Constraints to dark-matter properties from asteroseismic analysis of KIC 2009504

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Abstract. Asteroseismology can be used to constrain some properties of dark-matter (DM) particles [1]. In this work, we performed an asteroseismic modelling of the main-sequence solar-like pulsator KIC 2009505 (also known as Dushera) in order to test the existence of DM particles with the characteristics that explain the recent results found in some of the DM direct detection experiments. We found that the presence of a convective core in KIC 2009504 is incompatible with the existence of some particular models of DM particles.

1 Introduction

Stars slightly more massive than the Sun ($M > 1.1M_\odot$) develop a tiny convective core during the main sequence. In case of DM particles do not self-annihilate inside stars their accumulation leads to an efficient mechanism of energy transport that results in the suppression of the convective core expected to be present in main-sequence stellar models with masses between 1.1 and 1.3 $M_\odot$ in a dark-matter free scenario [1].

The presence of a convective core leaves a signature on the oscillation frequencies of a pulsating star, which, in principle, can be detected through the use of asteroseismic diagnostic tools, such as $dr_0/df_0$, $r_0$ and $r_2$ (e.g., [2,3,4]). Their frequency derivative (the ‘slope’) is expected to provide information about convective core’s properties and stellar age [4].

In this work, we test the existence of DM models with a given physics that may explain the positive results of the direct detections in the DAMA and CoGeNT experiments [5].

2 Method

To model KIC 2009505, we computed three grids of main-sequence evolutionary tracks using the CESAM code [6]. Grid 1 considers a free DM scenario while grids 2 and 3 consider two different DM scenarios following the prescription of [7] for the capture rate and of [8] for the energy transport by DM conduction. We considered a mass range of [1.1,3.1] $M_\odot$ (0.005 steps), an abundance of heavy elements range of [0.012,0.024] (0.0005 steps), we fixed the overshooting parameter to 0.1 and the mixing-length parameter [9] to 1.8. The physics used in the code was the same as described in [1]. Diffusion was taken into account following the prescription by [10]. The model oscillation frequencies were computed using the Aarhus adiabatic oscillation code ADIPLS [11].

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As non-seismic constraints to the modelling we considered the effective temperature, \( T_{\text{eff}} \), to be 6200±200, the logarithm of gravity, \( \log g \), to be 4.30±0.2, and the initial abundance of heavy elements to hydrogen ration, \( Z/X_s \), to be 0.023±0.09. For seismic constraints we considered the mean of the large frequency separation (e.g., [12]) for degrees \( l = 0 – 2 \) computed in the range of the observed frequencies, \( < \Delta \nu >_{012} \), as 88±0.6 and the absolute value of the slope of the diagnostic tool \( \Delta \nu_{010} \), \( |S\{\Delta \nu_{010}\}| \), as 0.0032±0.0006 (see [4] for details). Both non-seismic and seismic constraints were taken from [13].

3 Results

We found that all models in a DM free scenario show a convective core, with a mean radius of 0.06 ± 0.01\( R_\star \) in agreement with [13]. Similar results were observed in DM models whose particles have the properties that explain the positive results in the DAMA experiment. However, when the influence of the existence of DM particles with the properties that explain the positive results in the CoGeNT experiment was taken into account, none of the models of KIC 2009505 had a convective core. Moreover, we found that the average value of \( |S\{\Delta \nu_{010}\}| \) computed for these set of DM models is in disagreement with observations as these models do not show a convective core.

4 Conclusions

The existence of asymmetric DM particles with the properties that explain the positive results in the CoGeNT experiment would lead to the suppression of the convective core recently detected in the main-sequence solar-like pulsator KIC 2009505. We have shown that the sensitivity of the slope of the diagnostic tool \( \Delta \nu_{010} \) to the presence of a convective core can be used to rule out the existence of such DM models even when these models reproduce well the observed large frequency separation.

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