & Vaz (1990). Irradiation of a secondary star in dwarf novae was studied by Brett & Smith (1993) using LTE model atmospheres. Illumination in symbiotic stars was studied by Proga et al. (1996, 1998) and Schwank et al. (1997). The irradiation effects were also studies by Mitskevich & Tsymbal (1992) and by Sakhibullin & Shimanski (1996, 1997). Recently, X-ray irradiation of accretion discs was studied by Dubus et al. (1999).

In this study we shall assume that the binary is non-interacting, that means that there is no exchange of matter between the stellar components.

2. Model of a B binary

Our binary model consists of a B type primary (of different spectral types) and of a hot white dwarf secondary.

Model atmospheres: Our model atmospheres were calculated using our own computer code ATA (Kubát 1994, 1996, 1997b). Our code enables calculation of both spherically symmetric and plane parallel NLTE model atmospheres, so we had to decide which approximation is better for our study of the irradiation effects. Spherically symmetric model atmospheres are more general than the plane parallel ones, since they enable to include the curvature of a star. But if we add some source of external irradiation that is able to change the atmospheric structure, we can hardly preserve the spherical symmetry. The atmospheric radial structure will be different for each surface point. Consequently, we are not able to describe the whole stellar surface using one unique spherically symmetric model. Some degree of spherical symmetry will be retained only for extremely rapidly rotating stars. Since the spherical symmetry has been lost in any case, it is more convenient to study the irradiation effects using the plane parallel approximation, which may better describe a segment of the atmosphere.

Model atmosphere of a white dwarf: As a model of the atmosphere of a hot white dwarf we took the full NLTE plane parallel pure hydrogen model atmosphere for $T_{\rm eff} = 100000$K, $\log g = 7.5$ and a typical white dwarf mass of $0.6 M_\odot$ (i.e. radius $0.02 R_\odot$), which was published in Kubát (1997a).

Model atmosphere of a B star: The atmospheres of the B stars are represented as plane parallel NLTE pure hydrogen models with all lines considered. In order to study the effect of irradiation on different spectral subtypes, we used calculated irradiated models for several different spectral subtypes, namely B1, B3, B5, and B7. Corresponding values of $T_{\rm eff}$ and $\log g$ were taken from Harmanec (1988). These atmospheres were irradiated by a hot white dwarf at five different distances. The latter were taken as $20 M_\odot$ (i.e. the dilution factor $W = 10^{-6}$), $63 M_\odot$ ($W = 10^{-7}$), $200 M_\odot$ ($W = 10^{-8}$), $632 M_\odot$ ($W = 10^{-9}$), $2000 M_\odot$ ($W = 10^{-10}$).

3. Results

Results of our calculations are shown in Fig.1. The emergent spectrum was calculated using the computer code SYNSPEC (developed by I. Hubeny). Results may be summarized as follows.

- Irradiation affects *outer layers* of our model atmospheres. Large heating is found for later B model atmospheres (B7), almost negligible heating is found for earlier B model atmospheres (B1). The reason is the absorption in hydrogen Lyman continuum. At the depth of formation of the Lyman continuum temperature approaches the value for the non-irradiated atmosphere.

- The weak effect for earlier B stars is caused by the low abundance of neutral hydrogen (high ionization). High abundance of H I in later B stars causes large heating and results in temperatures much higher than for the earlier stars.

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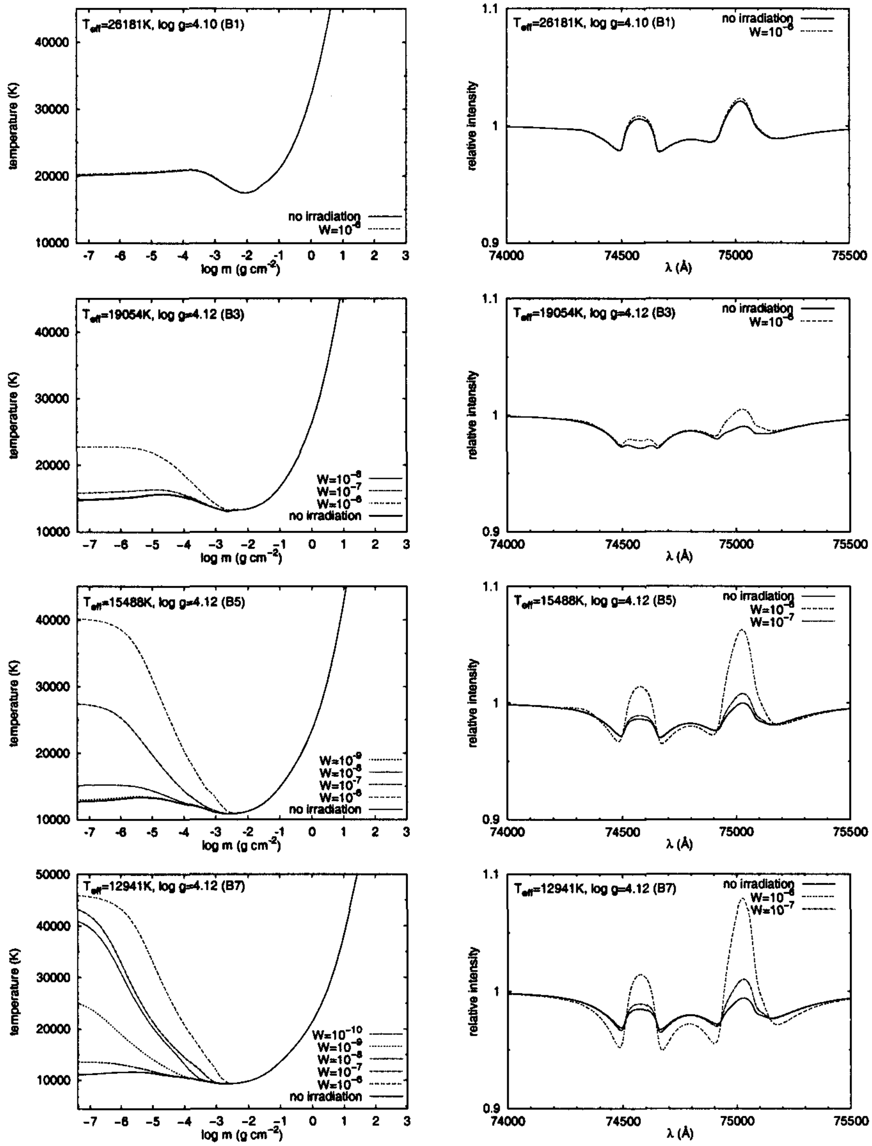

Figure 1. Temperature structure and the profile of the blend of infrared hydrogen lines near 7.5μm (5-6, 6-8, 7-11, 8-17) for the irradiated pure hydrogen NLTE model stellar atmospheres.

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- Infrared lines forming *at the same atmospheric depths* as the Lyman continuum are affected by higher temperature in the outer layers. As an example, a blend of hydrogen lines near $7.5\mu m$ ($5-6$, $6-8$, $7-11$, $8-17$) is plotted in Fig.1. We can see large emission caused by high outer temperature for cooler models.

On the other hand, test calculations of mutual irradiation of two identical B1 stars did not show any effect.

4. Conclusions

Although our calculations are done for an extremely simplified case of a pure hydrogen atmosphere, the results have wider impact. The large heating for later B stars is caused by the absorption in hydrogen Lyman continuum. Similar heating will be present in any atmosphere where an intense radiation (e.g. in UV) meets large absorption caused either by neutral hydrogen or by line blanketing, or by both.

The heating of the outer layers of a stellar atmosphere in a binary system is influenced by two important factors. First, of course, it is the amount of incoming radiation (that depends on the luminosity of the secondary star and on the distance between stars), and, second, it is the ability of the atmospheric matter to absorb the incoming radiation. The latter effect is the reason why cooler model atmospheres irradiated by the same amount of radiation as the hotter ones have higher temperatures in the outer layers.

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