RR LYRAE VARIABLES

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1. Historical Overview

On the basis of a historical overview we outline the relevant results which allowed to approach on firm basis the physical mechanisms which govern the radial pulsation of RR Lyrae variables, revealing the astrophysical parameters which account for their limiting amplitude pulsational behavior.

1.1. THEORETICAL ROUTE

After the pioneering papers by Eddington and Schwarzschild, the theoretical approach to the pulsational properties and modal stability of RR Lyrae variables finds its cornerstone in the seminal investigation by Christy (1966). In a series of thorough papers Christy (1968 and references therein) first showed that nonlinear radiative models can reproduce the main observational properties of RR Lyrae. He found, in close agreement with observational data, that first overtone (FO) pulsators are located at mean effective temperatures larger than the fundamental (F) ones. However, one of the main drawbacks of Christy's approach was that the bulk of the computed envelope models were followed in time only for a small number of periods and therefore they could supply only plausible guesses concerning the approach to limit cycle stability of radial motions.
This problem was solved by Stellingwerf (1974) and von Sengbusch (1975) who developed a relaxation method for evaluating the limiting amplitude modal behavior based on a linear perturbation analysis (*Floquet coeffi-*

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cients) at each limit cycle and at the origin. A further problem properly settled by Stellingwerf (1975) was the method for handling, through the artificial viscosity pressure, the development and the propagation of shocks both in the ionization zones and in the deeper layers of stellar envelopes. At the same time he was also able to put on a more secure physical basis the destabilization due to both hydrogen and helium ionization regions.

All along the seventies, although several relevant agreements, both linear and nonlinear calculations could not account for the quenching of the pulsation instability close to the red edge of the instability strip. Baker & Kippenhahn (1965), on the basis of linear nonadiabatic models including a mixing-length theory of convection, had earlier suggested that the damping of the pulsation was induced by convection. However, the linear and nonlinear calculations for evaluating F and FO red edges were at odds with observational data (Baker & Gough 1979). This thorny and long-standing problem was solved by Deupree (1979) and Stellingwerf (1982) who developed two different formulations to account for the coupling between radial pulsation and convective motions. In particular, Stellingwerf (1984 and references therein) by adopting a 1-D, nonlinear, nonlocal and time-dependent treatment of convection succeeded in evaluating, at fixed astrophysical parameters, the pulsation quenching caused by convection and therefore the location in the HR diagram of cool RR Lyrae instability boundaries. Subsequent improvements and refinements of this approach confirmed the overall theoretical scenario (Gehmeyr 1993), casting light on the role played by limiting amplitude calculations on modal behavior and pulsational amplitudes (Bono & Stellingwerf 1994) and their dependence on astrophysical parameters (Bono et al. 1997a).

1.2. OBSERVATIONAL ROUTE

The discovery and the first systematic searches for RR Lyrae variables in Galactic globular clusters date back to the observational investigations provided by Shapley and Bailey. However, Baade first recognized the paramount role played by *cluster-type variables* (this was the name originally adopted for RR Lyrae) for tracing the spatial distribution in the Galaxy of what we now call population II stars. One of the first important results obtained by Baade (Osterbrock 1996 and references therein) was that RR Lyrae were not an intrinsic property of globular clusters since in his search for RR Lyrae in three different clusters he found several variables of the same type in the field well outside the clusters. On the basis of the constancy of the mean absolute magnitude of RR Lyrae previously discovered by Shapley, he also suggested that these objects do not belong to the Galactic plane and that their "distances are comparable with those of the globular clusters".

RR Lyrae and globular clusters were the crown witnesses of a spherical and high space velocity stellar population, whereas the eclipsing variables were the tracers of a stellar population characterized by a flat distribution and low space velocities. The kinematics properties of these objects provided by Lindblad and Oort strengthen the observational scenario which led Baade to the pivotal discovery of two different stellar populations (Baade 1944).

Another seminal result obtained by Baade was the discovery of a large number of RR Lyrae in a region of the Galactic bulge that we now call *Baade's window* (BW). At the Vatican Conference on "Stellar Populations", he pointed out a "very curious" observational evidence concerning this group of variables. The period distribution of RR Lyrae in the BW showed a peak at P=0.33 days and, in contrast with variables in globular clusters characterized by the same periods, they presented asymmetrical light curves and canonical pulsational amplitudes (Baade 1958).

The Galactic RR Lyrae observational scenario was partially stirred up by the photometric and spectroscopic data collected by Preston (1959). In this investigation Preston introduced the ΔS parameter as a metallicity indicator and applied it to field RR Lyrae. The data presented in that paper show that there are at least three important "departures" from the common "mean" properties of RR Lyrae known at that time. In fact, he found that field short-period RRab (fundamental) variables are characterized by low ΔS values -i.e. high metal contents-, that they are distributed close to the Galactic plane and present small radial motions relative to the sun, in contrast with metal-poor variables which resemble the "pure population II" halo stars. The subtle consequence of this and of the subsequent thorough investigations is that the pulsational behavior and the rotational kinematic of RR Lyrae in different Galactic components (disk, bulge, halo) present substantial variations and therefore can be adopted as fundamental diagnostic tools of the Galactic structure (Suntzeff et al. 1991; Layden 1995 hereinafter L95).

In the last few years the modal behavior and both the evolutionary and pulsational properties of metal-poor RR Lyrae in globular clusters have been widely discussed (see e.g. Sandage 1993; Bono et al. 1997a). Nevertheless, only recently a detailed theoretical analysis of the evolutionary and pulsational characteristics of metal-rich RR Lyrae has been provided (Bono et al. 1997b,c and references therein).

The main aim of this paper is to discuss the comparison between theoretical predictions and observational data in the period metallicity plane and in the Bailey diagram (pulsational amplitude vs period). The reader interested to a more detailed analysis of both F and FO pulsators in the BW and in the Galactic field is referred to Bono et al. (1997c). In the final section we briefly outline some future developments.

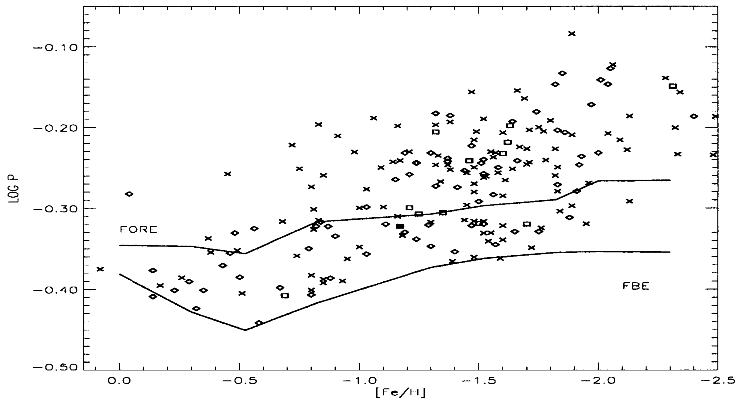

Figure 1. Pulsational periods as a function of metal abundance for Galactic field RRab variables collected by L95. The solid lines show the fundamental blue edge and the first overtone red edge. Crosses and squares are referred to variables with uncertain or unknown blue amplitudes and uncertain ΔS values respectively.

2. Field RR Lyrae Variables

As a first step in disclosing the evolutionary and pulsational properties of RRab variables we take into account the variation of the pulsational period as a function of the metal content. Figure 1 shows in this plane the data collected by L95. The metallicity indicators provided by the quoted author have been transformed into the Zinn & West (1985) metallicity scale by adopting the relation suggested by Suntzeff, Kinman & Kraft (1991). In this figure the Fundamental Blue Edge (FBE) and the First Overtone Red Edge (FORE) are also plotted. The theoretical periods have been evaluated by convolving, at selected metal contents, the stellar mass and the luminosity level predicted by ZAHB evolutionary calculations with the FBE and the FORE constructed by adopting the same input parameters (M, L, χ).

The agreement between theoretical predictions and observational data is quite satisfactory and some features of this figure are worth noting: 1) field variables are affected by the Oosterhoff dichotomy and indeed metal-poor variables ($[Fe/H] < -1.4$) are characterized by longer mean periods since the transition takes place close to the FORE, thus resembling Oosterhoff type II clusters. On the other hand, at higher metal contents the mean periods decrease since the transition takes place at the FBE, thus resembling Oosterhoff type I clusters. 2) Moving toward higher metal abundances the period at the FBE decreases. In fact, in agreement with observational data and with the Baade's "very curious" evidence, we find that at $[Fe/H] \approx -0.6$ the period at the FBE is approximately equal to 0.35 days. The subsequent increase at higher metal contents is mainly due to

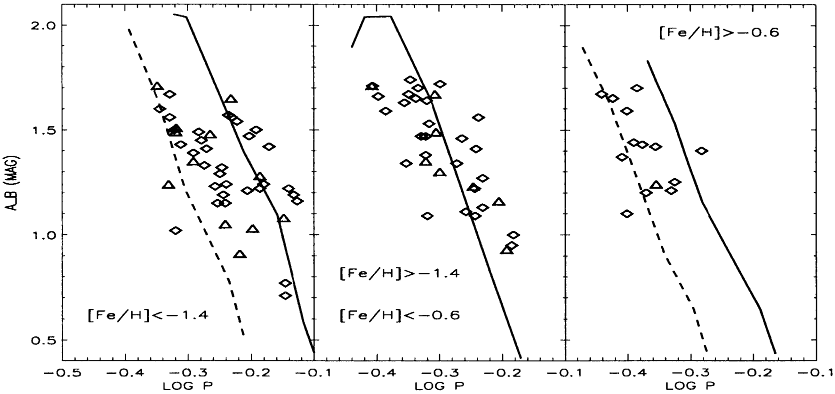

Figure 2. Bailey diagram, B amplitude versus period, for Galactic field RRab variables collected by L95. Each panel is referred to a different range of metallicity, see labeled values. The lines plotted in each panel show the theoretical amplitudes. Triangles are referred to variables with uncertain blue amplitudes.

the increase in the helium abundance since at these metallicities the range of stellar masses which populate the instability strip narrows and therefore the ZAHB luminosity levels attain quite similar values. This finding is quite interesting since the comparison between predicted and observed periods can provide useful constraints on the value of the enrichment ratio between helium and heavy elements in low-mass stars (Carigi et al. 1995).

Figure 2 shows the comparison into the Bailey diagram between predicted and observed field RRab amplitudes. The bolometric amplitudes have been transformed by adopting Kurucz's atmosphere models (1992). This figure shows quite clearly that the overall agreement is much less satisfactory. In fact, the theoretical amplitudes for metal-poor variables are in reasonable agreement with observational data, whereas for metal-intermediate and metal-rich variables the predicted amplitudes are systematically larger. In order to account for this effect we cannot rule out that the transformation from bolometric into B amplitudes through static atmosphere models could be affected by uncertainties and/or by systematic errors. Nevertheless, the large discrepancy (≈ 0.5 mag) we find at fixed period for metal-rich variables cannot be only due to transformation errors, since the same effect should be also present among metal-poor pulsators. However, let us note that this odd group of variables can be properly explained by assuming "young" metal-rich pulsators (i.e. $t \approx 1 - 2$ Gyr) since in this context the theoretical period-amplitude relation moves toward shorter periods. Finally it is worth underlining that quite recently a similar evidence of "young" low-mass stars in the solar neighborhood has been suggested by Gonzalez (1997) in his spectroscopic investigation of a sample of "51 Pegasi" stars.

3. Final Remarks

It is hardly necessary to point out the wide range of astrophysical parameters and questions in which RR Lyrae play a key role for properly addressing the evolutionary and pulsational behavior of low-mass stars. In this paper we briefly discussed a new theoretical scenario for metal-rich RR Lyrae stars developed by taking into account evolutionary and pulsational models. The comparison with current available data prompts that a subgroup of such variables could be much "younger" than previously assumed.
However, thanks to an unprecedented "Shapley mass production approach" (Osterbrock 1996), the microlensing experiments (EROS, MACHO, OGLE) collected huge photometric databases that, as soon as they are calibrated and complemented by metallicity and radial velocity evaluations, can become a fundamental benchmark for testing theoretical models. At the same time, a substantial improvement in the evaluations of astrophysical parameters based on RR Lyrae pulsational properties could be soon achieved.

References

Baade, W. 1944, ApJ, 100, 147
Baade, W. 1958, in Stellar Populations, ed. D.J.K. O'Connell, (Amsterdam: North Holland), 303
Baker, N. H., & Gough, D. O. 1979, ApJ, 234, 232
Baker, N. H., & Kippenhahn, R. 1965, ApJ, 142, 868
Bono, G., Caputo, F., Castellani, V., & Marconi, M. 1997a, A&AS, 121, 327
Bono, G., Caputo, F., Cassisi, S., Castellani, V., Incerpi, R., & Marconi, M. 1997b, ApJ, 478, April 10
Bono, G., Caputo, F., Cassisi, S., Incerpi, R., & Marconi, M. 1997c, ApJ, 283, July 10
Bono, G., & Stellingwerf, R. F. 1994, ApJS, 93, 233
Carigi, L., Colin, P., Peimbert, M., & Sarmiento, A. 1995, ApJ, 445, 98
Christy, R. F. 1966, ApJ, 144, 108
Christy, R. F. 1968, QJRAS, 9, 13
Deupree, R. G. 1979, ApJ, 234, 228
Gehmeyr, M. 1993, ApJ, 412, 341
Gonzalez, G. 1997, MNRAS, 285, 403
Kurucz, R. L. 1992, in IAU Symp. 149, The Stellar Populations of Galaxies, eds. B. Barbuy & A. Renzini (Dordrecht: Kluwer), 225
Layden, A. C. 1995, AJ, 110, 2288 (L95)
Osterbrock, D. E. 1996, Jour. for the History of Astron., 27, 301
Preston, G. W. 1959, ApJ 130, 507
Sandage, A. F. 1993, AJ, 106, 719
Stellingwerf, R. F. 1974, ApJ, 192, 139
Stellingwerf, R. F. 1975, ApJ, 195, 441
Stellingwerf, R. F. 1982, ApJ, 262, 330
Stellingwerf, R. F. 1984, ApJ, 284, 712
Suntzeff, N. B., Kinman, T. D., & Kraft, R. P. 1991, 367, 528
von Sengbusch, K. 1975, Mem. Soc. Roy. des Sci. de Liege, 6, VIII, 189
Zinn, R., & West, M. J., 1984, ApJS, 55, 45