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2008 J. Phys.: Conf. Ser. 118 012055

(http://iopscience.iop.org/1742-6596/118/1/012055)

Effect of mass loss on the driving of g-modes in B supergiant stars

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Abstract. MOST has detected p and g-modes in the B supergiant star HD163899. Saio et al. (2006) have explained the driving of g-modes in a post main sequence star by the presence of a convective shell which prevents some modes from entering the damping radiative core.
We show that this scenario depends on the evolution of the star, with or without mass loss. If the mass loss rate is high enough, the convective shell disappears and all the g-modes are stable.

1. Introduction

Saio et al. 2006 have reported the detection of 48 frequencies in a B supergiant star, HD 163899. HD 163899 (B2Ib/II) was observed by the MOST satellite (Walker et al. 2003) in June 2005 during 37 days: the frequencies are lower or equal to 2.8 c/d with amplitudes of the order of the mmag. P and g-modes were detected.

The driving of g-mode pulsations in a post-main sequence star is especially challenging since a strong radiative damping occurs in the core. Indeed those stars present a very dense radiative core and therefore a large Brünt-Väisälä frequency in the central regions which leads to a strong radiative damping (Unno et al. 1989).

Nevertheless an intermediate convective shell could prevent some modes from entering the radiative damping core and, in this case, the κ-mechanism in the superficial layers is sufficient to excite some g-modes (Saio et al. 2006).

The presence of the intermediate convective zone (ICZ) drastically depends on the behaviour of the convective core during the main sequence (MS) phase of evolution. Indeed massive stars have a growing or slowly receding convective core during part of their MS evolution. Therefore a chemical composition discontinuity appears at the top of the convective core during MS and the zone becomes semi-convective ($\nabla_{\rm rad} \approx \nabla_{\rm ad}$). During the post-MS phase the radiative envelope of the star expands and cools down. Its opacity increases and the region which was semi-convective during MS easily becomes convective.

2. Effect of mass loss

When taking mass loss into account, the semi-convective zone tends to disappear during the MS evolution (Chiosi & Nasi 1974, Chiosi & Maeder 1986). Therefore a high enough mass loss rate should prevent the ICZ to form in the post-MS phase.

In order to check this we have computed sequences with and without mass loss (see the evolutionary tracks on Fig. 1). We chose a mass loss rate of $10^{-7}\mathrm{M}_\odot$/yr. This mass loss is

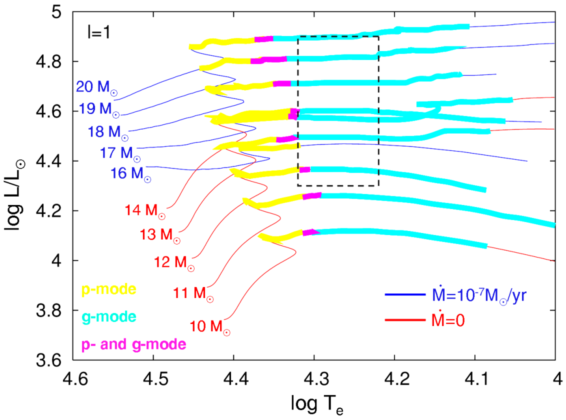

Figure 1. Evolutionary tracks for sequences computed with (blue) and without (red) mass loss. The excited p- and g-modes ($l = 1$) are shown in yellow and light blue respectively. Magenta modes represent both excited p- and g-modes. The dashed box stands for the error box of HD163899 (Saio et al. 2006).

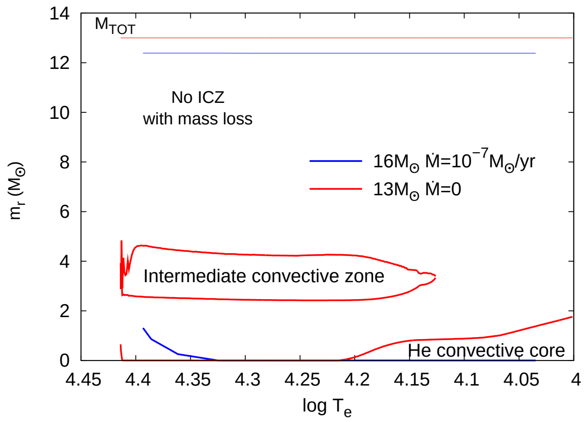

Figure 2. Evolution of the convective core and the ICZ in the post-MS phase for sequences computed with and without mass loss: 13M$_\odot$ with $\dot{M} = 0$ in red and 16M$_\odot$ with 10^{-7}M$_\odot$/yr in blue. Those sequences are approximately at the same location in the HR diagram. The thinner lines stand for the surfaces of both stars. No ICZ can be found in the star computed with mass loss.

of the order or slightly larger than the observed values (14M$_\odot$: 10^{-8}M$_\odot$/yr during MS and 10^{-7}M$_\odot$/yr after MS (Vink et al. 2001), although a recent analysis suggests that it could be overestimated by a factor 10 (Puls et al. 2006)). This however allows us to emphasize its effect on the ICZ and the driving of the modes. The excited p- and g-modes are shown on the different evolutionary tracks. Excited g-modes are present in all stars except for the sequences lower than 17M$_\odot$ computed with a mass loss of 10^{-7}M$_\odot$/yr: no excited g-modes can be observed if the introduced mass loss rate is high enough. To confirm the link to the presence or the absence of the ICZ, we show on Fig. 2 the evolution of the ICZ and of the helium convective core on the post-MS phase for a 13M$_\odot$ star computed without mass loss and a 16M$_\odot$ star with $\dot{\mathrm{M}} = 10^{-7}M_\odot$/yr. The star computed with mass loss does not present any ICZ: mass loss should therefore affect the driving of the modes.

3. Interpretation of the results

We analyzed 2 models in the post-MS stage ($\log \mathrm{T_e} = 4.26$), one computed with mass loss (16M$_\odot$, $\dot{\mathrm{M}} = 10^{-7}M_\odot$/yr, in blue) and the other one without mass loss (13M$_\odot$, $\dot{\mathrm{M}}$=0, in red).

In the model with mass loss, the Brünt-Väisälä frequency is very large in the whole radiative internal region since there is no ICZ (Fig. 3, blue). As a result, the mode eigenfunctions present very short wavelengths oscillations in all this region, with a high kinetic energy (Fig. 4). Therefore a strong radiative damping appears there, much more important than the κ-mechanism in the external regions. All g-modes are thus stable.

The model computed without mass loss has an ICZ, therefore the Brünt-Väisälä frequency is zero (slightly negative) in this region (Fig. 3, red). As a first result, some of the eigenfunctions have an increasing exponential behaviour towards the outer part of the star in the ICZ. Those modes are therefore reflected on the ICZ and their kinetic energy in the radiative core is much lower than in the radiative envelope (Fig. 4, red). As can be seen on Fig. 5 the radiative damping of the central regions is therefore much weaker. The κ-mechanism in the Fe opacity bump (at $\log \mathrm{T_e} \sim 5.3$) is therefore sufficient to excite some g-modes.

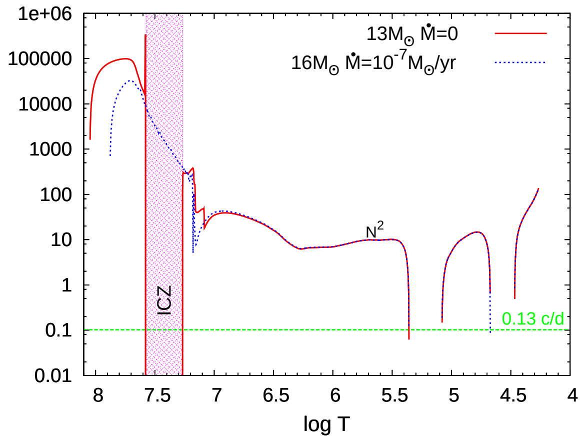

Figure 3. Dimensionless Brünt-Väisälä frequencies versus the effective temperature for the models computed with (blue) and without (red) mass loss. The ICZ presents in the model without mass loss is drawn in a magenta box.

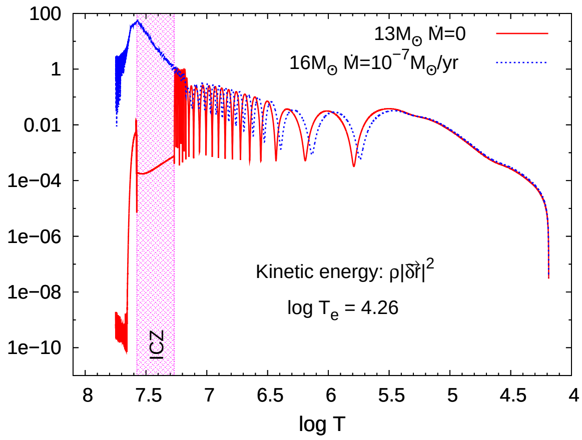

Figure 4. Kinetic energy for the mode frequency of 0.13 c/d. Unlike the blue mode (computed with mass loss) the red one is reflected on the ICZ. The ICZ of the model without mass loss is emphasized (magenta box).

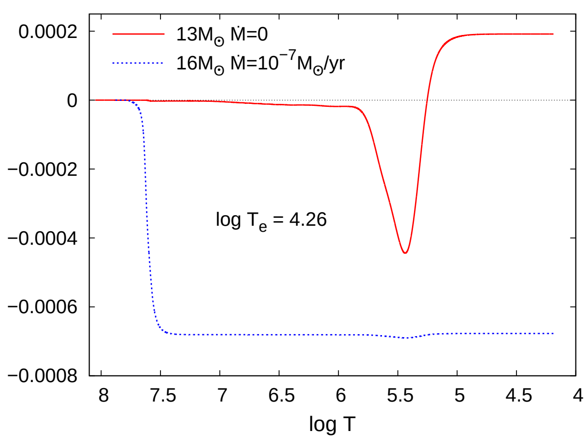

Figure 5. Work integral. The non-reflected mode (blue) is damped and the reflected one (red) is excited.

4. Conclusion

The existence of excited g-modes in B supergiants offers the possiblity to test the evolution of the internal structure of stars during the main sequence phase of evolution. Indeed the presence of an ICZ strongly depends on the evolution on the MS and, on the other hand, it is a necessary condition to excite g-modes. We have shown that mass loss (of the order of $10^{-7}M_{\odot}/yr$) can suppress the ICZ in a $16M_{\odot}$ star and therefore prevents the driving of the modes. Asteroseismology provides a new tool to constrain mass loss and more generally the evolution of massive stars.

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