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Survey of hydrodynamic RR Lyrae models

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Abstract. We present a grid of hydrodynamic RR Lyrae-type models covering a large range of physical parameters. These models were computed with the aim to analyse the mode selection in these stars and to search for the Blazhko-type modulation. Initial results of the survey are reported.

1 The data base of hydrodynamic RR Lyrae models

All models were computed with the Warsaw non-linear, convective pulsation codes [1]. Radiation is treated in the diffusion approximation and turbulent convection is treated with the model of Kuhfuß [2]. Each of the Lagrangian models comprise 150 mass shells extending down to 2×10^6 K. In the non-linear computations, each pulsation cycle is covered by at least 600 time-steps. All models adopt OPAL opacities [3] and Asplund et al. [4] solar mixture. Colors are computed using Kurucz [5] model atmospheres. The basic grid of physical parameters for non-linear models is presented in Tab. 1. Linear stability analysis is conducted in a much wider parameter range. Several sets of convective parameters that enter the turbulent convection model are considered. The full grid of models, with more than 10 000 light curves, will be published as an on-line database in 2015.

Table 1. The grid of physical parameters of models in the non-linear survey.

parameter	values
[Fe/H]	−2.5, −2.0, −1.5, −1.0, −0.5, 0.0
$M/\mathrm{M}_\odot$	0.50, 0.55, 0.60, 0.65, 0.70
$L/\mathrm{L}_\odot$	40.0, ..., 60.0, step 2.5
T_{eff}	step 50 K (within instability strip)

2 Mode selection problem

With radiative calculations stable double-mode pulsation cannot be found (e.g. [6]). Inclusion of the turbulent convection in the Florida-Budapest code led to success for both Cepheid and RR Lyrae models [7,8]. In Smolec & Moskalik [9,10] we showed however, that the double-mode Cepheid pulsation in these models is caused by unphysical neglect of negative buoyancy in convectively stable regions. Once buoyancy is properly treated, stable, non-resonant double-mode Cepheid pulsation cannot be found.

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In this study we analyse the problem for RR Lyrae models. Mode selection analysis comprise of few steps (see e.g.[9]). For each of the models non-linear integrations are carried with few different initial conditions. The growth of amplitudes of the fundamental and first overtone modes is followed using the analytical signal method (e.g. [8]), which yields hydrodynamic trajectories. Next, we fit these trajectories with amplitude equations to get the saturation coefficients. Finally amplitude equations are solved, yielding all possible fixed points and their stability. The procedure is repeated along a horizontal (L = const) model sequence and derived saturation coefficients allow to deduce the mode selection for arbitrary effective temperature and finally in the full HR diagram.

So far, our search for stable double-mode pulsation yielded negative result. The typical mode selection scenario we find is the following: first overtone pulsation on the hot side of the instability strip, fundamental mode pulsation on its cool side and either-or domain in between. In the either-or domain, model pulsates either in the fundamental mode or in the first overtone, depending on initial conditions (direction of evolution). Since double-mode pulsators exist and are numerous, we conclude that the modelling of double-mode RR Lyrae pulsation remains an open issue (just as in the case of classical Cepheids).

3 Search for the Blazhko-type modulation

The Blazhko effect is a quasi-periodic modulation of pulsation amplitude and phase which affects nearly 50% of stars pulsating in the fundamental mode (for a review see [11]). Despite being discovered more than 100 years ago, its physical origin remains unclear. Among many models proposed to explain the phenomenon, the model of Buchler & Kolláth[12], in which modulation is caused by the half-integer resonance between the radial modes (9:2 resonance between the fundamental mode and the ninth overtone, $P_{\rm F}/P_{\rm 9O} = 9:2$) is the most promising one. It is supported by the analysis of amplitude equations and recent *Kepler* observations (see [11]), but lacks confirmation from hydrodynamic modelling.

We searched for Blazhko-type modulation in our RR Lyrae models, unfortunately, it was not found so far. In the models with decreased eddy-viscous dissipation, we find period doubling effect, caused by the half-integer resonance, but not modulation akin to the Blazhko modulation.

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