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AN APPROACH TO A STABILITY ANALYSIS OF AN SDO STAR

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Abstract. The first stability analysis of a structural model of an sdO star is presented. A non-adiabatic code of oscillations is used to search for modes in the frequency range 0.4 to 15 mHz. All of the computed modes were found stable. We draw the attention, however, to 3 different stability regions.

Key words: stars: sdOs, post-EHB

1. INTRODUCTION

O-type hot subdwarfs (sdOs) are pre-WD stars with masses around 0.5 $M_\odot$ and stellar parameters between 40 000 and 100 000 K in $T_{\rm eff}$ and 4.0–6.5 in log g. The few interpretations found in the literature about sdOs physical nature depict them as objects with a C/O core and a helium burning shell (Groth et al. 1985), from where they get their luminosity, and which are mostly devoid of hydrogen in their atmospheres.

As can be inferred from their scattered positions on the HR diagram (HRD), appearing both in the post-AGB (Asymptotic Giant Branch) and post-EHB (Extreme Horizontal Branch) domains, there may be different evolutionary paths which can bring a star to the sdOs loci.

We have started a photometric campaign searching for possible pulsations in these objects which, if succesful, could open a new field to gain important information for sdOs. So far, we have observed about 40 sdOs, with 3 possible pulsators found. Some structural models were constructed for two of these objects and their evolutionary paths calculated on the HRD.

We also present first preliminary results of pulsational stability of one of these structural models.

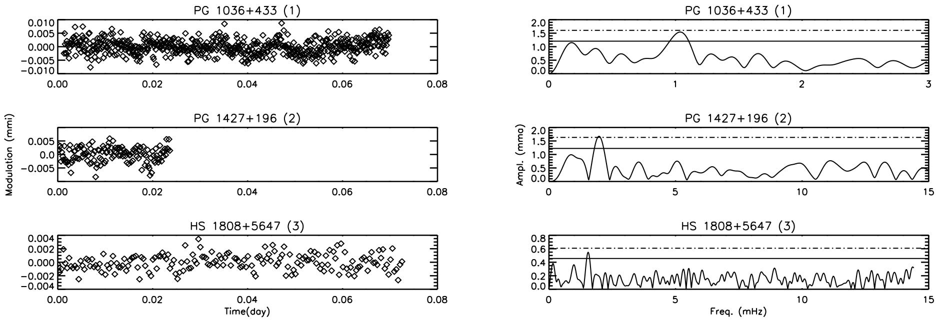


Fig. 1. Light curves and power spectra of promising pulsating sdOs. The horizontal lines are 3 & 4 times the mean Fourier noise.

2. STRUCTURAL MODELS AND EVOLUTIONARY PATHS

The structural models were constructed to account for the physical parameters of sdOs 1 & 2 which were found particularly promising for pulsations in our photometric campaigns (Rodríguez-López et al. 2004) and whose light curves and Fourier transforms are shown in Fig. 1. For object number 3 (from a recent campaign) the construction of the models is under way.

Models 1 & 2 were calculted to match the physical parameters of object 1, and models 3 to 6 were constructed to account for object 2. These models were calculated with the stellar evolution code of Jimenez et al. (2004) evolving Z=0.02 $1\,M_\odot$ stars from the Main Sequence with mass loss on the red giant branch at rates 70 – 85% higher than the canonical Reimers formula rates. Some relevant properties of the models are given in Table 1.

The complete evolutionary tracks in the HRD of models 3 to 6, and the evolution to the WD phase of models 1 & 2 are shown in Fig. 2.

3. STABILITY ANALYSIS AND DISCUSSION

Using the non-adiabatic pulsation code of Moya et al. (2004) we have calculated modes for $l = 0, 1, 2, 3, 4$ with frequencies between 0.4 and 15 mHz, for model 1 of Table 1. The structural models were calculated with a refinement of the fractional mass depth parameter log q ($=\log(1\text{-}M_r/\,M_\odot)$) from 0 to ~ -13. In Fig. 3 the

Table 1. Main physical parameters of the structural models

Model number	$T_{\rm eff}$ (K)	logg	M ($M_\odot$)	η_R	X(H)	X(He)	X(C)	Z
1	79 000	5.70	0.478	0.675	0.21	0.72	3.4E-02	0.07
2	79 000	5.95	0.491	0.650	0.68	0.30	3.0E-03	0.02
3	55 000	5.89	0.471	0.685	0.43	0.55	9.6E-04	0.02
4	55 000	5.95	0.471	0.690	0.33	0.65	6.3E-04	0.02
5	55 200	5.98	0.471	0.695	0.27	0.71	9.0E-04	0.02
6	55 000	6.02	0.470	0.700	0.18	0.78	1.5E-02	0.04

growth rate parameter (η) is plotted versus frequency. A positive value of η would mean we have an unstable mode, while a negative value indicates stability. The plot shows that all of the computed modes were found to be stable.

However, we can notice 3 different regions in the scanned frequency range. Two regions where η achieves less negative values and hence the modes have a tendency to instability: one with low frequencies (from about 0.5 to 2 mHz) corresponding to high radial order g modes, and other with high frequencies (from about 9 to 12 mHz) corresponding to low radial order p modes. The modes in the region in between (from 2 to 9 mHz) were found highly stable.

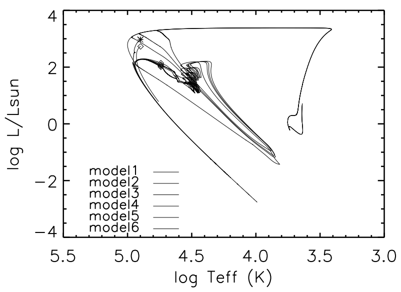


Fig. 2. Evolutionary tracks followed by the models in the HRD. Model 1 is marked with an asterisc and the rest of the models with a diamond.

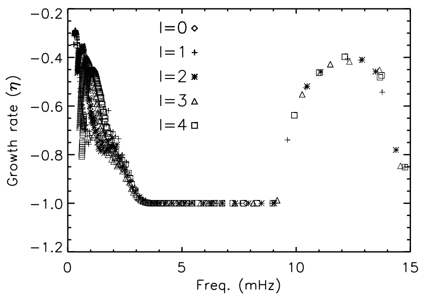
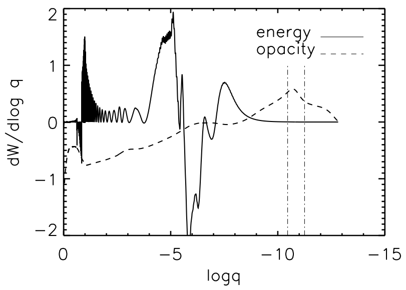


Fig. 3. Growth rate parameter (η) vs. frequency for $l = 0,1,2,3,4$ of model 1.

We have plotted the derivative of the work integral ($\mathrm{d}W/\mathrm{d}\log q$), which gives the net amount of energy gained or lost by the displaced material during one pulsation cycle, and the logarithm of the opacity vs. $\log q$ for a representative mode of each one of these regions for $l = 2$. A negative (positive) value of $\mathrm{d}W/\mathrm{d}\log q$ indicates that this region contributes locally to driving (damping) of the mode.

In the first region (Fig. 4 left) the energy concentrates at log $q \sim -6$ in the proximity of the small bump in the opacity profile. At this depth in the star the density and temperature are high, making it an important zone in the overall driving of pulsations. Therefore the mode gains energy and becomes a bit more unstable. This opacity bump is due to the C/O partial ionization zone, whose κ-mechanism is the responsible for driving the pulsations found in the PG 1159 spectral class (Starrfield et al. 1983). Our structural model has a low carbon mass fraction, but He enhancement often occurs together with a C enhancement, so we can speculate that by enhancing the metallicity and hence the magnitude of the opacity bump, we might get unstable modes. It might well be that we need accurate envelope compositions to construct individual structural models for each sdO, as it is also the case for the PG 1159 stars (Quirion et al. 2004).



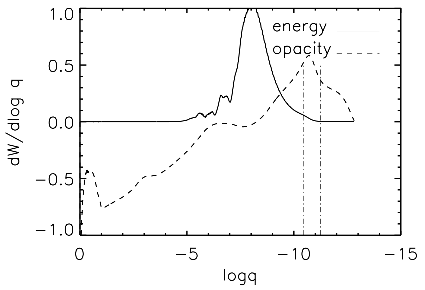


Fig. 4. **Left**. Energy and opacity for the g99 mode at $\nu \sim 0.6$ mHz. **Right**: The g10 mode at $\nu \sim 4.5$ mHz. The dashed-dotted line depicts the convection zone.

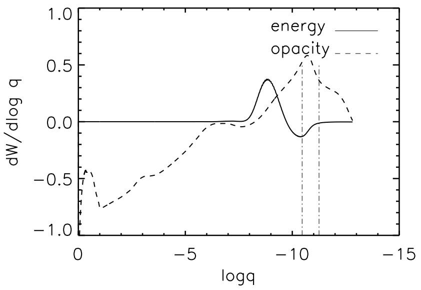


Fig. 5. Energy and opacity for the p3 mode at $\nu \sim 10$ mHz.

At intermediate frequencies the energy concentrates at $\log q \sim -8$ (Fig. 4 right). However, this region is not associated with an opacity bump and the modes are highly stable.

At higher frequencies (Fig. 5) the energy shifts even more towards the surface, at $\log q \sim -10$, approaching to the highest opacity bump located at $\log q \sim -11$, and the modes have again a tendency to instability. However, we would not expect unstable modes. Even though the opacity bump is strong, the density there is not large enough to drive pulsations. Besides, the low ratio of the thermal to dynamical timescales in this zone would make the energy redistribution too efficient for the mode to become unstable.

Work is in progress to test for all these possibilites.

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