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The role of turbulent pressure and shell thickness in one-zone convective models

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Abstract. We present a set of one-zone models that account for the coupling between pulsation and convection. The turbulent pressure term is taken into account and we identify well-defined regions in the space of parameters where the models approach limit-cycle stability (pulsational instability) for both radiative-dominated and completely convective models. Numerical experiments performed indicate that the turbulent pressure acts as a driving mechanism for Long Period Variables.

Key words. Stars: atmospheres – Stars: oscillations – Stars: variables: Cepheids – Stars: AGB – Methods: numerical

1. Introduction

The simplest one-zone model that accounts for the time-dependent coupling between pulsation and convection was suggested by Stellingwerf (1986). He computed models associated to the Cepheid instability strip, disregarding the long-term behavior. His results support the generally-accepted view that convection is a damping mechanism for models located close to the cool edge of the instability strip. In this work, we present an extended version of the one-zone model, investigating the limit-cycle behavior and accounting for the role of the turbulent pressure and of the thickness of the convective layer.

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2. The model

The model has an equilibrium radius R_0 and a one-zone envelope of variable radius R on top of a compact core of radius R_c. The equation of motion, of convective transport and the energy equation provide the dynamical system describing the temporal evolution of the radius $X \equiv R/R_0$, the nonadiabatic pressure H and the convective velocity U_c of the one-zone envelope — equations 33 to 35 in Stellingwerf (1986). In the present work we have introduced explicitly the turbulent pressure mentioned in Stellingwerf (1986) which was not taken into account in that work. The derivation of the final nonlinear convective equations are

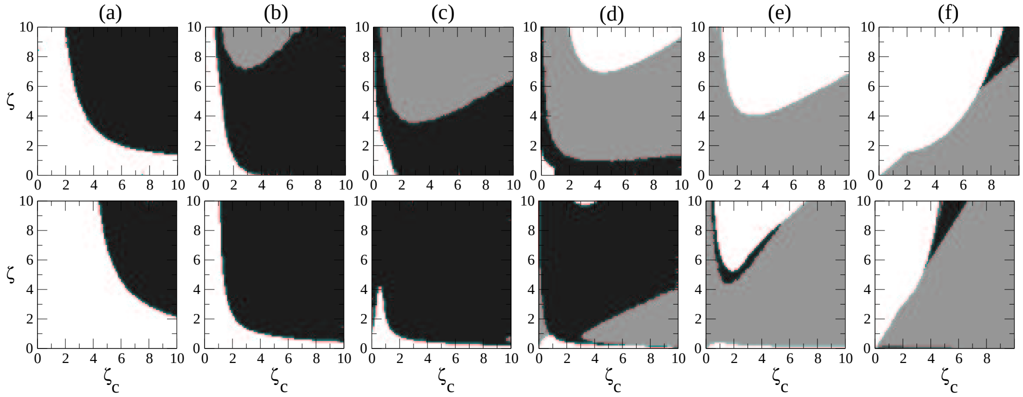

Fig. 1. The (ζ, ζ_c)-plane for several values of γ_c, representing pulsationally unstable (black), pulsationally stable (grey) and vibrationally unstable behavior (white). The parameters adopted to construct the individual cases are : η = 0.888 and *(a)* γ_c=0.1, *(b)* γ_c=0.2, *(c)* γ_c = 0.3, *(d)* γ_c=0.4, *(e)* γ_c=0.5 and *(f)* γ_c=1.0; *(upper panels)* no turbulent pressure and *(lower panels)* turbulent pressure included.

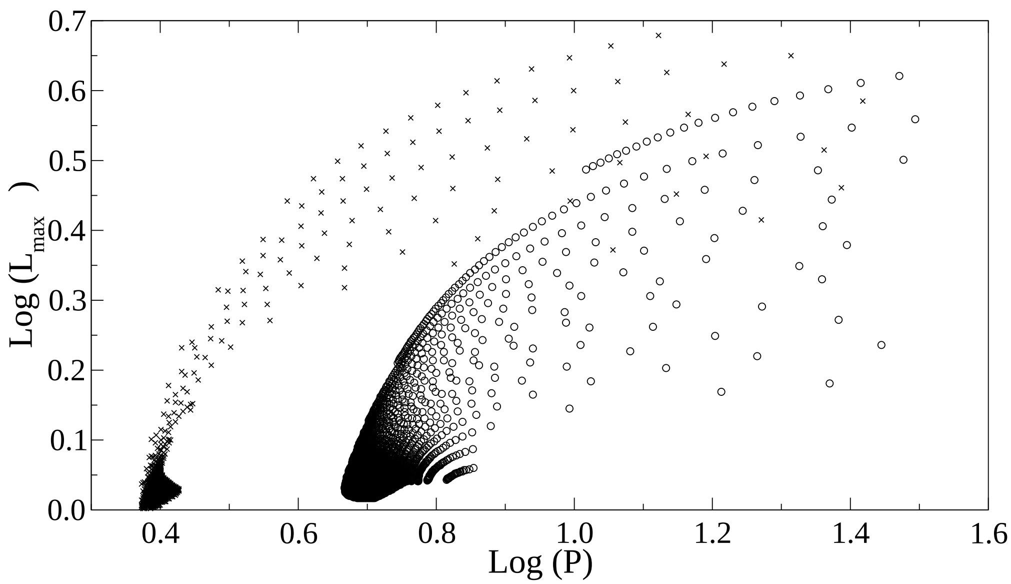

Fig. 2. Period versus maximum luminosity for γ_c=0.4, η=0.75 (thick shell) *circles* and η=0.888 (thin shell) *crosses*. Turbulent pressure is included.

detailed in Munteanu et al. (2005). The evolutionary status of the star is reflected in the shell thickness $\eta \equiv R_c/R_0$ and in the convective/radiative luminosity splitting at equilibrium, $\gamma_c \equiv L_{c,0}/(L_{c,0}+L_{r,0})$, with "r" and "c" subscripts referring to convective and radiative components, respectively. As in Stellingwerf (1986), we associated a value of η = 0.888 and γ_c < 0.5 for a Cepheid model, while the case γ_c = 1.0 characterizes red giants and supergiants. Besides γ_c, our control parameters are: the dynamical to thermal time scales ratio, ζ, and the dynamical to convective time scales ratio, ζ_c (Munteanu et al. 2005).

3. Results and discussion

We present in Fig. 1 the results concerning the (ζ, ζ_c)-plane showing the limit-cycle behavior and in Fig. 2, the influence of the shell thickness on the period distribution. The turbulent pressure removes the sharp discontinuities along the light and velocity curves and also leads to the formation of an instability-strip behavior (panel *d*). The light and velocity curves obtained in the transition from the hot (low ζ_c) to cool (high ζ_c) are in good agreement with those resultant from high-resolution nonlinear models. While no limit-cycle regions exist for $\gamma_c \in (0.5, 1.0)$ and $\zeta, \zeta_c \in [0, 10]$, limit-cycle models exist for the γ_c=1.0 (panel *f*). This behavior marginally depends on the value of the adiabatic exponent, and thus the driving is indeed induced by convection and turbulent pressure. In spite of the simple one-zone modeling, this is a very interesting finding and we attribute this case to the instability strip of variable red giants and supergiants.

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