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Effects of diffusion in β Cephei stars

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Abstract

We investigate the effects of the radiatively-driven diffusion of Fe, C, N and O in β Cephei stellar models.

Computations

As suggested by Cox et al. (1992) and by Pamyatnykh et al. (2004), radiatively-driven diffusion and consequently the accumulation of iron affect the excitation of the pulsation modes of β Cephei stars, increasing the number of excited modes. We have shown in a previous study that the accumulation of iron occurs near the opacity bump (Bourge & Alecian 2006, Bourge et al. 2006) and that it excites several higher order radial pulsation modes. We present here the results of our latest fully evolutionary calculations.

We have computed a 10 $M_\odot$ stellar model with the initial mass fractions $X_0 = 0.7392$, $Z_0 = 0.0122$. We do not introduce overshooting but the helium convection zone is extended to the surface. The stellar model is evolved using CLES v.18.11 (Scuflaire 2005) modified to include radiative forces and mass loss. The diffusion velocities are computed by solving Burgers' equations (Burgers 1969). The radiative forces are computed using adapted routines and tables from OPCD v.2.1 (Seaton 2005). The mass loss is computed according to the theoretical formula of Vink et al. (2000, 2001), scaled down by 1 dex (see Puls et al. 2006).

During the main sequence phase of evolution, the local radiative accelerations on Fe are always higher than the local gravity (except in the central regions, where diffusion is insignificant). We can thus expect an accumulation of iron where the gradient of the radiative accelerations is positive (i.e. where $\log T \approx 6.2, 5.2$ and near the surface). Iron stratification results from the competition between microscopic diffusion (dominated by the radiative forces), convection and mass loss. During the main sequence, the mass loss increases by more than one order of magnitude ($\approx 5 \times 10^{-11}$ to 10^{-9} $M_\odot$/yr). On the first half of the main sequence, the radiative forces dominate and the accumulation of iron occurs in the iron convection zone (enhancement by a factor of about 2) and at the surface. When the central hydrogen mass fraction reaches 0.3, the mass loss starts to dominate and the iron overabundances decrease, to finally disappear at the TAMS. Our results show that for a 10 $M_\odot$ stellar model the introduction of microscopic diffusion including radiative forces and mass loss leads to a significant accumulation of iron in the metal opacity bump. As shown by Pamyatnykh et al. (2004), Bourge & Alecian 2006, Bourge et al. (2006) and Miglio et al. (2007), this leads to an increase of the range of excited frequencies and of the width of the instability strip. This could also provide an explanation for the existence of low metallicity β Cephei stars, as in the SMC and LMC (Pigulski et al. 2002, Kołaczkowski et al. 2006).

Similarly we also followed the evolution of the abundances of C, N, O. Near the surface, the radiative force on N is larger than the ones on C and O, and larger than the local gravity. This leads to a slight enrichment in nitrogen at the surface. Rotational mixing is usually used as an explanation for the N-enrichment observed in early B-type stars. Our results show that the radiative forces could also contribute to this N-enrichment, at least in the case of some β Cephei stars (see Morel et al. 2006, 2007, Morel & Aerts 2007), most of which are known to be slow rotators. Complete evolutionary calculations are still in progress.

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Clockwise from the left: Michael Bazot, Alfred Tillich, Mélanie Godart, Stéphane Charpinet, Christoffer Karoff, Pierre-Olivier Bourge and Marc-Antoine Dupret, with Suzanna Randall and Don Kurtz discussing in the background.