Part 1.5. General Aspects

https://doi.org/10.1017/S0252921100015864 Published online by Cambridge University Press

Radial and Nonradial Pulsations as Probes of Stellar Physics
ASP Conference Series, Vol. 259, 2002
C. Aerts, T.R. Bedding, & J. Christensen-Dalsgaard, eds.

Empirical Luminosities and Radii of Stars in the β Cep, SPB and δ Sct Instability Domains

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Abstract. For 26 stars with effective temperatures known from directly measured angular diameters and total absolute fluxes (Code et al., 1976), HIPPARCOS parallaxes (ESA, 1997) can be used to derive empirical luminosities and radii. The empirical effective temperatures and luminosities allow a comparison of the position of these stars in the fundamental H-R diagram with evolutionary tracks. Note that no calibration, photometric or any other, is involved in the process. As noted by Jerzykiewicz & Molenda-Żakowicz (2000), the comparison shows an overall coincidence with the phases of slow nuclear burning of the solar composition evolutionary tracks, computed with OPAL opacities and moderate amount of overshooting from the convective core.

Several of the stars fall in the theoretical β Cep, SPB or δ Sct instability domains. Unfortunately, none of them is known to be an SPB variable, while the two that have been classified as δ Sct stars lack convincing evidence of variability. For the four β Cep stars that occur in the sample, the empirical radii are used to identify the radial order of pulsation.

1. Fundamental H-R diagram after HIPPARCOS

For 32 O5 to F8 stars Code et al. (1976, henceforth CDBH) derived $T_{\rm eff}$ from observed fluxes, f, and angular diameters, θ, establishing the $T_{\rm eff}$ scale that is still in use. At the time, reliable parallaxes, π, were available for 13 of the 32 CDBH stars. These 13 stars CDBH plotted in a fundamental H-R diagram using the luminosities, L, derived from f and π. HIPPARCOS (ESA, 1997) provides reliable parallaxes for 26 CDBH stars; the parallaxes can be used for plotting an updated version of the fundamental H-R diagram such as the one shown in Fig. 1. The plotted points fall in (23 stars) or close to (3 stars) the regions of slow nuclear burning as predicted by $Y = 0.30$, $Z = 0.02$ evolutionary tracks, computed with OPAL opacities and moderate amount of overshooting from the convective core, e.g., the tracks of Schaller et al. (1992) for the overshooting parameter, $d_{\rm over}$, equal to 0.2 times the pressure scale height.

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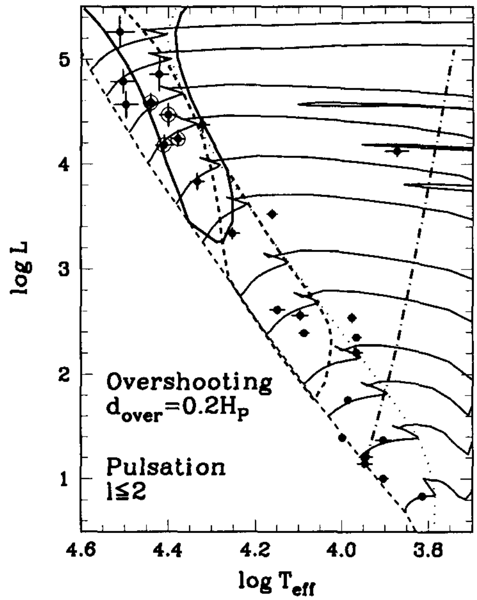

Figure 1. Fundamental H-R diagram for CDBH stars with reliable HIPPARCOS parallaxes (dots). The evolutionary tracks (thin solid lines) are from Schaller et al. (1992), while the β Cep and SPB instability domains (thick solid and dashed lines, respectively) and the blue edge of the Cepheid instability strip (dot-dashed line) are from Pamyatnykh (1999). The four encircled dots are the β Cep stars discussed in the text.

2. Pulsating stars in the fundamental H-R diagram

As can be seen from Fig. 1, several CDBH stars fall in the β Cep, SPB or δ Sct instability domains. Unfortunately, none of the CDBH stars in the SPB domain is known to be an SPB star. Two CDBH stars, α Lyr and β Leo, are classified in the General Catalogue of Variable Stars (Kholopov et al., 1998) as DSCTC (this sub-class is defined in the catalogue as "low amplitude group of δ Sct variables") but in neither case the evidence for short-period variability is convincing. In addition, α Lyr lies to the left of the blue edge of the Cepheid instability strip. The only pulsating CDBH stars are the four well-known β Cep variables, shown in the figure as encircled dots and listed in Table 1. Note that one of them, α Vir A, has stopped pulsating (Lomb, 1978), and that the remaining four stars in the β Cep instability region are not β Cep variables.

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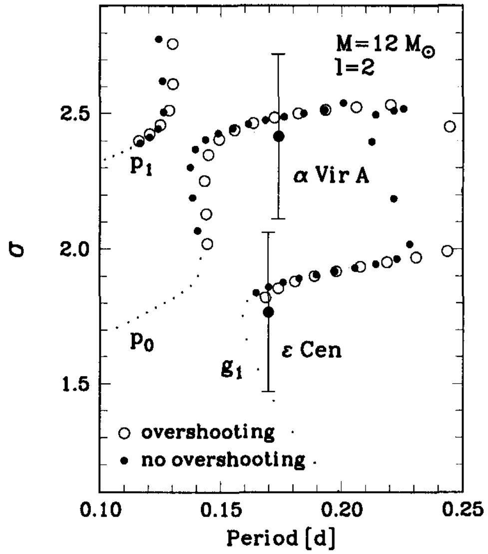

Figure 2. The almost-empirical dimensionless frequencies, σ (circles with error bars), compared with the computed ones (dots and open circles). Small dots denote stable modes.

3. Radial order of the modes seen in the four β Cep stars

The empirical radii, $R/R_\odot = 107.5\,\theta/\pi$, given in the third column of Table 1, and the masses read off the evolutionary tracks, given in the fourth column, yield almost-empirical dimensionless frequencies:

$$\sigma = \omega(4\pi G\langle\rho\rangle)^{-1/2}.$$

Fig. 2 illustrates a comparison of the almost-empirical dimensionless frequencies of α Vir A and ϵ Cen with the computed ones (Pamyatnykh, 1999 and private communication). From this and a number of similar diagrams we could derive the following conclusions:

1. In the case of α Vir A and ϵ Cen an excellent fit is obtained for p_0 and g_1, respectively, if $\ell = 2$ is assumed; an $\ell = 1$ would not have fitted at all. Note that our value of ℓ agrees with the totally independent determinations of Watson (1988) and Cugier et al. (1994) quoted in Table 1.
2. For β Cru the result is the same as for α Vir A, i.e., p_0 and $\ell = 2$, but the fit is not as good.
3. For β CMa both observed modes can be fitted. One (probably the $P_1 = 0.25003$ d mode) with p_1 and $\ell = 0$, and the other ($P_2 = 0.25129$ d), with g_1 and $\ell = 2$. An $\ell = 1$ would also be a possibility if the overshooting were neglected.

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Table 1. The four β Cep stars in the fundamental H-R diagram

Name	Period(s) [d]	Radius [$R_\odot$]	Mass [$M_\odot$]	ℓ	Source of ℓ
β Cru	0.19119	8.6 ± 0.6	15.2 ± 1.1	2	(2),(3)
β CMa	0.25129	9.0 ± 1.0	13.5 ± 1.1	2	(1)
	0.25003			?	
α Vir A	0.1738	7.7 ± 0.6	11.5 ± 0.6	2	(2)
ϵ Cen	0.16961	6.2 ± 0.7	11.8 ± 0.8	2	(3)

(1) Ledoux (1951), (2) Watson (1988), (3) Cugier et al. (1994)

Ledoux (1951) has shown that identifying the P_2, P_1 doublet with two components of a rotationally split $\ell = 2$ mode is contradicted by observations.
4. For the data at hand, the standard deviation of the dimensionless frequency, s_σ, is determined by the ratio of θs_π to π, where s_π is the standard deviation of π. Decreasing s_π by a factor of 2 would decrease s_σ by a factor of 1.6. Further improvement of the accuracy of σ would require not only more accurate parallaxes but also better angular diameters.

Acknowledgments. Research supported by KBN grant 5 P03D 014 20.

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Discussion

C. Aerts : The mode identifications you gave for β Cru and ϵ Cen are not supported by LPV studies.

M. Jerzykiewicz : The discrepancies between the LPV and photometric identifications of the spherical harmonic degree ℓ are well known (see, e.g., Dziembowski & Jerzykiewicz, 1999). I tend to believe the photometric ones.

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