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Nonlinear pulsation models of red giants

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Abstract. We present results of 1D hydrodynamical calculations for two red giant models which include a time dependent turbulent convection model. The calculations indicate that the inclusion of a turbulent viscosity in the models may be what is required to bring the model pulsation amplitudes down into agreement with observations. Calculations for a high mass and luminosity model show a double-peaked light curve comparable, to that observed for high luminosity LMC Miras.

Key words. hydrodynamics – stars: late-type – stars: oscillations

1. Introduction

It is now reasonably well established that Mira variables pulsate in the fundamental mode. Currently, there are no satisfactory models for red giants pulsating in the fundamental mode at large amplitude. Existing models tend to be driven too hard and have excessive amplitudes. The linear stability analysis of Xiong, Deng & Cheng (1998) indicates that turbulent pressure and turbulent viscosity play an important role in the pulsation dynamics of red giants. Currently, published calculations of nonlinear models for red giants ignore this dynamical coupling of the convection with pulsation. Here we present two red giant models from a nonlinear radial pulsation code which includes the time dependent convection model of Kuhfuß (1986). Table 2 shows the model parameters for the two models. Further details can be found in Olivier (2004).

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2. Results

Most of the energy flux in the interior is due to convection with the turbulent diffusive flux being less than 2% of the total flux. Also the turbulent pressure is not negligible as its gradient is significant at the outer edge of the convection zone. Fig. 1 shows the luminosity, velocity and radius variations of the 1 $M_{\odot}$ model at limit cycle. The model is pulsating in the fundamental mode with a bolometric amplitude consistent with that expected of such stars ~0.8 mag (Feast et al. 1982). The model, however, does show luminosity spikes that are not observed in real stars. We note that for a model with α_{μ}=0, a bolometric amplitude of ~1.3 mag was found at its limit cycle. The model has a period of ~ 320 days.

Fig. 2 shows that most of the pulsation driving occurs in the H ionization zone. Turbulent pressure only has a small nett damping effect, with turbulent viscosity the dominant damping mechanism in this model. In the

Table 1. Model parameters with $Z = 0.01$

$M/M_\odot$	$L/L_\odot$	$\mathrm{Log}\,T_{eff}$	α_Λ	α_t	α_μ
1.00	5000	3.47	1.3	0.7	0.5
5.00	35000	3.52	1.4	0.7	0.5

driving regions the nett input of energy during a pulsation cycle should be positive, to be available to do work. The energy input over the whole stellar envelope is of course zero over one cycle. The nett convective energy input is positive in the driving regions, while the nett radiative energy input is negative. This leads one to speculate that the driving mechanism for these stars is strongly related to the variation of the convective flux in the H ionization region during pulsation.

The $5\,M_\odot$ model shows a clearly defined double peaked light curve with a period of ~515 days (Olivier & Wood 2005). It is known that some high luminosity (and intermediate mass) Mira light curves do have a double peaked shape.

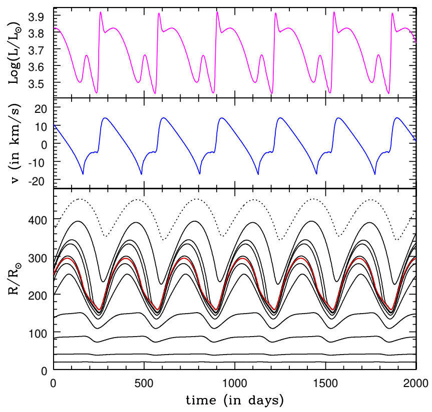

Fig. 1. Various quantities plotted against time for the low mass model. Bottom panel: radius variation of 10 mass zones (black), surface radius (dotted) and at $\tau = \frac{2}{3}$ (red). Middle panel: velocity variation at $\tau = \frac{2}{3}$. Top panel: surface luminosity variation.

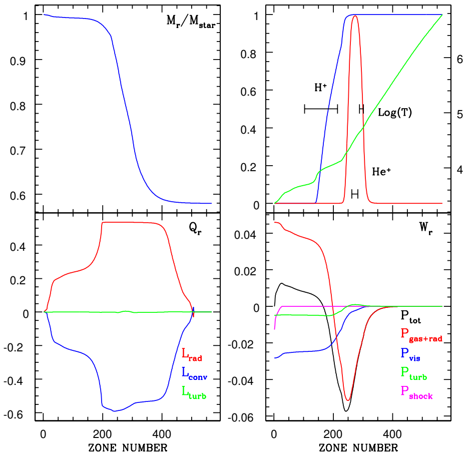

Fig. 2. Various quantities plotted against zone number for the low mass model. Top left: Mass fraction. Top right: Curves are for H^+ and He^+ ionization fractions and temperature for a model at ~320 days in Fig. 1. Horizontal lines delineate motion of 50% H^+, maximum of He^+ and 50% He^{++}. Bottom left: Integrands, from core to surface, of the energy transferred per zone per pulsation cycle in 10^{45} ergs. Bottom right: Integrands, from core to surface, of work done per zone per cycle in 10^{45} ergs.

3. Conclusions

We have presented two nonlinear red giant pulsation models which include a time dependent turbulent convection model. The turbulent viscosity parameter α_μ shows potential as an important determinant of the pulsation amplitude. A value of α_μ=0.5 is effective in giving the correct bolometric amplitude for the low mass model.

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