Uncertainties in the white dwarf core chemical profiles and their impact on asteroseismology of ZZ Ceti stars: first results.

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1.1 Abstract

White dwarf (WD) asteroseismology is a powerful tool that exploits the comparison between observed pulsation periods in WD stars, and those periods computed with theoretical representative models. Despite significant achievements undertaken through WD asteroseismology (see Romero et al. 2012), there remain several important uncertainties linked to prior evolution, such as extra-mixing process, the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction rate, etc. The uncertainties associated to these processes are then transferred to the seismological analysis of WDs. Here, we present an estimate of the uncertainties in the C/O chemical profiles of the cores of WD stars, and their impact on ZZ Ceti pulsations. In particular, we focus on the uncertainties resulting from the incomplete knowledge of the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ nuclear reaction rate. Specifically, we have computed evolutionary sequences of stars with initial masses between 1M$_\odot$ and 5 M$_\odot$ and solar metalicity ($X_H = 0.725, Z = 0.01$), from the ZAMS to the WD phase, by considering the highest and lowest extreme values of the reaction rate provided by Kunz et al. (2002), and the rate given in Angulo et al. (1999) (hereinafter "standard" rate). We present here the first results of a larger project aimed at assessing the impact that uncertainties in the pre-WD evolution have on the asteroseismological analysis of ZZ Ceti stars.

1.2 Numerical tools

The study presented in this work is based on fully evolutionary computations performed with the LPCODE evolutionary code. A full description of the relevant characteristic of this numerical tool can be found in Althaus et al. (2005). For the pulsation computations, we employ the nonradial pulsation code described in Córsico & Althaus (2006).

1.3 The $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction rate

As it is well known, $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ is one of the most important reaction rates in astrophysics. Even so, it is not well determined. Fig. 1 shows a comparison between rates provided by different authors: Kunz et al. (2002), and Angulo et al. (1999) (NACRE). The ratio between both adopted rates (solid line) does not exceed the value of 2. Note that, for helium burning in intermediate mass stars, T$_9$∼ 0.1.

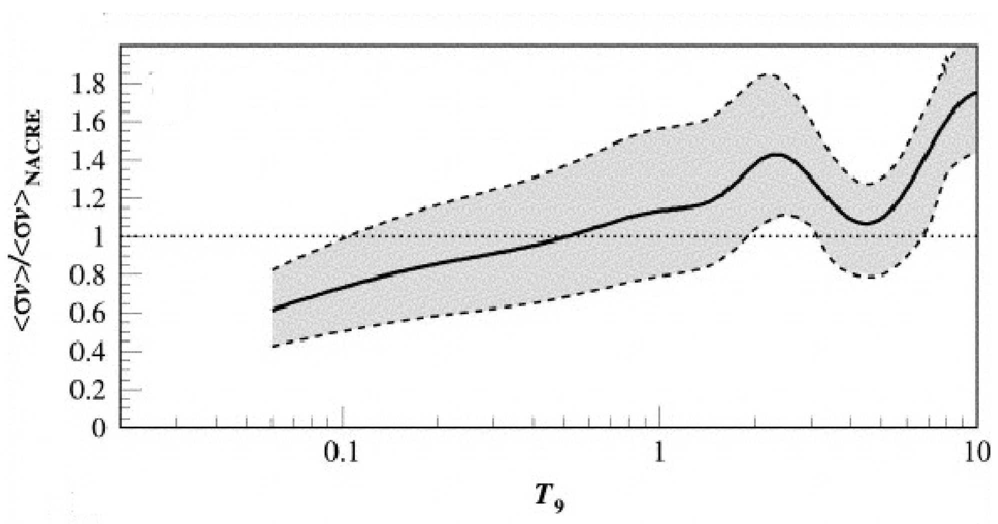
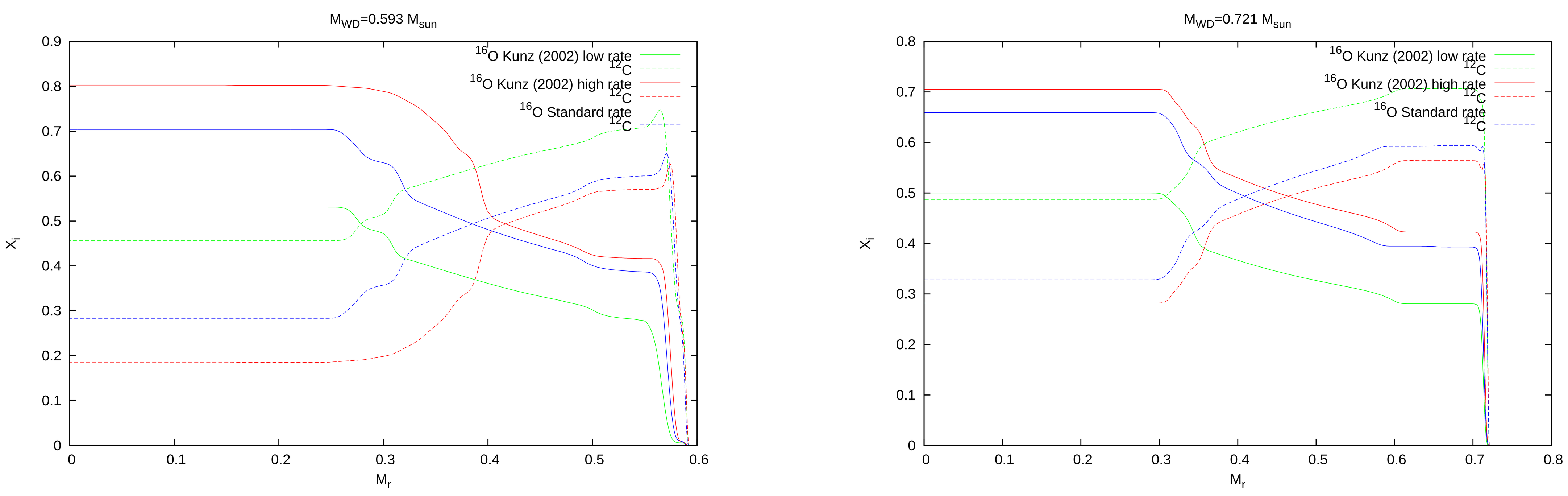


Figure 1 Comparison (ratio) of the Kunz et al.'s reaction rate, with the previous rate from the compilation of Angulo et al. (standard rate). The solid line corresponds to the rate adopted by Kunz et al. and the dashed lines refer to the high and low rates adopted by those authors (Kunz et al. 2002).

In Fig. 2 we show chemical profiles corresponding to the diminished and increased reaction rates (low and high rates of Kunz et al.) and also for the standard rate of Angulo et al., for two different stellar masses. It can be appreciated how the profiles change when the different rates are adopted.

1.3 The $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction rate



(a) (b)

Figure 2 Chemical profiles obtained from progenitors of 1.75M$_\odot$ (M$_{\rm WD}$=0.593M$_\odot$) and 3.25M$_\odot$ (M$_{\rm WD}$=0.721M$_\odot$) resulting from the distinct reaction rates.

1.4 Procedure

To evaluate the uncertainties related to the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction rate, we compute evolutionary models from the ZAMS to the stage of thermal pulses, considering the three different reaction rates for the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$, previously cited. The different chemical profiles obtained with the different rates, were appropriately implanted in pre-existent WD models at T$_{eff}\sim 10^5$ K. For the implant process, we created a specific routine that was coupled to the LPCODE evolutionary code. This routine consistently interpolates the chemical abundances from the models obtained to the previously generated WD models. Thus, with our procedure, we are skipping the evolutionary stages between the end of thermal pulses stage and the hot WD stage, and so we drastically reduce the computation time. This is because the post thermal pulses stage is one of the most time consuming stages in evolutionary computation. A set of 14 evolutionary sequences with progenitor masses from 1M$_\odot$ to 5M$_\odot$, and with hydrogen envelopes $4\times10^{-10} \leq \mathrm{M_H/M_\star} \leq 10^{-4}$ were calculated for each reaction rate (where, from now on, M$_\star$ refers to M$_{\rm WD}$).

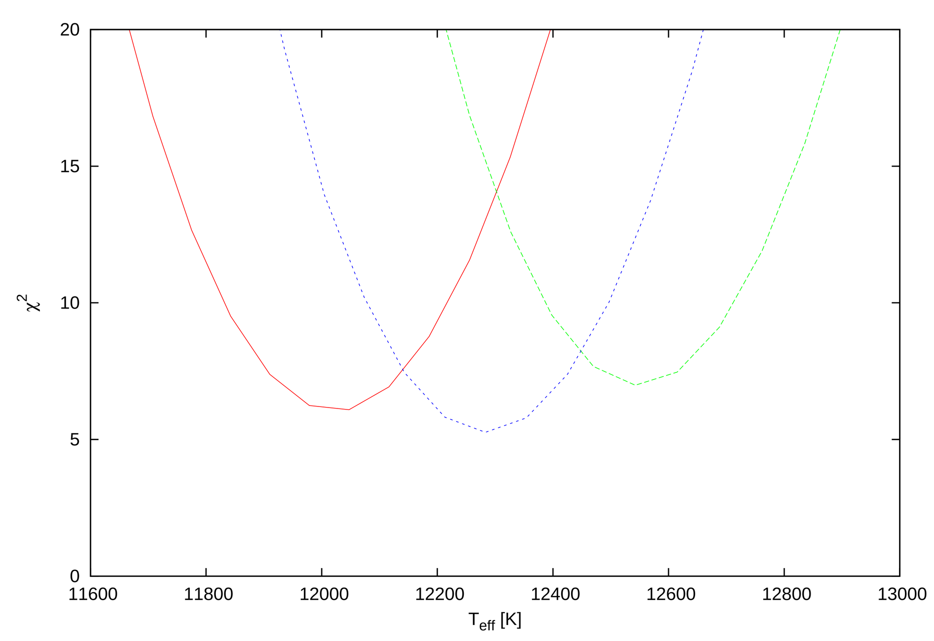
1.5 Asteroseismological fits

We have performed exploratory asteroseismological period fits to the well studied ZZ Ceti star G117-B15A by employing three different sets of evolutionary DA WD models, each one obtained with the distinct reaction rates already described. We search for the model that minimizes the quality function defined as (e.g., Córsico et. al. 2009):

$$\chi^2 = \chi^2(M_\star, M_H, T_{eff}) = \frac{1}{N}\sum_{i=1}^{N} min[\Pi_k^{th} - \Pi_k^{obs}]^2$$

.

In Fig. 3 we depict the quality function in terms of the effective temperature for the three different cases. In the Table below we show the structural characteristics of the three different asteroseismological models obtained.



(c)

Figure 3
The figure shows the quality function of our best fit models for each reaction rate. The red solid line corresponds to the Kunz et al.'s high rate, dotted blue line to the Angulo et al.'s standard rate and the dashed green line to the Kunz et al.'s low rate. The three solutions are characterized by a minimum value of $\chi^2 \approx 6$, and fall at different effective temperatures.

Quantity	Kunz's low rate	Standard rate	Kunz's high rate
T$_{eff}$ [K]	12542	12283	12047
M$_\star$/M$_\odot$	0.593	0.593	0.593
log(g)	7.998	8.000	8.002
L$_\star$/L$_\odot$	0.362×10^{-2}	0.332×10^{-2}	0.359×10^{-2}
$\mathrm{M_H/M_\star}$	1.747×10^{-6}	2.174×10^{-6}	2.125×10^{-6}
$\mathrm{M_{He}/M_\star}$	2.712×10^{-2}	2.408×10^{-2}	2.061×10^{-2}
X_C, X_O (center)	0.456, 0.531	0.283, 0.703	0.184, 0.802

1.6 Conclusions and future work

In this work we found that the uncertainties in $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction rate have an strong impact in the shape of chemical profiles and in the central abundances of C and O, (see Fig. 2). However, the impact on asteroseismological results is not so important as we would expect at the outset. In particular, we found variations on T$_{eff}$ of about 500 ºK between the asteroseismological models derived by considering the extreme values of the reaction rate. For the stellar mass and hydrogen envelope we have not found appreciable variations. However, we warn that it will be necessary to continue exploring the parameter space in order to have a definitive conclusion about their uncertainties. This will be the motive of future work.

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