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Pulsations of massive stars beyond TAMS: effects of mass loss, diffusion, overshooting

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Abstract. We present an influence of mass loss, element diffusion and convective overshooting on instability areas of SPBsg stars with masses of $13 - 18\,M_{\odot}$. Evolutionary phases before and after helium core ignition are considered. We discuss how these effects affect the structure of the blue loops and hence a coverage of instability areas.

Keywords. stars: early-type, stars: supergiants, stars: oscillations, stars: evolution

1. Introduction

The discovery of g-mode pulsations in B-type post main sequence star HD 163899 (B2 Ib/II; Klare & Neckel 1977; Schmidt & Carruthers 1996) has led to a new class of pulsating variables named Slowly Pulsating B-type supergiants (SPBsg; Saio *et al.* 2006). Despite efforts of a few different groups (Saio *et al.* 2006; Godart *et al.* 2009; Daszyńska-Daszkiewicz *et al.* 2013) these objects are still very poorly known. There is no agreement even on the evolutionary status of these stars and the formation and properties of the blue loops are one of the biggest uncertainties related to the precise determination of it. Here, we investigate the influence of element diffusion, mass loss and overshooting on emerging of the blue loops and the coverage of instability areas.

2. Theoretical models

The models with masses $M = 13 - 18\,M_{\odot}$ have been calculated with MESA evolution code (Paxton *et al.* 2011, 2013) and non-adiabatic pulsation code of Dziembowski (1977). We use OPAL opacity tables (Iglesias & Rogers 1996) computed for the AGSS09 mixture (Asplund *et al.* 2009). Ledoux criterion for convective instability and exponential model of overshooting (Herwig 2000) are used. Pulsation calculations cover spherical harmonic degrees $\ell = 0, 1, 2$. All effects of rotation are neglected. We use the mass-loss models by Vink *et al.* (2001) for $\log T_{\rm eff} > 4.0$ and de Jager *et al.* (1988) for $\log T_{\rm eff} < 4.0$. If element diffusion is applied, Burglers equations are solved with the method and diffusion coefficients of Thoul *et al.* (1994).

3. Instability areas

We calculated instability areas with various parameters. Inward overshooting from the outer convective zone on the RGB phase is included in all presented models because it appeared to be indispensable for the emergence of the blue loops in the studied range of stellar masses. In the left panel of Fig. 1 we depict reference models (OPAL tables, $Z = 0.015$) without mass loss and element diffusion. The central panel shows models with element diffusion and models with mass loss are depicted in the right panel. The instability areas on the blue loops have similar size for reference models and models

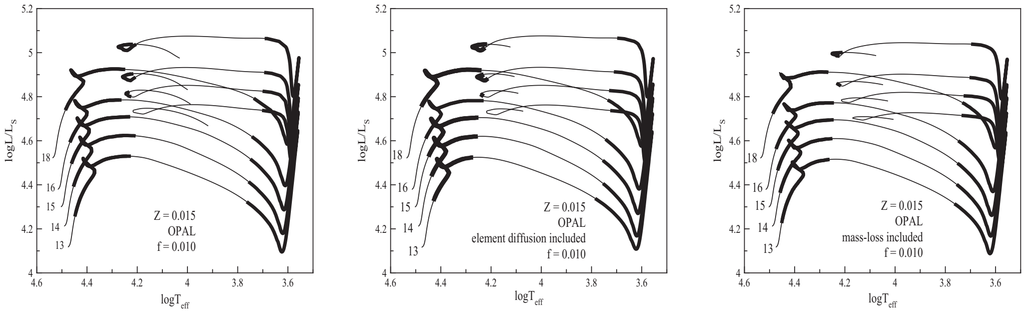

Figure 1. The HR diagrams with the evolutionary tracks for masses $M = 13-18\,M_\odot$ calculated until the end of the core helium burning with OPAL tables and metallicity $Z = 0.015$. Instability areas are shown with thick lines. In the left panel reference models without additional effects are shown, the central panel shows models with element diffusion and the right panel – models with mass loss included.

with diffusion. The presence of mass loss leads to shrinking of the blue loop and hence to decreasing the instability area. The instability areas during hydrogen-shell burning phase are very similar for all three cases.

4. Conclusions

Overshooting, element diffusion and mass loss affect pulsations mainly through their influence on the blue loops. Their influence on the instability areas during hydrogen-shell burning phase is negligible. The most important effect is the inward overshooting from outer convective zone on the RGB phase because it is essential for the development of the blue loops in the studied models. The presence of mass loss leads to smaller or entirely vanishes the instability areas on the blue-loops whereas the effects of element diffusion on the blue loops and hence the shape of the instability strip are very small.

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