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Radial velocities and iron abundances of field RR Lyraes. I.

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Abstract. We present systemic velocities and iron abundances for 56 RR Lyraes, the majority of which have been observed by the HIPPARCOS satellite. Comparison between our systemic velocities and previous values identifies several binary candidates only one of which, TU UMa, was previously suspected of being a binary. However, spectra of the unusual RR Lyrae BB Vir show no evidence of line doubling and hence do not support the recent claims that this star may have a Blue Horizontal Branch companion. Comparison between our abundances and previous determinations shows reasonable agreement except with the recent work of Layden (1994) where we find systematic differences. Several of the stars included on the HIPPARCOS observing list as RR Lyraes are shown to be mis-classified. Of particular interest are the stars V363 Cas and AT And which, by analogy with XZ Cet, may be anomalous Cepheids[1].

Key words: stars: abundances; V 363 Cas; AT And — stars: binaries spectroscopic — stars: variable — stars: kinematics

1. Introduction

During its lifetime, the HIPPARCOS satellite observed approximately 180 RR Lyraes. From these observations an homogenous set of proper motions and V magnitudes will shortly be published. In particular, the unprecedented accuracy of proper motions, ± 2 milliarcsecs/yr, makes it worthwhile to repeat the Statistical Parallax analysis of Hawley et al. (1986) and Strugnell et al. (1986) in order to re-determine the RR Lyrae absolute magnitude-metallicity relation.

The Statistical Parallax method requires, in addition to proper motions and V magnitudes, radial velocities and abundances. Examination of the list of RR Lyraes observed by HIPPARCOS showed that many have either no published radial velocities and abundances or else they were of relatively low quality. Consequently during the last two years we have made spectroscopic observations of these RR Lyraes at McDonald Observatory in Texas and in this paper we present the resulting radial velocities and iron abundances. Further observations were made at the Calar Alto Observatory, Spain, and the Sutherland Observatory, S. Africa, and these results will be presented in a subsequent paper (Solano et al. 1997).

2. Observations

Spectra of the RR Lyraes were taken with the Sandiford Echelle Spectrometer (McCarthy et al. 1993) on the 2.1 m telescope of the McDonald Observatory, Texas. We had four one-week runs in December 1993, March 1994, June 1994 and December 1994. The spectra cover the wavelength range 5 900 Å – 8 100 Å with a resolving power of 60 000. This wavelength range includes Hα, the OI triplet at 7771, 7774 and 7775 Å and numerous lines of both calcium and iron.

The exposures times were limited to 15 minutes for the RR Lyraes in order to prevent "phase blurring". In general, three spectra were obtained for each RR Lyrae. The first spectrum was arbitrarily assigned as phase zero and then, using the published periods from the GCVS, two further spectra were obtained, separated by plus and minus a third of a cycle from the first spectrum. The signal-to-noise ratio of the spectra varied between 5 and 30 at Hα depending on the magnitude of the star and the quality of the seeing. After each RR Lyrae observation an arc was taken.

The spectra were reduced using the MIDAS package installed at IUE, Vilspa. After bias-subtracting and flat-fielding we used the context ECHELLE within the package. This automatically finds the centre of the

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[1] The Appendix is available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

orders, "tracks" them across the CCD chip and then extracts them by summing over a selected input width of pixels. From tests on the order profiles we chose a width of 6 pixels which corresponds to 3 arcsec on the sky (the inter-order separation is typically 12 pixels). No background subtraction was made since tests showed this to be negligible. After wavelength calibration the centers and equivalent widths of selected lines were measured using an interactive routine within MIDAS.

3. Radial velocities

Radial velocities were measured using the wavelength shift of the line centers of the OI triplet at 7771.94, 7774.17 and 7775.39 Å. These lines were selected since, firstly, they are unblended; secondly, at the temperatures of RR Lyraes, their strength increases as the effective temperature increases thus the lines can be used at all phases of the pulsation cycle in both "ab" and "c" type stars; and, thirdly, because oxygen is over-abundant in the more metal-poor RR Lyraes (Clementini et al. 1995; Fernley & Barnes 1996), the lines could be seen in the spectra of all the stars. Despite this there were a number of spectra where, due to a combination of low metallicity in the star and poor S/N in the spectra, we were forced to measure the radial velocity from the wavelength shift of the line centre of Hα at 6562.81 Å.

On each night we observed between two and four IAU radial velocity standards (see Table 1 for the complete list of standard stars).

Table 1. IAU radial velocity standards

Star (HR)	Radial velocity (km s^{-1})
33	14.7
1101	27.9
3145	71.0
4540	5.0
5694	53.5
7560	0.1
8969	5.3

Comparing our velocities, derived from both Hα and OI triplet, with the published values showed differences that were always $\leq$ 2 km s^{-1}with an rms value, over the four observing runs, of 1.1 km s^{-1}.

As mentioned in the previous section, our goal was to obtain three well-phased spectra per RR Lyrae and then to derive the systemic velocity by fitting these three measurements to the "standard" RRab Lyrae radial velocity curve given by Liu (1991). A free parameter in the Liu curve is the amplitude. Liu found 22 RRab Lyraes with published radial velocity curves and these have a mean amplitude of 61.5 km s^{-1} with an rms scatter of 8.4 km s^{-1}. Liu shows that there is a correlation between light curve amplitude and velocity amplitude; however, since the light curve amplitude is not known for many of the stars in our sample, we have used the mean amplitude of 61.5 km s^{-1}to construct the "standard" curve. Amongst the stars we observed there are 8 RRab Lyraes and 2 RRc Lyraes with good quality radial velocity curves available in the literature. Comparing our values of the systemic velocity with the literature values for the 8 RRab Lyraes showed a mean difference of 0.2 km s^{-1}and an rms difference of 3.7 km s^{-1}. For the RRc Lyraes, where the velocity amplitude is smaller and the velocity curve more symmetric, we determined the systemic velocity by simply taking a mean of our three measurements. Again, comparing our systemic velocities with the literature values showed, for the two RRc Lyraes, a mean difference of -0.3 km s^{-1}and an rms difference of 2.3 km s^{-1}.

Thus for those stars where we have three well-phased radial velocities, measured from the OI triplet, a realistic 1 σ error in the systemic velocity is typically 3 km s^{-1}. For those stars with only two measurements (the minimum number for any of the stars) or those stars where some of the measurements used Hα, a higher error is appropriate. For the case where Hα was used in the measurement this higher error arises from several sources, principally the lower S/N of the spectra which reduces the accuracy of the measurement. In addition, there are problems due to the presence of emission in Hα at certain phases of the pulsation (e.g. Preston & Paczynski 1964; Gillet & Crowe 1988), which distorts the measurement of the line centre and also the larger radial velocity amplitude obtained from Hα (Oke et al. 1962), which degrades the fitting to the "standard" curve. In these cases we assume an error of $\pm$10 km s^{-1}.

The list of measured RR Lyraes and their systemic velocities is given in the Appendix (available electronically).

3.1. Binary candidates

Because the Horizontal Branch is a relatively short-lived phase of stellar evolution most companion stars will be much fainter than the RR Lyrae itself, i.e. the companions will either be low-mass main sequence stars or white dwarfs. In general therefore, the only methods available to detect companions are to look for variations in either the time of maximum light or the systemic velocity. In Table 2 we list those RR Lyraes which show significant differences between our values and previous values of the systemic velocity. Examination of the spectra of these stars showed no evidence of line doubling for any of them.

The only one of these stars previously suspected to be a member of a binary is TU UMa. Saha & White (1990), using published times of maximum light, calculated the orbital parameters for TU UMa and our value of the systemic velocity is not inconsistent with their prediction.

Table 2. Binary candidates

RR Lyrae	Systemic velocity km s^{-1} This work	Previous work	Ref. (see Appendix)
CI And	23 ± 3	99 ± 30	11
DM Cyg	-35 ± 3	-49 ± 30	15
		59 ± 30	11
BK Dra	-82 ± 10	-27 ± 30	11
XX Hya	95 ± 10	-10 ± 35	18
		52 ± 24	11
ST Leo	177 ± 3	150 ± 4	6
		166 ± 10	16
		170 ± 35	15
		181 ± 39	11
CN Lyr	27 ± 3	67 ± 30	11
TU UMa	101 ± 3	84 ± 1	1
		90 ± 2	10
		92 ± 1	13
		77 ± 2	14

For the other stars, a literature search showed there were insufficient published times of maximum light to attempt an orbital solution and clearly it would be of value to place the stars in a long-term observing programme in order to acquire these data.

4. Iron abundances

To determine the iron abundances we used the FeII lines at 6416.9 Å and 6432.7 Å. These lines have several useful attributes from the point of view of the present analysis. Firstly, they are strong enough to measure in even the most metal-poor stars in our sample. Secondly, their equivalent width (EW) is relatively insensitive to temperature over the temperature range covered by both RRab and RRc Lyraes during the pulsation. This is particularly important since it reduces one of the main sources of error in the abundances, that due to uncertainties in the temperature assignments. Finally, they are free of non-LTE effects (Lambert et al. 1995). The measured EWs are listed in Table 3.

Using the line data and procedures described in Fernley & Barnes (1996, hereafter FB96) we computed a grid of theoretical EWs for these two FeII lines over the range $5750 - (250) - 7250$ K in $T_{\rm eff}$, $0.0 - (0.5) - 2.0$ in $[M/H]$ and 2.5 and 3.0 in log g.

4.1. RRab Lyraes

As discussed in FB96, during the phase interval from $0.35 - 0.85$, RRab Lyraes undergo an isothermal contraction and there is considerable evidence that the temperature variation from star to star during this phase interval is relatively small, i.e. 6050 ± 200 K. To select the RR Lyrae spectra taken during this phase interval we firstly fitted the measured radial velocities to the standard velocity curve in order to obtain the true phases of our spectra and secondly examined the Hα profiles to select the ones that were narrowest and free of emission.

The measured EWs on these spectra were then matched with the synthetic EWs at $T_{\rm eff} = 6\,050$ K and $\log g_{\rm eff} = 2.75$ (see discussion in FB96) in order to derive the abundances listed in the Appendix. We estimate the typical uncertainty in these abundances as ± 0.13 dex, mainly due to the measurement error (± 0.09). Our method of estimating the measurement error was to take the mean value of the abundance difference derived from the two Fe II lines. This showed a range of value between 0.00 and 0.28 dex with a mean value of 0.09. Smaller uncertainties arise from possible errors in the temperature of ± 200 K (± 0.04), the gravity of ± 0.2 dex (± 0.07) and the gf values (± 0.04).

4.2. RRc Lyraes

RRc Lyraes have smaller temperature and gravity variations during the pulsation cycle and we have therefore adopted a different procedure for these stars than for the RRab Lyraes. For the RRab Lyraes we analysed only those spectra taken during the phases $0.35 - 0.85$, to which we assigned a particular value of temperature ($6\,050 \pm 200$ K) and $\log g_{\rm eff}$ (2.75 ± 0.2) for all the stars. For RRc Lyraes we analysed all the spectra of all the stars, assuming a single value of temperature ($7\,100 \pm 150$ K) and $\log g_{\rm eff}$ (3.0 ± 0.2).

The value of temperature is based on the following work. Sandage (1981) calculated mean temperatures from $(B-V)$ colours and an unpublished colour-temperature transformation of Bell for the RRc Lyraes in six globular clusters and this showed a range in mean $T_{\rm eff}$ of $6600 - 7500$ K depending mainly on period but with a weaker dependence on metallicity. Amongst field stars the Baade-Wesselink analyses by Liu & Janes (1990) & Fernley et al. (1990) of the stars TV Boo ($P = 0.31$ days, $[M/H] = -2.2$), T Sex ($P = 0.32$ days, $[M/H] = -1.2$) and DH Peg ($P = 0.26$ days, $[M/H] = -0.9$) give mean temperatures of 7020, 7105 and 7160 K using $V-K$ colours and the calibration of $V-K$, $T_{\rm eff}$ (FB96) based on the ATLAS9 models of Kurucz (1992, private communication). T Sex is at the "mid-point" of RRc Lyraes, both in terms of period and metallicity, and using the other two stars to set the temperature range as we vary metallicity at constant period (TV Boo) or vary period at constant metallicity (DH Peg) we adopt $T_{\rm eff} = 7100 \pm 150$ K as representative of the mean temperature of all RRc Lyraes. This is consistent with, but narrower than, the temperature range found by Sandage (1981); however, the Sandage photometry is more difficult than the field star photometry (fainter stars, more crowded field) and $B-V$ is subject to greater

Table 3. Equivalent widths (mÅ) of the FeII lines at 6416 and 6432 Å

Star	6416 Å	6432 Å	Star	6416 Å	6432 Å	Star	6416 Å	6432 Å
SW And	109	122	DM Cyg	125	140	V455 Oph	75	70
AT And	23	32	SU Dra	13	11	VZ Peg	—	10
CI And	85	—	SW Dra	—	29	DZ Peg	32	28
BR Aqr	64	79	BK Dra	—	23	AR Per	104	117
BH Aur	150	151	BB Eri	35	45	XX Pup	23	31
RS Boo	98	116	SZ Gem	19	25	HK Pup	36	41
AE Boo	20	22	SZ Hya	19	16	KZ Pup	108	—
UY Cam	13	18	XX Hya	41	37	VY Ser	9	9
Z CVn	14	17	DD Hya	48	57	AP Ser	17	18
SS CVn	36	47	ST Leo	34	48	T Sex	16	24
UZ CVn	23	22	AX Leo	34	—	SX UMa	16	18
AA CMi	122	127	BX Leo	26	26	TU UMa	—	21
V363Cas	103	102	TT Lyn	—	22	AB UMa	76	79
EZ Cep	116	136	TW Lyn	—	132	AF Vir	—	34
RR Cet	18	23	CN Lyr	99	106	BB Vir	29	27
RZ Cet	33	42	IO Lyr	51	59			
U Com	—	27	KX Lyr	128	106			

uncertainty than $V - K$ for temperature determinations of RR Lyraes (Fernley 1993a)

Concerning log $g_{\rm eff}$, since we use spectra at all phases of the pulsation, then for our purposes the dv/dt term cancels out and $\log g_{\rm eff}$ is given by the "static" gravity. FB96 suggest that for RRab Lyraes $\log g_{\rm st} = 2.89$. For RRc Lyraes this is higher from the following argument. Assuming the horizontal branch is horizontal than the higher mean temperatures of "c" types ($\approx$ 500 K) imply lower radii ($\approx$ 16%) and, assuming the masses of "ab" and "c" types are the same, hence higher gravities by 0.13 dex.

4.3. Comparison with previous work

Most previous work on RR Lyrae abundances expresses the results in the ΔS notation (Preston 1959). To facilitate comparison, both with this work and the very extensive analysis of Layden (1994), we have converted these ΔS values to [Fe/H] using the relation

$$[\mathrm{Fe/H}] = -0.13 - 0.195 * \Delta S \qquad (1)$$

which is the mean of the calibrations of Clementini et al. (1995), Lambert et al. (1996) and FB96, all of whom have recently made abundance analyses of a small sample of bright field RR Lyraes using intermediate to high-resolution optical spectra. The resulting comparison are shown in Fig. 1a (using results from various authors) and Fig. 1b (using the results of Layden).

In Fig. 1a it can be seen that there is reasonable agreement. Three stars are particularly discrepant (AB UMa, AT And and BK Dra) but if these are removed then we obtain

$$[\mathrm{Fe/H}]_{\rm other} = 1.05 * [\mathrm{Fe/H}]_{\rm us} + 0.04 \qquad (2)$$

with a standard deviation of 0.19 dex. As discussed previously, the error on our abundances is $\pm$0.13 dex and so this standard deviation suggests a similar level of error applies to other analyses. It should be noted that the fit in Eq. (2) is the bisector of the least squares fits of y upon x and x upon y (since the errors in x and y are approximately equal). This relation in Eq. (2) is plotted as the dotted line in Fig. 1a.

Concerning the work of Layden (1994) it can be seen in Fig. 1b that his metallicities are systematically lower than ours. Three stars (UZ CVn, AX Leo and TW Lyn) are particularly discrepant. If these are excluded, the remaining 27 stars have a mean difference of 0.21 dex. Layden used a variation of the ΔS method in which a group of standard stars defined iso-abundance lines in the EW(CaIIK), EW(Hδ) diagram. This diagram was then used to determine the metallicities of the survey stars. Five of Layden's standard stars were observed by us and comparing his adopted [Fe/H] values for these stars with our derived values shows close agreement (mean difference for the five stars is 0.02 dex, in the sense of Layden being more metal-poor). Given the good agreement between ourselves and Layden as to the metallicities of his calibrating stars, which cover the full range of metallicity, it is puzzling that the other stars are not in better agreement. The main difference between the calibrating stars and the other stars is, of course, that the calibrating stars are brighter and we show in Fig. 2 a plot of the difference $[\mathrm{Fe/H}]_{\rm us} - [\mathrm{Fe/H}]_{\rm Layden}$ as a function of the V magnitude.

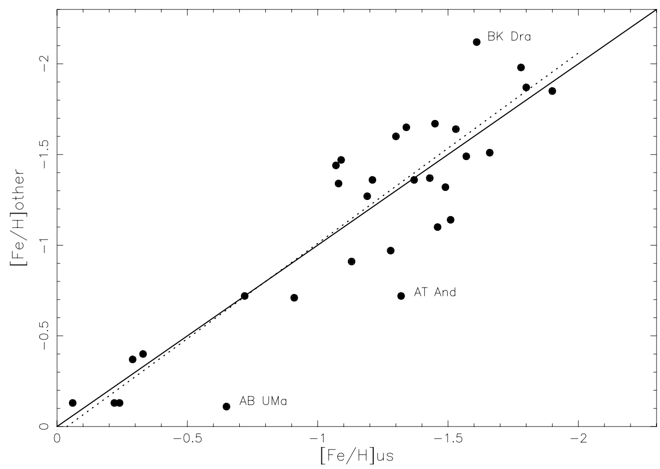

Fig. 1. a) A comparison bewtween the [Fe/H] values of the present work and previous work (excluding Layden 1994). The solid line has intercept at zero and a slope of unity and the dotted line is the best-fit to the data. Over the range $-2 \leq$ [Fe/H] ≤ 0 the difference between the two lines is always $\leq$ 0.05 in [Fe/H]

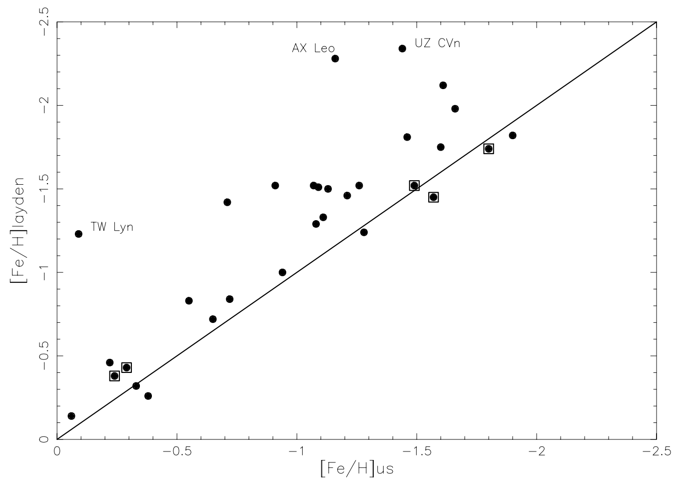

Fig. 1. b) A comparison between the [Fe/H] values of the present work and those of Layden (1994). The solid line has intercept at zero and a slope of unity. The dots inserted in squares are for the stars used by Layden as calibrators. It can be seen that the [Fe/H] values of Layden and ourselves are in good agreement for the calibrating stars, whereas for the general sample of stars the Layden values are more metal-poor There is a clear trend in Fig. 2 with the fainter stars showing much larger differences.

As a further check we compared both our [Fe/H] values and Layden's [Fe/H] values with the compilation of Blanco (1992). He lists the "best" ΔS values, from the literature, for a large number of field RR Lyraes. After converting these ΔS values to [Fe/H], using Eq. (1) of this paper, we find a mean difference between Blanco and ourselves of 0.02 (in the sense we are more metal-rich) from 19 stars in common and a mean difference between Blanco and Layden of 0.09 (in the sense Layden is more metal-poor) from 82 stars in common. However, plotting these differences (Blanco-us and Blanco-Layden) against V magnitude does not show any trend analogous to Fig. 2. Neither Layden (1996, private communication) nor ourselves have any convincing explanation for Fig. 2.

In summary, our metallicities are consistent with all previous work except that of Layden whose values appear to be systematically more metal-poor by between 0.1 and 0.2 dex.

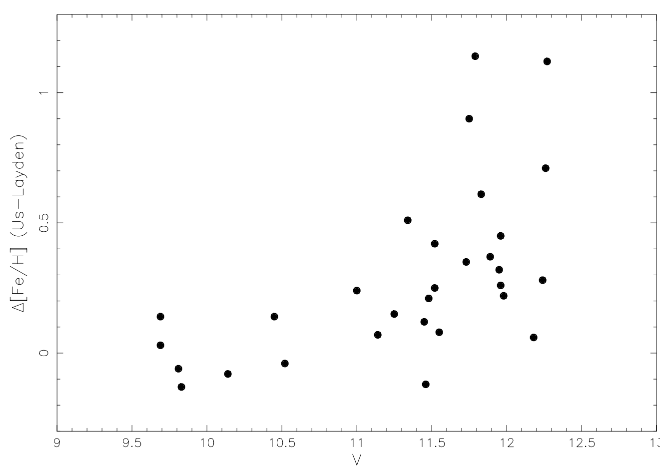

Fig. 2. The difference in metallicity derived by Layden and ourselves as a function of the V magnitude of the star. It can be seen that the brighter stars (which include the calibrating stars) have relatively small differences. Fainter than $V \approx 11$ there is considerable scatter but the Layden metallicities are clearly shifted to lower metallicity

5. Misclassified and unusual stars

The following stars were included in the HIPPARCOS list of RR Lyraes but are probably not RR Lyraes.

V753 Cen and LS Her:

V753 Cen has a period of 0.221 days and LS Her a period of 0.231 days. These are too short for RRc Lyraes and we did not observe them.

V429 Ori:
Using the GCVS period of 0.5017 days we took two spectra, a third of a cycle apart, in December 1993 and a further spectrum in December 1994. These showed, firstly, a constant velocity of 109 ± 2 km s^{-1}and, secondly, a narrower Hα than found for RRab Lyraes. The width of the Hα profile suggests the star we observed was of mid-G spectral type. At the HIPPARCOS coordinates of this star: ($\alpha(2000.0) = 04^{\rm h}56^{\rm m}12.0^{\rm s}$; δ (2000.0) = $-03^{\rm d}31^{\rm m}24^{\rm s}$) a search of the HST Guide Star Catalogue shows a star ($V = 11.2$) at exactly the same position. There are several fainter stars, $V \approx 13$, approximately three arcmins away, but the nearest star of similar brightness is more than 6 arcmins away. The most probably explanation is that there is a variable in this region but either the coordinates or the magnitude are seriously in error.

ET Hya:
Using the GCVS period of 0.685519 we took a spectrum in March 1994 and then three well-phased spectra in December 1994. These showed a constant velocity of 16 ± 2 km s^{-1}. The Hα profile was consistent with other RRab Lyraes. A search of HST Guide Star Catalogue shows a star at exactly the HIPPARCOS coordinates: ($\alpha(2000.0) = 08^{\rm h}35^{\rm m}5.7^{\rm s}$; δ (2000.0) = $-08^{\rm d}50^{\rm m}45^{\rm s}$) with another star of similar brightness only 43 arcsecs away. It seems likely the two stars have been confused, in particular we note that Layden (1994), on the basis of six velocity measurements, derived a systemic velocity of 320 ± 20 km s^{-1}and [Fe/H] = −1.69.

NSV 5394:
HIPPARCOS included this object as an RR Lyrae. It has coordinates ($\alpha(2000.0) = 11^{\rm h}56^{\rm m}6.3^{\rm s}$; δ (2000.0) = $45^{\rm d}32^{\rm m}45^{\rm s}$) and $V = 9.0$. The possibility of such a bright variable being hitherto undiscovered seemed improbable and indeed on our first attempt to observe this star it was clear from the TV Acquisition screen that it was a double star with approximately $2-3$ arcsecs separation between the two components. Probably the presence of such a close companion has led to a spurious identification as a variable.

KN Per and BB CMi:
Our spectra showed a broad and shallow Hα which was clearly different to the Hα profile of other RR Lyraes. These stars have been studied as part of the Behlen Observatory Variable Star Survey (Schmidt 1991) and on the basis of those observations they have been classified as Eclipsing Variables (KN Per (Schmidt 1991) and BB CMi (Schmidt 1995)).

XZ Cet:
This star has the period of a fundamental mode RR Lyrae but the light curve shape and amplitude resemble more closely an overtone pulsator. Teays & Simon (1985), from a comparison of both the light curve and physical characteristics of the star with pulsation models, concluded that XZ Cet was probably an anomalous Cepheid rather than an RR Lyrae. Anomalous Cepheids are more luminous than RR Lyrae and are believed to have gained mass, presumably from a companion. We took several spectra of the star and interestingly we find a significant difference between our systemic velocity, 190 ± 10 km s^{-1}, and that of Layden (1994) who found 167 ± 10 km s^{-1}. There was no evidence of line doubling.

Teays and Simon show the star has similar temperatures, during the pulsation cycle, to an RRab Lyrae but a lower gravity. Using our spectra taken on the descending branch then for $T_{\rm eff} = 6050 \pm 200$ K and $\log g = 2.5 \pm 0.25$ we find [Fe/H] = -2.10 ± 0.13, in reasonable agreement with the value of -2.27 ± 0.13 found by Layden (1994).

V363 Cas and AT And:
The radial velocity measurements for these stars showed relatively small amplitudes. This is consistent with the light curve amplitudes which, according to the GCVS, are also unusually small (0.43 mags for V363 Cas and 0.50 mags for AT And). Thus the stars appear to be similar to XZ Cet (period implies fundamental mode pulsation but the light curve is more consistent with overtone pulsation). We have included the stars amongst the RR Lyraes in the Appendix but clearly there is some uncertainty in the classification.

V1719 Cyg and SS Psc:
There is some confusion in the literature regarding the classification of certain stars as RRc Lyraes or large amplitude δ Scutis. Large amplitude δ Scutis are A–F stars in the early post-main sequence stage of evolution (e.g. Mc Namara & Feltz 1978; Breger 1980). Amongst Pop. II stars the periods of the large amplitude δ Scutis (also known as SX Phe stars or Variable Blue Stragglers) are typically $\leq$ 0.10 days and thus they are clearly separated from RRc Lyraes, which have periods $\geq$ 0.25 days. However, amongst Pop. I the large amplitude δ Scutis (also known as dwarf Cepheids or AI Vel stars or RRd stars) have periods of $\approx$ 0.12 days but the tail of the distribution extends to longer periods hence the confusion with the RRc Lyraes. The simplest method of discriminating between the two groups is in term of surface gravity since long period, large amplitude δ Scutis will have larger masses, $\approx 2\ M_\odot$, than RRc Lyraes, $\approx 0.7\ M_\odot$.

Most of the stars with periods $\approx$ 0.25 days that we observed are metal-deficient and therefore the RRc Lyrae identification is secure, however, three of the stars we observed (DE Lac, P = 0.25 days; V1719 Cyg, P = 0.27 days; SS Psc, P = 0.29 days) have metallicities approximately solar. This is confirmed by the published Strömgren photometry of McNamara & Feltz (1978) and Johnson & Joner (1986) from which the following parameters were derived by the authors: $T_{\rm eff} = 6960$, $\log g = 3.57$, [Fe/H] = 0.2 for DE Lac; $T_{\rm eff} = 7020$, $\log g = 3.44$, [Fe/H] = 0.4 for V1719 Cyg and $T_{\rm eff} = 7300$, $\log g = 3.29$, [Fe/H]

= 0.0 for SS Psc. In particular, the high gravities found for these stars suggest they are more probably δ Scutis. It may be questioned whether the calibration of Strömgren photometry is valid for pulsating stars; however Siegel (1982) obtained gravities from Strömgren photometry of 3 RRab Lyraes and these gravities are in good agreement with the value adopted by us in Sect. 4.1 (Siegel found a mean value for the three stars of $\log g = 2.71$; we adopt $\log g = 2.75$).

BB Vir:
BB Vir has a period, amplitude and light curve shape that imply it is a fundamental mode pulsator. However, in a recent study Kinman & Caretta (1992) found its $B-V$ colour was too blue compared to other fundamental mode RR Lyraes of similar period and metallicity. They suggested the star may have a Blue Horizontal Branch companion. Fernley (1993b) compared IUE spectra of BB Vir and RR Lyrae itself and this showed that BB Vir has a large ultraviolet excess, compatible with the presence of a BHB companion.

We took two spectra of BB Vir on 19 March 1994 at 6.32UT and 11.10UT which, using the ephemeris of Fernley (1993b), corresponds to phases 0.34 and 0.75 respectively. This phase interval covers very nearly the full radial velocity amplitude of the star and we found $\Delta V_{\rm r} = 36$ km s^{-1} from the two spectra. However, we detected no obvious line doubling in either Hα or the OI triplet, both of which should be stronger for the proposed companion than for BB Vir itself.

An alternative explanation is that the star is an unusually long period "c" type; however, both the amplitude and the light curve shape argue against this, as does its position in the period - temperature diagram (Fernley 1993a).

We note that BB Vir may have both variable amplitude (the GCVS lists it as "Blazhko Effect?") and a variable period (see discussion in Kinman & Caretta 1992). It may be that BB Vir is a fundamental mode RR Lyrae that has, for some reason, evolved a long way beyond the fundamental blue edge without yet changing mode. This "hysterisis" effect is well-known in globular clusters and it is possible BB Vir is an extreme example of it. We have included the star amongst the RR Lyraes in the Appendix but clearly it may not be a "normal" RR Lyrae.

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