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NONRADIAL INSTABILITY STRIPS FOR POST-AGB STARS

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ABSTRACT We test several pre-degenerate (PNN and DO) and degenerate (DB) models for stability against nonradial oscillations. These models lie on the 0.6 $M_\odot$ evolutionary track calculated by Iben (1989). The post-AGB stars have a residual CO core with only a little surface hydrogen and helium. In order to match all the observed pulsators, we use three different surface compositions for the DO stars, and a pure helium surface for the DB white dwarfs. We find 3 DO and 1 DB instability strips that we compare to the available observations.

INTRODUCTION

The post-Asymptotic Giant Branch (post-AGB) stars on the theoretical Hertzsprung Russell diagram (logL, logT plane) extend from $T_e \sim 30\,000$ K at high luminosities, where the stars have recently undergone envelope ejection, up to temperatures which exceed 150,000 K. Later the evolutionary tracks curve toward the white dwarf cooling line. Stellar evolution theory allows for both hydrogen rich (DA) and helium rich (DB) white dwarfs (e.g. Wood and Faulkner 1986), depending on how the envelope ejection occurred. In this paper we explore the question: what is the cause of the observed multimodal, low amplitude DOV star pulsations consistent with a theoretical scenario that takes into account stellar evolution results? The observed oscillations are nonradial g-modes. We consider here both the pre-degenerate DOV stars ($T_{eff} \gtrsim 130\,000$ K), and the DBV pulsating white dwarfs.

MODELS

Our models are based on an evolutionary post-AGB track sequence calculated by Iben (1989), for a 0.6 $M_\odot$ star. We take snapshots along the track, fixing the effective temperatures of the models, and changing the surface composition. We build DB models from 28,000 to 17,000 K with a pure helium surface, and three hotter classes of DO models with respectively 50%, 10% and no helium at the surface. All helium composition profiles are derived from those of Iben. We use the Los Alamos Astrophysical Opacity Library tables for the outer composition layer in each model where the pulsation driving and damping takes place. Each complete stellar model has an internal temperature profile very close to the original Iben model. Our resulting models have $log(L/L_{\odot})_{Stel} - log(L/L_{\odot})_{Iben} \leq 0.04$. More details of the models and the pulsation analysis are given in Stanghellini *et al.* (1990).

RESULTS

We test our models for nonradial pulsational stability using a code by Pesnell (1990), and we find four post-AGB instability strips. In Figure 1 we show the unstable models as filled circles in the logL-logT plane, respectively, for (1) 50% He, 50% C, (2) 10% He, 90% C, (3) 50% O, 50% C surface compositions (DOV stars), and (4) for 100% He (DBV stars). In cases (1) and (2) we obtain two similar instability strips, and the width increases as the helium surface abundance decreases. Helium clearly poisons the pulsation driving (which is the result of the CO ionization κ and γ mechanisms) for models close to the high luminosity blue bend. In case (3) we obtain a very wide instability strip without any pulsational blue edge. The high temperature limit to this instability region occurs only because the evolutionary track has its blue extremum there. For higher mass stars the blue limit might even be hotter. Case (4) shows the narrow instability strip for helium (DBV) white dwarfs that is caused by convection blocking (Pesnell, 1987 and Cox *et al.*, 1987) at the bottom of the convection zone.

The unstable periods for the low degree g-modes are thousands of seconds for the highest luminosity models, but along the white dwarf cooling track, they center around 500 seconds as observed.

COMPARISON WITH THE OBSERVATIONS

We compare the observed DOV and DBV pulsators with our instability strips in Table 1. Column (1) gives the name for the 6 PNNi pulsators, and we list together all the PG pulsators presently known, namely PG 1159-035, PG 1707+427, PG 2131+066, and PG 0122+200. Column (2) and (3) give the surface temperature and luminosity. For the PG stars, L is a lower limit, and L values have been derived for the range of log g given in the references. Column (4) names the strip(s) relative to Figure 1, and column (5) the references to the L and T data. Sanduleak 3 was discovered only in June 1990 (Bond, private communication). Comparing our DB strip with the observations, we find it to be very close to the one empirically derived by Liebert *et al.* (1986), which extends from 21,000 ± 2,000 K to 29,000 ± 3,000 K. Our analysis also allows cooler DBV pulsators, but perhaps the time dependence of our frozen in convection prevents cool DB pulsations.

CONCLUSIONS

Following the stellar evolution results, we find (1) a 50% He, 50% C instability strip for 31,000 $\leq T_e \leq$ 80,000K, (2) a 10% He, 90% C strip for 25,000 $\leq$ $T_e \leq$ 80,000 K, (3) a CO instability locus for $T_e \geq$ 25,000K, and (4) a DB instability strip for 17,000 $\leq T_e \leq$ 26,000 K. The strips become narrower as the helium abundance increases in the pulsation driving region (near but not at the surface). There is good agreement between the CO instability locus and the observed DOV pulsators (although more observations can improve the comparison with the helium surface composition strips). We get good agreement between the empirical and the theoretical DBV instability strip.

TABLE 1 Observed DOV Parameters

Name	$log T_{eff}$(K)	$log L/L$	strip(s)	ref
K1 16	5.18	4.40	3	K83
NGC 1501	4.96	4.04	3	KS84
NGC 6905	4.70	4.30	1,2,and 3	B88
NGC 2371	5.01	2.94	3	KS84
Longmore 1			3	BM90
Sanduleak 3			3	
PG stars	5.00	1.1 to 3.1	3	Ba89, W88, We85

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REFERENCES

Barstow, M. A. 1989, *IAU Colloq. 114*, p. 202. (Ba89)

Bianchi, L. 1988, ESA SP-281, 173. (B88)

Bond, H. E., and Meakes, M. G. 1990, *Astr. J., submitted*. (BM90)

Cox, A. N., Starrfield, S. G., Kidman, R. B., and Pesnell, W. D. 1987, *Ap. J.*, **317**, 303.

Grauer, A. D., and Bond, H. 1984, *Ap. J.*, **277**, 211.

Grauer, A. D., Bond, H. E., Liebert, J., Fleming, T. A., and Green, R. F., 1987, *Ap. J.*, **323**, 271.

Dean, J. Jr. 1989, *private communication*

Kaler, J. B. 1983, *Ap. J.*, **271**, 188. (K83)

Kaler, J. B., and Shaw, R. 1984, *Ap. J.*, **278**, 195. (KS84)

Liebert, J., Wesemael, F., Hansen, C. J., Fontaine, G., Shipman, H. L., Sion, E. M., Winget, D. E., and Green, R. F. 1986, *Ap. J.*, **309**, 241.
Pesnell, W. D. 1987, *Ap. J.*, **314**, 598.
Pesnell, W. D. 1990, *Ap. J.*, Nov. 2.
Stanghellini, L., Cox, A. N., and Starrfield, S. G. 1990, *in preparation*.
Wesemael, F., Green, R. F., and Liebert, J. 1985, *Ap. J. Suppl.*, **58**, 379. (We85)
Werner, K., Heber, U., and Hunger, K. 1988, *IAU Colloq. 114*, p. 194. (W88)
Wood, P. R., and Faulkner, D. J. 1986, *Ap. J.*, **307**, 659.

Fig. 1. Post-AGB (DOV) and helium (DBV) instability strips.

DISCUSSION

WAELKENS: Did you look for nonradial instability in the high luminosity zone, where the post-AGB track encounters the Cepheids strip?
STANGHELLINI: Not so far. We only considered T_e > 130,000K, but we plan to look cooler for models that even have some surface helium.
KAWALER: An evolutionary dilemma: your models will all be DB white dwarfs forever, including when they cool to between 30,000 and 15,000 K. But at these temperatures, Liebert and others show that there are no DB's. Can you fit your models into any *conventional* evolutionary scenario?
STANGHELLINI: This can be explained with diffusion that occurs later in the evolution of these objects, when the residual or even very lightly accreted light elements float to the white dwarf surface. There is no problem for the DOV stars if the CO in the pulsation driving layers at 10^{-}[illegible] into the model is not poisoned by any hydrogen or helium.