Theoretical Implications of Triple-Mode RR Lyrae Pulsations

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Abstract

We argue that triple-mode RR Lyrae pulsation with low amplitudes might be quite common. It is shown that until very accurate abundance data become available, triple-mode RR Lyrae stars are the only hope to estimate reliable stellar parameters from the periods alone.

1. Introduction

The motivation of this study comes from the following observations: (1) most of the radiative RR Lyrae models are *linearly excited* in some range of temperature in the three lowest order radial modes; (2) many RR Lyrae stars show *non-repetitive* light variation. Accurate photoelectric observations might reveal some low-amplitude mode contamination (*e.g.* Fernley *et al.* 1990); (3) marginally stable modes in a limit cycle may oscillate at low amplitudes because of *stochastic mode excitation* (Kovács and Buchler, in preparation). Some high-amplitude δ Scuti stars seem to support the existence of such a multimode pulsation (*e.g.* Walraven *et al.* 1992).

We address the following questions in this note: (a) How much the knowledge of the periods of the first three radial modes constrains the derived stellar parameters? (b) Is there any limit cycle in which the other two modes are simultaneously marginally stable?

2. Determination of M and Z

A large number of RR Lyrae models have been computed in the range $0.6 - 0.9$, $40 - 70$, $6000 - 8000$ for M, L and T_{eff} respectively. Two sets of models have been computed for $Z = 0.0001$ and $Z = 0.001$, both with $X = 0.7$ and with solar (*i.e.* Anders-Grevesse) mixtures. We used the opacities published by Rogers and Iglesias (1992).

The novel sensitivity of the period ratios on Z due to the revised opacities seriously jeopardizes the applicability of the single period ratio method for the mass determination. For three periods, however, the effect of Z can be largely eliminated. The $P_1/P_0 - P_2/P_0$ *versus* P_0 diagram shows very little dependence on Z (Fig. 1).

In conclusion, if three periods are known, then the $P_0 \rightarrow P_1/P_0 - P_2/P_0$ diagram can be used for a mass determination. With this mass, the $P_0 \rightarrow P_2/P_0$ diagram constrains the metal abundance.
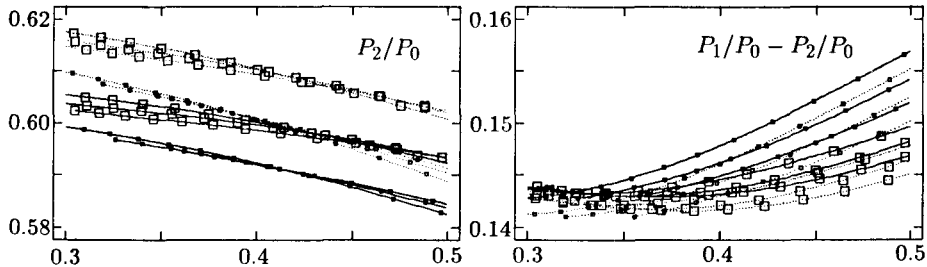

Figure 2. Period ratio diagrams. *Dotted lines:* $Z = 0.0001$, *solid lines:* $Z = 0.001$; *small squares:* $M = 0.6$, *large squares:* $M = 0.8$. At each mass three luminosity values are plotted with $L = 40, 50, 60$. Horizontal axis: P_0 in [day].

3. Limit cycle stability

One possible scenario for triple-mode RR Lyrae pulsation is that the marginally stable modes in a limit cycle get stochastically excited due to turbulent convection. A limit cycle analysis of a sequence of RR Lyrae models showed that *simultaneous marginal stability* is possible only in the *second overtone* limit cycle. Predictions of evolution calculations do certainly allow (re)entering into the instability strip from the very hot side, where only the second overtone could be excited.

4. Conclusions

Theoretical considerations suggest that triple-mode RR Lyrae pulsation is possible. If it is observed, the periods put further significant constraints on the stellar parameters (especially on M and Z) over those of the traditional single period ratio method. So far only AC And (Fitch and Szeidl 1976) could be possibly identified as a triple-mode RR Lyrae star pulsating in the first three radial modes. For recent analyses of two RRc stars we refer to Peniche *et al.* (1989) and Hobart *et al.* (1991).

Based on the commonly observed non-repetitive variation of the light curves and on the theoretical possibility of triple-mode pulsation, we think it would be very important and profitable to search for low-amplitude pulsations in RR Lyrae stars.

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