Mon. Not. R. Astron. Soc. **293,** L61–L64 (1998)

The slope of the RR Lyrae M_V–[Fe/H] relation

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Accepted 1997 October 16. Received 1997 October 13; in original form 1997 July 7

ABSTRACT
We review the available observational data to show that the slope of the RR Lyrae M_V–[Fe/H] relation is 0.18 ± 0.03. The recent claim by Feast that, because of biases, the true slope is much steeper is not justified.

Key words: stars: variables: other – globular clusters: general.

1 INTRODUCTION

The absolute magnitudes of RR Lyrae stars have important astrophysical implications, in particular for the determination of the distances, and hence ages, of the Galactic globular clusters. It is known that the luminosity of the RR Lyraes is a function of chemical composition and that the value of the slope of the absolute magnitude–metallicity relation is critical in determining the age spread among the globular clusters.

In a recent article in this journal, Feast (1997) reviewed the subject of RR Lyrae absolute magnitudes. In particular he re-analysed the results from the applications of the Baade–Wesselink method (hereafter B–W) to derive a much steeper slope for the M_V–[Fe/H] relation than had previously been claimed by the authors of the B–W analyses (e.g. Liu & Janes 1990a; Jones et al. 1992; Cacciari, Clementini & Fernley 1992; Skillen et al. 1993; Fernley 1994). The argument made by Feast for the steeper slope is that it compensates for various biases. In this letter we examine the evidence for the existence (or not) of these biases (Section 2). We then look at other evidence, in particular the recent observations by Fusi Pecci et al. (1996) of globular clusters in M31 (Section 3).

2 BAADE–WESSELINK RESULTS

In Table 1 we list field RR Lyraes with the best-determined absolute magnitudes from B–W analyses. The metallicities are from the compilation in Fernley et al. (1997). Based on stars with several different metallicity estimates, the

Table 1. Basic data.

Star	[Fe/H]	M_v	Log(P_o)	Comments
SW And	-0.24	0.94	-0.354	
WY Ant	-1.48	0.55	-0.241	
X Ari	-2.43	0.57	-0.186	
RS Boo	-0.36	0.85	-0.423	
TV Boo	-2.44	0.58	-0.380	'c' Type
RR Cet	-1.45	0.68	-0.257	
UU Cet	-1.28	0.62	-0.218	
W Crt	-0.54	0.96	-0.385	
DX Del	-0.39	0.71	-0.325	? Evolved
SU Dra	-1.80	0.63	-0.181	? Evolved
SW Dra	-1.12	0.68	-0.244	
RX Eri	-1.33	0.66	-0.231	
RR Gem	-0.29	0.89	-0.401	
TW Her	-0.69	0.80	-0.398	
RR Leo	-1.60	0.76	-0.345	
TT Lyn	-1.56	0.65	-0.224	
RV Oct	-1.71	0.68	-0.243	
V445 Oph	-0.19	1.09	-0.401	
AV Peg	-0.08	1.10	-0.409	
DH Peg	-1.24	0.69	-0.468	'c' Type
AR Per	-0.30	0.87	-0.371	
RV Phe	-1.69	0.86	-0.224	
BB Pup	-0.64	1.13	-0.318	? Evolved
VY Ser	-1.79	0.61	-0.146	
T Sex	-1.34	0.66	-0.364	'c' Type
W Tuc	-1.57	0.48	-0.192	? Evolved
TU UMa	-1.51	0.70	-0.253	
UU Vir	-0.87	0.80	-0.322	

Note: We estimate errors of ± 0.15 dex in [Fe/H] and ± 0.15 mag in M_V (see text for discussion).

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absolute magnitudes suggest a random error of ± 0.15 dex in [Fe/H]. The abolute magnitudes are from the compilation in Fernley (1994) with one star, SS Leo, excluded for the reasons discussed in that paper. These absolute magnitudes have random errors of ± 0.10 mag (e.g. Jones et al. 1992). In addition, it is known from observations of RR Lyraes in globular clusters that there is a spread in M_V at a given [Fe/H] (e.g. Sandage 1990), and we take a value for this intrinsic scatter of ± 0.12 mag. Thus the combined random error on M_V is ± 0.15 mag. Finally, for the three RRc Lyraes (TV Boo, DH Peg and T Sex) we have added 0.125 to the observed periods in order to convert them to the fundamental period (van Albada & Baker 1971).

There are several cluster RR Lyraes with published B–W analyses (M4, Liu & Janes 1990b; M5 and M92, Storm, Carney & Latham 1994). The results from these analyses are consistent with the field stars; however, we have not included them in Table 1 because of their larger errors.

Because there are errors in both M_V and [Fe/H], we have used a 'maximum likelihood' program to determine the slope and zero-point of the relation. We find

$$M_V = 0.20 \pm 0.04[\mathrm{Fe/H}] + 0.98 \pm 0.05, \qquad (1)$$

which has an rms scatter of 0.12 mag. Feast, by contrast, determined the slope and zero-point by a least-squares regression of [Fe/H] on M_V, normally referred to as the 'inverse' relation. He obtained

$$M_V = 0.33 \pm 0.05[\mathrm{Fe/H}] + 1.13 \pm 0.14, \qquad (2)$$

which has an rms scatter of 0.15 mag. The small differences between equations (1) and (2) of this paper and equations (3) and (4) of Feast are a result of our using more recent [Fe/H] values. The two fits are illustrated in Fig. 1.

The first point we make is that a regression of [Fe/H] on M_V, equation (2), is only correct if M_V has no error (Bevington 1969), whereas it can clearly be seen in Fig. 1 that the *dominant* error is in M_V. Equation (1), which uses a 'maximum likelihood' algorithm that allows for errors in both [Fe/H] and M_V, is formally the correct relation (Feigelson & Babu 1992).

Feast's argument for using equation (2) is that it compensates for various biases. First, Feast is concerned about Malmquist biases. In earlier papers (Feast 1972, 1987, 1994) he discusses the application of relations such as equations (1) and (2) of this paper to determining the distances of groups of objects which (a) are selected by apparent magnitude and (b) have certain forms of luminosity function. In these papers he argues that 'inverse' relations, such as equation (2) of this paper, compensate for Malmquist biases. Ignoring for a moment whether equation (2) does compensate for Malmquist bias, let us first consider whether this bias is in general a problem. The most frequent and important use of RR Lyraes as standard candles is to determine the distances to globular clusters, both in the Galaxy and in other galaxies. Since globular clusters are discrete and clearly identifiable objects, the Malmquist bias does not arise. There may be circumstances in which RR Lyraes are used as distance indicators and the Malmquist bias is relevant, e.g. observing RR Lyraes along the line of sight of Baade's windows in order to determine the distance to the Galactic Centre. In our opinion it is more sensible to deal with the bias in the particular study in which it arises. To use a general paper on RR Lyraes to derive a relation that may (or may not) compensate for a bias that in most cases does not exist, is potentially misleading.

Secondly, Feast discusses biases in the metallicity of the stars selected for B–W analyses. Because the metallicity distribution of RR Lyraes is strongly peaked around [Fe/H] of -1.5 (e.g. Fernley 1993, fig. 4), if the B–W analyses had simply used a random sample of stars then clearly the metallicity extremes would have contained few stars and the parameter space would have been inadequately sampled.

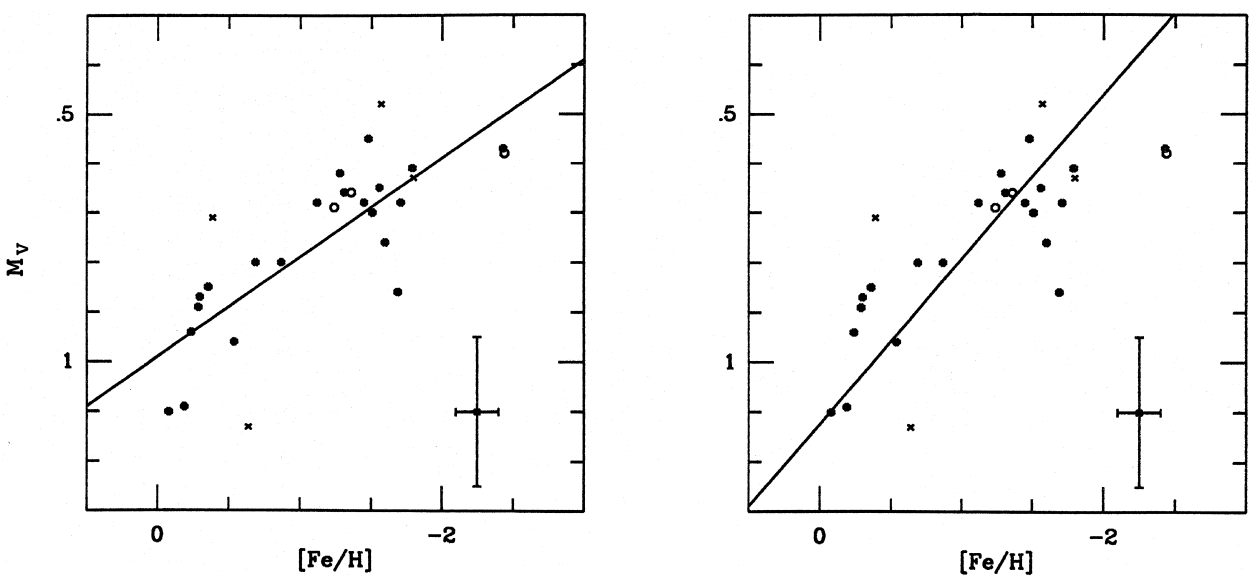

Figure 1. Data from Table 1 (RRab Lyraes shown as filled circles, RRc Lyraes shown as open circles and stars of uncertain evolutionary status shown as crosses). The solid line in the left-hand plot is from equation (1) and the solid line in the right-hand plot is from equation (2). A typical error bar is shown in the lower right-hand corner of both panels.

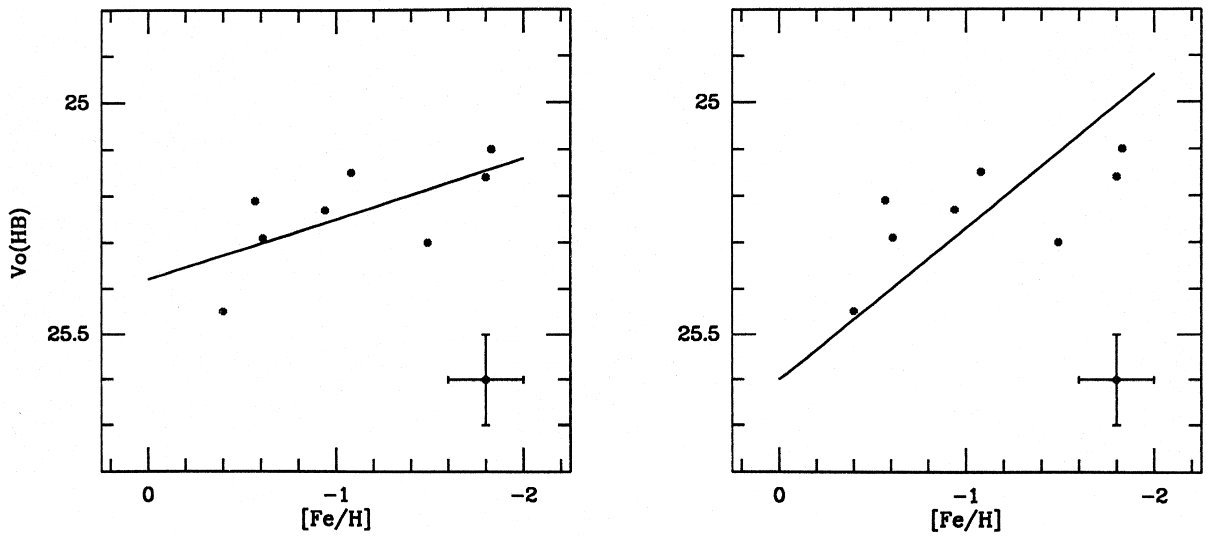

Figure 2. The globular clusters in M31 (data from Fusi Pecci et al. 1996). The left-hand plot shows the slope of 0.13 found by Fusi Pecci et al. and the right-hand plot shows the slope of 0.33 using the Feast relation, equation (2).

However, when selecting the stars for B–W analyses, the observers have tried to overcome this effect and it can be seen in Fig. 1 that they have been relatively successful at the metal-rich end, $[Fe/H] \geq -1$, but less so at the metal-poor end, $[Fe/H] \leq -2$. It may be argued that the two very metal-poor stars (X Ari and TV Boo) are biasing the solution. If we remove these then we obtain

$$M_V = 0.23[Fe/H] + 1.01, \quad (3)$$

which is only slightly steeper than equation (1).

There are other, more subtle, biases that can be claimed in the selection of the B–W stars. In particular, Jones et al. (1992) argued that there is a bias in period which leads to an over-representation of evolved stars (these are stars that are in the instability strip during their post-horizontal branch evolution, i.e. stars that were initially on the horizontal branch to the blue of the instability strip and are now evolving towards the asymptotic giant branch). Such stars would be brighter than normal RR Lyraes. One star, SS Leo, is clearly in this category and has not been included in Table 1; however, there are other stars that may also be evolved (DX Del, Jones et al. 1992; SU Dra and W Tuc, Cacciari et al. 1992; BB Pup, Skillen et al. 1993), and eliminating these (but reinstating X Ari and TV Boo) gives

$$M_V = 0.19[Fe/H] + 0.98, \quad (4)$$

which is only slightly shallower than equation (1).

In conclusion, we can say that equation (1) is statistically correct and that the biases claimed by Feast are either non-existent or have only a small effect. By contrast, Feast introduces a large bias by neglecting observational error when forming the inverse relation, equation (2).

3 M31 GLOBULAR CLUSTERS

Fusi Pecci et al. (1996) have analysed *Hubble Space Telescope* observations of eight globular clusters in M31, and for each cluster they have estimated m_{HB}, the magnitude of the horizontal branch in the region of the RR Lyrae instability strip. Taking [Fe/H] values from the literature, they find an M_V–[Fe/H] slope of 0.13 ± 0.07. The data are shown in Fig. 2, where it can be seen that, although there are relatively few clusters, they do show a reasonably uniform sampling in metallicity over the range $-1.8 \geq [Fe/H] \geq -0.4$ and hence there is no obvious bias in this respect.

4 CONCLUSIONS

Combining the slopes given previously (B–W results 0.20 ± 0.04, M31 globular clusters 0.13 ± 0.070) and inversely weighting by the variances gives 0.18 ± 0.03.

A zero-point of $M_V = 0.75 \pm 0.13$ at $[Fe/H] = -1.53$ has recently been derived by Fernley et al. (1997) using both the B–W results referred to in this paper and the recently released *Hipparcos* proper motions and parallaxes. The implications of this RR Lyrae M_V–[Fe/H] calibration for the local distance scale and the ages of the globular clusters are discussed in that paper.

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