Pulsational instability of high-luminosity H-rich pre-white dwarf stars

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Abstract. We present a pulsational stability analysis on high-luminosity H-rich (DA) white dwarf models evolved from low-metallicity progenitors. We found that the ε mechanism due to H-shell burning is able to excite low-order g modes.

1 Introduction

The majority of the stars will end their lives as white dwarf (WD) stars. Hence, it is important to study them in order to understand stellar evolution and the history of the stars in our galaxy. There are two main types of WDs: H-rich WD ($\sim$ 80% of the WD stars), which are called "DA" WD stars, and H-deficient WDs, called "non-DA" WD stars. Although their progenitors are different, both of them can undergo pulsational instabilities, making possible an asteroseismological analysis. In general, they are found to pulsate with g modes with periods in the range of $\sim 100 - 7000$ s. The mechanisms responsible for the pulsations are usually the $\kappa - \gamma$ mechanism acting in the ionization zones of the abundant chemical elements or the convective driving mechanism in cool WDs. There is another excitation mechanism that may produce instabilities of short-period g modes: the ε mechanism, induced by nuclear reactions and which depends strongly on the temperature ([5]).

In this work, we extend the work of [2] who showed that low-luminosity DA WDs exhibit pulsations excited by the ε mechanism, and now, we concentrate on the high-luminosity phase.

2 Analysis

We computed non-adiabatic non-radial g mode pulsation periods, employing the pulsation code described in [3], for DA WD evolutionary models with stellar masses in the range of 0.53 to 0.75 $M_{\odot}$, and progenitor metallicities $Z = 0.0001, 0.0005$ and 0.0010. In this high-temperature regime, there

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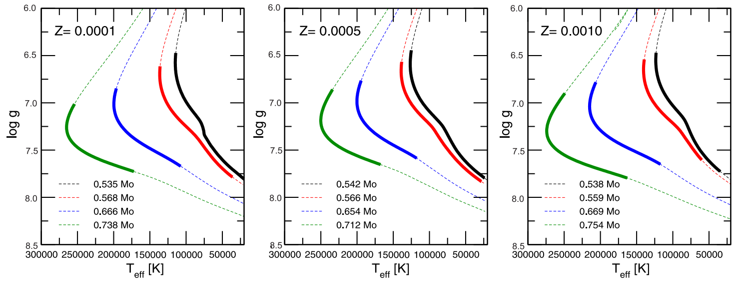

Figure 1. Evolutionary tracks of WD models on the $T_{\rm eff}$-log g plane. Each panel corresponds to a different metallicity value of the WD progenitors. Thick segments on the tracks depict DA WD models with unstable low-order g modes destabilized by the ε mechanism.

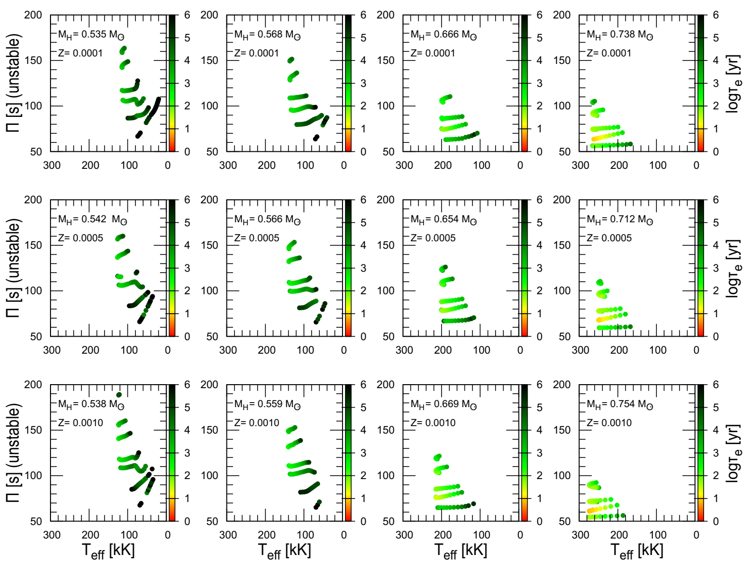

Figure 2. Periods of unstable dipole g modes in terms of the effective temperature for our WD models for different progenitor metallicities. Color coding indicates the e-folding time (τ_e) of each unstable mode (right scale).

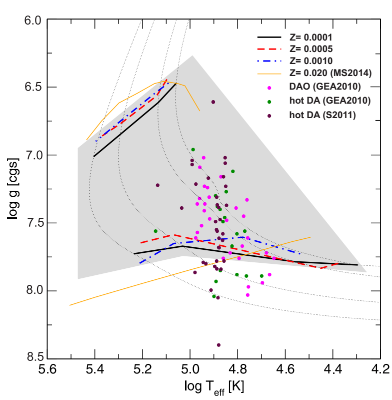

Figure 3. Instability domain (shaded area) of low-order g modes excited by the ε mechanism on the $\log(T_{\rm eff}) - \log(g)$ plane. Thick lines show the edges of the instability region for different progenitor metallicities. Also included are the results of [6] for solar metallicity. Dots of different colors show the DAO and hot DA stars from [4] and hot DA stars from [7]. Dotted lines depict evolutionary tracks corresponding to $Z = 0.0001$.

are no uncertainties in the pulsation stability computations due to convection. Initial WD models are the result of the complete evolution from the zero-age main sequence, considering H- and He-burning, thermal pulses in the AGB and post-AGB phases, until the pre-WD and WD stages (see [1]). Thus, the initial H content and the residual nuclear burning are the result of the complete previous evolution. During the WD stage, element diffusion due to chemical and thermal diffusion and gravitational settling was allowed to operate.

In Figure 1 we show the evolutionary tracks of the WD models on the $T_{\rm eff} - \log(g)$ plane for different metallicity values (Z) of the WD progenitors. As shown by the thick segments on the tracks, there is a wide region where DA WD models have unstable low-order g modes destabilized by the ε mechanism. It is clear that, for low-metallicity progenitors and for lower mass, the range of instability extends to lower $T_{\rm eff}$. Next, we analyzed the pulsation spectrum in terms of the effective temperature, for different progenitor metallicities and different masses. We display the results in Figure 2, where we included a color coding for the e-folding time (τ_e) of each unstable mode, that represents a measure of the time taken for the perturbation to reach an observable amplitude. We can see from this figure that, for a fixed value of Z, the pulsation spectrum spans a wider range of periods for lower mass, and becomes narrower with increasing mass. Furthermore, for larger mass, the periods are destabilized at higher $T_{\rm eff}$. If we change the value of Z and compare the situation for approximately the same values of the mass, we find that the unstable period domain remains almost unaltered. Thus, the range of periods excited is not sensitive to Z. Finally, in Figure 3 we show the instability domain of low-order g modes excited by the ε mechanism on the $\log(T_{\rm eff}) - \log(g)$ diagram. We can see that the instability region extends to significantly lower effective temperature for lower values of Z, in comparison with the results of [6] for solar metallicity.

3 Summary and conclusions

We found that some dipole ($\ell = 1$) low-order ($k = 1-7$) g modes with periods in the range $\sim 50-200$ s are destabilized by nuclear burning through the ε mechanism in DA WD models at high luminosities, in line with previous results ([6]). Our results indicate that the instability domain is sensitive to both the stellar mass and the metallicity of the progenitor stars. In particular, the instability domain extends to lower $T_{\rm eff}$ for lower Z and lower masses. By comparing with the computations of [6], who considered only solar metallicity, we found that the instability given by the ε mechanism extends to substantially lower effective temperatures, particularly for low-mass ($M_* \sim 0.53 - 0.55\, M_\odot$) WD models. We also found that the range of unstable periods is sensitive to the stellar mass, and does not depend on the progenitor metallicity. Specifically, the longest unstable periods are longer for lower mass. The results presented in this work indicate that a search for photometric variations in hot DA WDs is worth doing.

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