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PERIOD CHANGES OF 23 FIELD RR LYRAE STARS [1]

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ABSTRACT

The secular period behavior of 23 field RR Lyrae stars is studied in order to determine if the observed period changes could be attributed, at least in the mean, to stellar evolution. The sample of stars is subdivided into two Oosterhoff groups based on the metallicity and period-shift. Despite the small sample size, we found a distinct bias toward positive period changes in the group II variables. The period changes of the group I variables, however, are small and in the mean near zero. This is consistent with the behavior predicted by the recent evolutionary models, as was the case for the variables in globular clusters. This provides yet another support for the Lee, Demarque, and Zinn (1990) evolutionary models of RR Lyrae stars and their explanation of the Sandage period-shift effect.

1. INTRODUCTION

According to the theory of stellar pulsation (van Albada and Baker 1971), the fundamental period (P_f) of a RR Lyrae star is a function only of luminosity L, mass M, and effective temperature T_{eff}:

$$\log P_f = 0.84 \log L - 0.68 \log M - 3.48 \log T_{eff} + 11.497, \qquad (1)$$

where P is in days and L and M are in solar units. Consequently, the periods of RR Lyrae stars should be either increasing, if the stars evolve from blue to red in the HR diagram, or decreasing, if they evolve from red to blue (cf. Eddington 1918).

In his recent theoretical investigation of the secular period changes of RR Lyraes in five best studied globular clusters, Lee (1991) has shown that most of the observed

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period changes could be attributed to the evolutionary effects. For variables in metal-rich Oosterhoff group I clusters (e.g., M3, M5), the evolutionary tracks run first blueward, then redward at slightly higher luminosities (see Fig.1 of Lee *et al.* 1990). The rate of blueward evolution through the instability strip is relatively slow, giving a small negative rate of period change. Faster positive period changes occur as the redward evolution proceeds. For the metal-poor Oosterhoff group II clusters (e.g., M15, ω Cen), all stars within the instability strip are predicted to evolve redward from the blue side of the instability strip (see Fig.2 of Lee *et al.* 1990), producing a large positive rate of period change. Therefore, in the Oosterhoff group I clusters, where the majority of RR Lyrae stars are near the zero-age horizontal-branch (ZAHB), the period change rates are predicted to be small and in the mean zero, whereas in the group II clusters, where most of the RR Lyrae stars are evolving from blue to red toward the end of their core helium burning phase, large positive period change rates are predicted.

The purpose of the present paper is to investigate whether the period change behavior of field RR Lyrae stars is similar to that of RR Lyraes in globular clusters. The field RR Lyrae stars are at the heart of the recent debate on the Sandage (1982, 1990b) period shift effect (Lee 1990, Caputo and De Santis 1992), and hence it is of considerable importance to determine whether the observations of these stars are consistent with the Lee *et al.* (1990) evolutionary models.

2. THE SAMPLE OF FIELD RR LYRAE STARS

The sample of 23 field RR Lyrae stars was compiled from the literature (Tsesevich 1969, Lub 1977, Hübscher *et al.* 1987, 1989, 1990, Fernley *et al.* 1990), where one can find period and maximum light times of these variable stars from the previous observations. These observations span enough time intervals ($\sim$ 80 yrs) to detect the period changes. Table 1 lists the variables separated into two Oosterhoff groups. These two groups are expected to have different evolutionary condition and therefore have different mean period change behavior. In this table, columns (1) and (2) give the variable name and period obtained from Tsesevich (1969). Metal abundance indicator Δs of Preston (1959) are listed in column (3). Column (4) lists the blue amplitude (in magnitudes) taken from Sandage (1990b, see his Table 3). The metallicities of column (5) are on Zinn and West (1984) scale obtained from Δs observations of Butler (1975). The period-shifts at constant amplitude, $\Delta \log P(A_B)$, of column (6) is defined as the difference in period between a variable and the fiducial line of M3 variables at constant amplitude (see Sandage 1990a for the M3 fiducial line). References for periods and maximum light epochs are given in

Table 1. Sample of Field RR Lyrae Stars.

Name (1)	$\log P$ (2)	Δs (3)	A_B (4)	$[Fe/H]_{ZW}$ (5)	$\log P(A)$ (6)	References (7)
			Group I			
AA Aql	-0.442	0	1.78	-0.45	-0.077	a,b,c
SW Aqr	-0.338	5	1.74	-1.24	0.021	a,b
BR Aqr	-0.317	3	1.52	-0.92	0.014	a,b
CP Aqr	-0.334	3	1.70	-0.92	0.020	a,b
TT Cnc	-0.249	7	1.29*	-1.56	0.052	a
RU Cvn	-0.242	6.3*	1.41*	-1.45	0.075	a
RY Com	-0.329	3	1.56*	-0.92	0.007	a
SW Dra	-0.244	3	1.22*	-0.92	0.048	a,c,d,e
TW Her	-0.398	2	1.66*	-0.77	-0.049	a,c,d
VX Her	-0.342	5	1.72	-1.24	0.015	a,b,c,d,e
VY Lib	-0.273	6.3*	1.46	-1.45	0.050	a,b
IO Lyr	-0.239	3	1.24*	-0.92	0.056	a,d
ST Oph	-0.340	6	1.79	-0.40	0.026	a,b,e
V445 Oph	-0.401	1	1.27	-0.61	-0.102	a,b,f
TU UMa	-0.254	6	1.15*	-1.40	0.030	a,e
ST Vir	-0.386	0.8*	1.59*	-0.57	-0.046	a
UU Vir	-0.323	2	1.50	-0.77	0.005	a,b
			Group II			
BO Aqr	-0.159	6	1.51	-1.40	0.171	a,b
UY Boo	-0.187	10	1.54	-2.04	0.147	a,b,d
SV Eri	-0.146	9	1.13	-1.88	0.105	a,d
SS Leo	-0.203	7	1.47	-1.56	0.122	a,b,f
TV Leo	-0.172	10	1.62	-2.04	0.172	a,b
AT Ser	-0.127	9	1.24	-1.88	0.168	a,b

* From Table 1. of Blanco (1990)

[a] Tsesevich (1969)

[b] Lub (1977)

[c] Hübscher *et al.* (1987)

[d] Hübscher *et al.* (1989)

[e] Hübscher *et al.* (1990)

[f] Fernley *et al.* (1990)

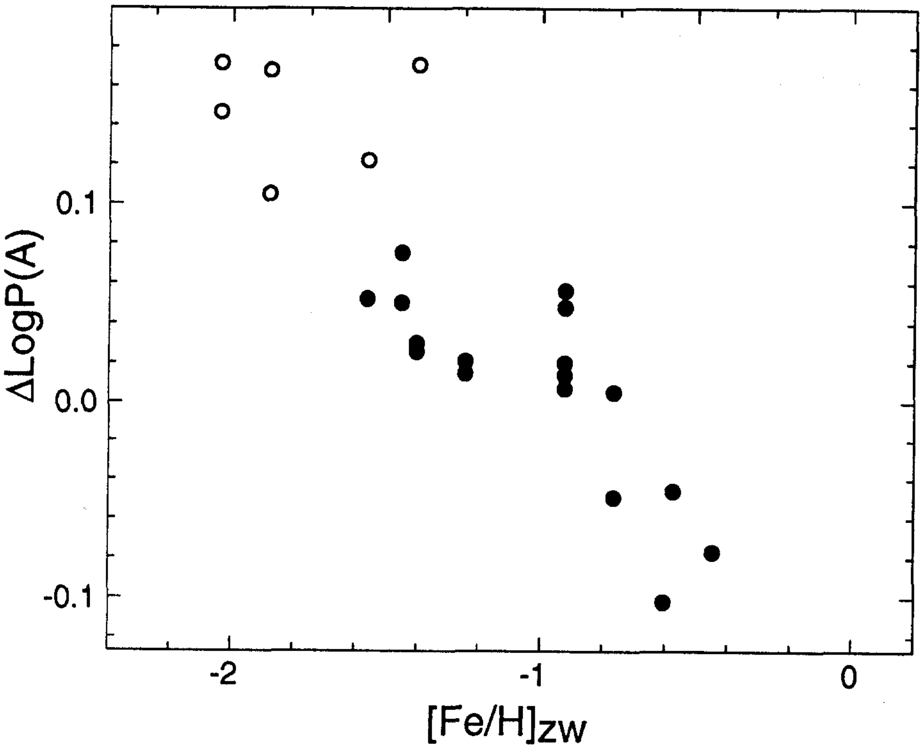

Figure 1. Correlation of the period shift(at constant amplitude) with metallicity for 23 field RR Lyrae stars. The filled and open circles denote the group I and group II variables, respectively(see text).

column (7). The subdivision of the field RR Lyrae stars into two Oosterhoff groups is based on the period-shift and metallicity. The field star correlation of period shifts at constant amplitude $[\Delta \log P(A_B)]$ with [Fe/H] is shown in Figure 1, from the data listed in Table 1. The stars in group I are relatively metal-rich and have small period-shifts like the variables in the Oosterhoff group I cluster M3. Those in group II, however, are relative metal-poor and have large period-shifts as are the variables in the Oosterhoff group II cluster M15. Judging from our previous analyses on field and cluster RR Lyrae variables (Lee 1990), the division was made at [Fe/H] ≈ -1.4 and $\Delta \log P(A_B) \approx 0.08$. It is clear from Figure 1 that the stars are well divided into two groups according to the above criteria.

3. PERIOD CHANGE RATES

Using the photometric data compiled above, period change rates were determined for 23 field RR Lyrae stars by means of the phase shift diagrams. Phases (ϕ) were computed using the following relation:

$$\phi = frac[(JD - JD_o)/period], \tag{2}$$

where "frac[ ]" refers to the fractional part of the argument, and JD_o is the time of an arbitrary zero point epoch. In the phase shift diagrams, the abscissa is the Julian date and the ordinate corresponds to the phase at maximum light (ϕ_{max}). Typically, straight lines, parabolas, or combinations of more than three straight lines, which represent the constant periods, uniformly varying periods, and abrupt period changes, respectively, give adequate descriptions of the obsreved phase shifts as a function of time.

In the case of uniformly varying periods (i.e., constant period change rate), we assume, following Nemec *et al.* (1985), that the period is changing according to

$$P(t) = \alpha + \beta(t - t_o), \tag{3}$$

where $P(t)$ is the period at time t, t_o is an arbitrary zero-point epoch, $\alpha = P(t_o)$, and β is the period change rate dp/dt. Phases are obtained from the relation (see Nemec *et al.* 1985):

$$\phi(t) = \phi(t_o) + (1/\alpha)(t - t_o) + (\beta/2\alpha^2)(t - t_o)^2. \tag{4}$$

Consequently, plotting phases at maximum light, for each epoch, the phase shift relation is in the form of a parabola. By fitting parabolas to the observational points, the period change rate could be determined from the curvature term ($c = \beta/2\alpha^2$). An upward parabola results when the period is increasing (i.e., positive β), and a downward parabola results when the period is decreasing (i.e., negative β). A straight line corresponds to a star of constant period (i.e., $\beta = 0.0$), with the slope of the line being a function of the difference between the true and the assumed periods. If the phase curve is straight horizontal line, period is constant with a assumed period agreeing with the true value (Wesselink 1974, Nemec *et al.* 1985). However, observational evidence seems to indicate that some period changes appear to be sudden from one constant period to another (Wehlau *et al.* 1975). In this case the phase shift diagram will be a series of straight lines of various slopes.

Table 2 and Table 3 list the period change behavior of 23 field RR Lyrae stars of group I and group II, respectively. In both tables, column (1) gives variable

Table 2. Period Change Rates of Field RR Lyrae Stars of Group I.

Name (1)	Period (d) (2)	Epoch (JD) (3)	$10^9 \times c$ (4)	β (d/Myr) (5)	β (cycles/Myr) (6)
BR Aqr(V)	0.4818824	2426578.541	-1.03	-0.17	-0.35
CP Aqr(V)	0.463407	2427634.333	-0.48	-0.08	-0.17
TT Cnc(V)	0.5634445	2425647.452	1.71	0.40	0.70
RU Cvn(V)	0.5732492	2420227.340	-0.45	-0.11	-0.19
VX Her(V)	0.45537282	2421750.483	-1.26	-0.19	-0.42
VY Lib(V)	0.5339413	2425653.691	-0.58	-0.12	-0.23
AA Aql(C)	0.36178688	2424347.397	0.00	0.00	0.00
SW Aqr(C)	0.45930295	2425097.377	0.00	0.00	0.00
SW Dra(C)	0.56967021	2426224.589	0.00	0.00	0.00
TW Her(C)	0.3996001	2421545.234	0.00	0.00	0.00
IO Lyr(C)	0.57712108	2429374.432	0.00	0.00	0.00
ST Oph(C)	0.45035643	2418159.662	0.00	0.00	0.00
V445 Oph(C)	0.3970234	2427543.543	0.00	0.00	0.00
TU UMa(C)	0.557665	2425760.441	0.00	0.00	0.00
UU Vir(C)	0.47560558	2419505.314	0.00	0.00	0.00
RY Com(A)	0.46894836	2425007.450	-	-	-
ST Vir(A)	0.41084567	2425325.590	-	-	-

name and also indicates whether the period varies uniformly with time (V), changes abruptly (A), or is constant (C). In column (2), the adopted period is given from Tsesevich (1969), and column (3) gives the zero point epoch at which the period, recorded in column (2), was determined. The curvature term of the parabola (c) in column (4) were obtained from the least square fitting method. Columns (5) and (6) give different representations for the calculated period change rate, expressed in d Myr^{-1} and cycles Myr^{-1}, respectively. The period change rate for stars of constant period could be considered to be zero, and we ignored stars that have abrupt period changes in our analysis. Figure 2 and Figure 3 show the phase shift diagrams for stars of group I and group II, respectively. It is clear from these Figures that all stars show their phase shift diagrams without ambiguity. In particular, UY Boo and AT Ser of group II (Figure 3) represent the typical case of abrupt period changes.

Table 3. Period Change Rates of Field RR Lyrae Stars of Group II.

Name (1)	Period (d) (2)	Epoch (JD) (3)	$10^9 \times c$ (4)	β (d/Myr) (5)	β (cycles/Myr) (6)
SV Eri(V)	0.71370172	2421159.757	6.32	2.35	3.29
SS Leo(V)	0.626341	2427966.767	0.42	0.12	0.19
TV Leo(V)	0.6728418	2419852.286	1.09	0.36	0.54
BO Aqr(C)	0.6940238	2426589.421	0.00	0.00	0.00
UY Boo(A)	0.65081997	2428996.818	-	-	-
AT Ser(A)	0.746581	2422461.660	-	-	-

The phase-shift diagrams of RY Com and ST Vir (group I) are not presented here, but they also show the similar abrupt period changes.

4. DISCUSSION

Despite the small sample of stars, inspection of the period change rates in Table 2 and Table 3 shows the distinct difference between two groups. In Table 4, we compare the mean period change rates for two groups, where one can see the distinct bias toward positive period changes in group II. This result is consistent with that expected by the synthetic HB models (Lee 1991), which reproduce the observed period changes for variables in globular clusters (Stagg and Wehlau 1980, Smith and Sandage 1981, Nemec *et al.* 1985, Wehlau *et al.* 1992). Synthetic HB models suggest that in the clusters where the majority of RR Lyrae stars are near the ZAHB (i.e., Oosterhoff group I clusters), the period changes will be small and in the mean zero, whereas in the clusters where most of the RR Lyrae stars are evolved stars that are evolving from blue to red (i.e., Oosterhoff group II clusters), the mean β is predicted to be greater than zero with a tail to the distribution reaching fairly large period changes (Lee 1991). Our result for group II, which has the similar charicteristics of the RR Lyraes in the Oosterhoff group II clusters, shows similar evolutionary effect, whereas the result for group I, does not show large period changes, as expected.

To summarize, RR Lyrae stars in globular clusters and those in the galactic field are alike as they show the similar period change behavior, which could be ascribed to the evolutionary effects. This provides yet another support for the Lee *et al.* (1990)

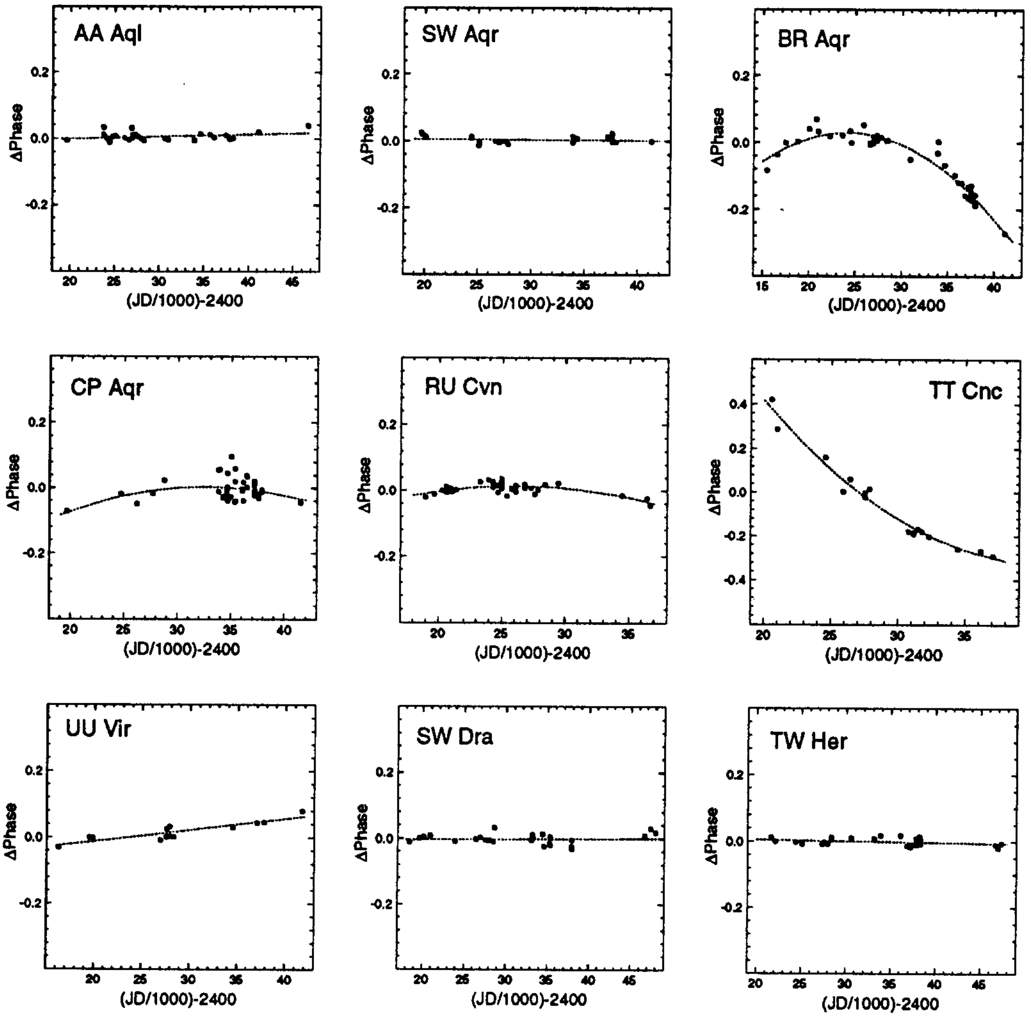

Figure 2. Phase shift diagrams for field RR Lyrae stars of group I.

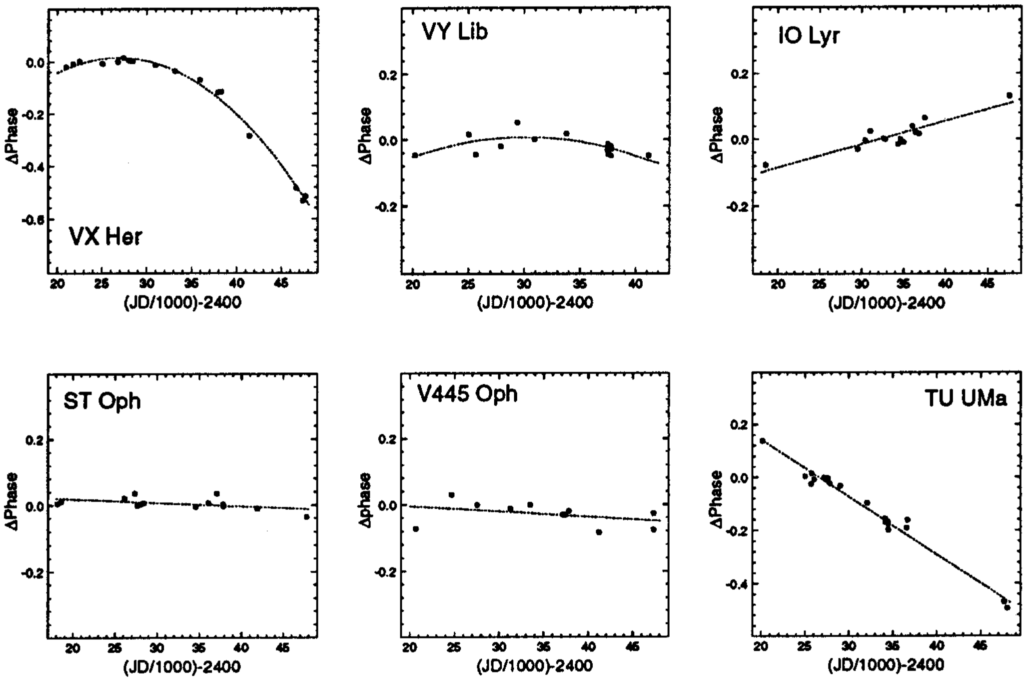

Figure 2. continued

Table 4. Mean Period Change Rates.

Group	Number of Stars	$< \beta >$ (d/Myr)
I	15	-0.02 ± 0.03
II	4	0.71 ± 0.48

and Lee (1990) evolutionary models of RR Lyrae stars. Additional observations of RR Lyrae stars, now in progress at the Yonsei University Observatory, will undoubtedly help to clarify this prblem further.

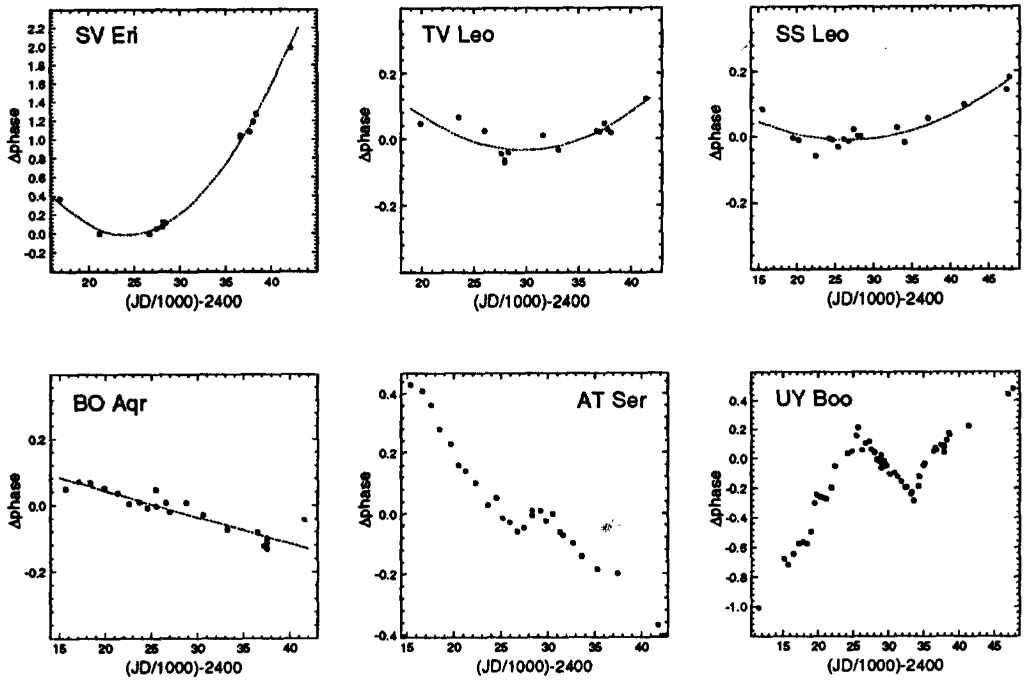

Figure 3. Phase shift diagrams for field RR Lyrae stars of group II.

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