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The ε-mechanism in PMS and MS δ Scuti stars

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Abstract

δ Scuti type stars are known to pulsate in nonradial low-order p and g modes. These oscillation modes are driven by the so-called κ-mechanism involving the second helium ionization zone. However, since g modes have significant amplitudes near the stellar core, their excitation might be influenced by the ε-mechanism which is associated to the nuclear energy production. We investigate the effect of the ε-mechanism on the stability of oscillation modes in 1.5 $\mathrm{M}_\odot$ pre-main sequence and main sequence stars.

1. Introduction

The production of nuclear energy in the center of the star contributes to the excitation of oscillation modes. This process is known as the ε-mechanism. The effects of this mechanism are generally small compared to the term of transfer which tends to damp the pulsations in these layers. We show the results obtained with the inclusion of the ε-mechanism in the code MAD (Dupret 2001, Grigahcène et al. 2005) used in Liège to compute the nonadiabatic corrections to the oscillation frequencies calculated for intermediate mass stellar models produced by the Code Liégois d'Evolution Stellaire CLES[1].

2. Pre-main sequence models

Though nuclear reactions become really efficient only during the main sequence, they are already present during the pre-main sequence phase. Actually, as soon as the temperature and density become sufficient, nuclear reactions occur in the inner parts of the star. Figure 1 draws the evolution track in the HR diagram of a 1.5 $\mathrm{M}_\odot$ star along its pre-main sequence phase. We can see that ^2H is burned in the center of the star during the Hayashi sequence while the central combustion of ^3He occurs before the structure readjustment due to hydrogen burning through the CNO cycle. Even if this energy production is not sufficient to contribute significantly to the stellar luminosity, it could influence the excitation of some pulsation modes.

Figure 2 represents the excitation of low to high order g modes of degree $l = 1$ in 1.5 $\mathrm{M}_\odot$ pre-main sequence models. We see that low-order g modes are affected by the nuclear reactions, particularly the mode (l_1,g_1). Table 1 gives the dimensionless damping coefficients with and without the ε-mechanism, $c_{d,\varepsilon}$ and c_d respectively, for the mode (l_1,g_1) at different moments during the pre-main sequence phase. A positive value of the damping coefficient means that the pulsation mode is not excited while a negative value indicates that the mode is unstable. At 1.22 Myr, the mode (l_1,g_1) is already excited without the inclusion of nuclear

[1] Details about CLES can be found at the following address: http://www.astro.ulg.ac.be/∼scuflair

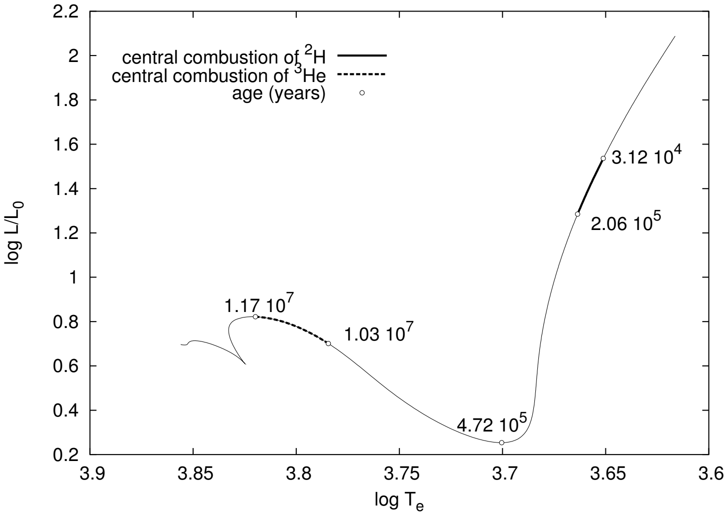

Figure 1: Evolutionary track of a star with $M = 1.5\ M_{\odot}$, $Z = 0.020$ and $\alpha_{ov} = 0.2$ during its pre-main sequence phase. The thick lines cover the models where ^2H and ^3He are burned in the centre of the star (solid and dashed lines respectively).

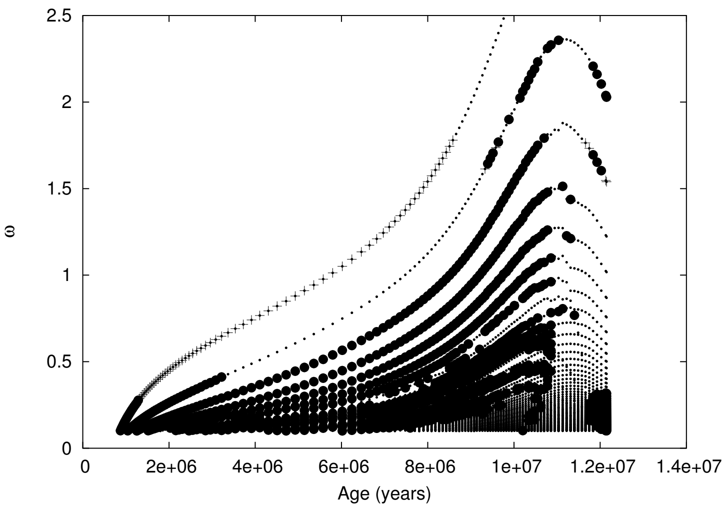

Figure 2: Dimensionless angular frequencies of degree $l = 1$ along the pre-main sequence. Small dots represent stable modes, filled circles correspond to excited modes without the ε-mechanism and plus signs correspond to additional excited modes when the ε-mechanism is taken into account.

Table 1: Dimensionless damping coefficients with and without the ε-mechanism, $c_{d,\varepsilon}$ and c_d respectively ($\Delta c_d = c_d - c_{d,\varepsilon}$), ω represents the dimensionless angular frequency.

	Age (Myr)	ω	c_d	$c_{d,\varepsilon}$	Δc_d
	1.22	0.25	$-1.17620\,10^{-3}$	$-1.17680\,10^{-3}$	$6\,10^{-7}$
(l_1,g_1)	4.93	0.88	$3.9845\,10^{-11}$	$-1.18966\,10^{-11}$	$5.17\,10^{-11}$
	8.58	1.78	$3.89519\,10^{-11}$	$-1.64992\,10^{-13}$	$3.91\,10^{-11}$

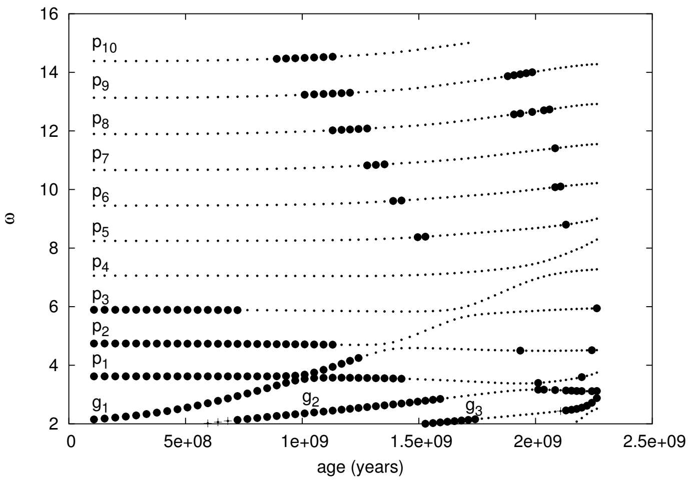

Figure 3: Evolution of dimensionless angular frequencies of degree $l = 1$ during the main sequence. Small dots represent stable modes, filled circles correspond to excited modes without the ε-mechanism and plus signs correspond to additional excited modes when the ε-mechanism is taken into account.

reactions and the influence of the ε-mechanism is very small. At 4.93 and 8.58 Myr, this mode is very close to the limit between stability and excitation, i.e. its damping coefficient is close to zero. The apparition of unstability comes from the inclusion of the ε-mechanism in the nonadiabatic computations.

3. Main sequence models

We also studied the effects of the ε-mechanism on low order p and g modes in 1.5 $\mathrm{M}_\odot$ main sequence models. In Fig. 3 are plotted the oscillation frequencies of these modes. The mode (l_1,g_2) becomes excited a little sooner with the ε-mechanism than without. Some of the results concerning the modes (l_1,g_2) and (l_1,p_3) are given in Table 2. We see that the p mode is absolutely not affected by the central production of nuclear energy. Like the other p modes observed in δ Scuti stars, it is exclusively excited by the κ-mechanism. The damping coefficients of such modes are 10^5 times larger than those of low order g modes ($c_d \sim 10^{-6}$ for p modes against 10^{-11} for g modes). Again, the ε-mechanism induces slight changes in the dimensionless damping coefficients of low-order g modes but these coefficients remain close to zero.

Table 2: Dimensionless damping coefficients with and without the ε-mechanism for p and g modes belonging to main sequence models with $1.5\mathrm{M}_\odot$.

	Age (Gyr)	ω	c_d	$c_{d\varepsilon}$	Δc_d
(l_1,g_2)	0.595	2.01	$3.00928\,10^{-11}$	$-1.75551\,10^{-11}$	$4.76\,10^{-11}$
	1.09	2.42	$-4.7683\,10^{-10}$	$-4.99630\,10^{-10}$	$2.28\,10^{-11}$
	1.43	2.69	$-2.95353\,10^{-9}$	$-2.97587\,10^{-9}$	$2.23\,10^{-11}$
(l_1,p_3)	0.108	5.89	$-9.87982\,10^{-6}$	$-9.87982\,10^{-6}$	0
	0.681	5.89	$-7.45657\,10^{-6}$	$-7.45657\,10^{-6}$	0
	1.01	5.87	$5.28564\,10^{-5}$	$5.28564\,10^{-5}$	0

4. Conclusions

We have shown that p modes are not affected by the nuclear reactions occurring in the central parts of a 1.5 $\mathrm{M}_\odot$ δ Scuti star during the main sequence. The same conclusion can be drawn for low and high order p modes of pre-main sequence models. However, low-order g modes are somewhat sensitive to the ε-mechanism. This is explained by their respective amplitudes in the deep stellar interior where g modes have larger amplitudes than p modes. However the influence of the ε-mechanism on the excitation of g modes is very small in comparison with the effects of the κ-mechanism on p modes.

In future work, we could extend this study to other classes of variable stars. In β Cephei stars, for instance, the CNO cycle is more efficient than the pp chain, and produces very large amount of nuclear energy. Therefore, the influence of the ε-mechanism on g or even on p modes could be significant and maybe detectable in main sequence β Cephei stars.

An evolution phase that should be investigated too is the hydrogen shell burning phase. During this stage, a lot of interactions between g and p modes occur, leading to the apparition of a large number of special modes called mixed modes. These modes have large amplitudes in the region of the limit of the convective core which corresponds to the region where nuclear reactions take place. The hydrogen shell burning phase accumulates the conditions under which the ε-mechanism could be the most efficient.

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References

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