ABSOLUTE MAGNITUDES OF RR LYRAE STARS

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ABSTRACT

Using firstly, the Hipparcos proper motions and the method of Statistical Parallax and secondly, the Hipparcos parallax of RR Lyrae itself and thirdly, the Baade-Wesselink results from the literature we find the zero-point of the RR Lyrae absolute magnitude - metallicity relation to be M_v = 0.72±0.10 at [Fe/H] = −1.52. The small error on this zero-point reflects the remarkably good agreement between the three (independent) methods. Taking a value of 0.18±0.03 for the slope of the relation from the literature we obtain a distance modulus of the LMC of 18.31. This is compared to other recent determinations of the distance to the LMC.

1. INTRODUCTION

RR Lyraes are one of the primary distance indicators, both within the Galaxy and within the Local Group, and in this article we use the recently released Hipparcos data to estimate their absolute magnitudes. In Section 3 we consider the trigonometric parallaxes and in Section 4 the proper motions and the method of statistical parallax. In Section 5 we then take these results and combine them with previous work to derive an M_v, [Fe/H] calibration for RR Lyraes. Finally in Section 6 we discuss the distance to the LMC using this calibration and compare it with other recent determinations of the LMC distance modulus. We begin in Section 2 with a brief discussion of the data.

2. THE DATA

For the purposes of the present paper the following data were required: intensity mean V magnitudes, reddenings, parallaxes, proper motions, radial velocities and metallicities. These data were taken both from Hipparcos and previously published work and a full listing will appear in Fernley et al. (1997a). Here we make only a few comments:

1. Of the 180 stars listed as RR Lyraes in the Hipparcos Input Catalogue we removed 36 stars, either because they were not RR Lyraes or because the data were missing or of poor quality.

2. In order that the V magnitudes were homogeneous we used the Hipparcos photometry. For each star the raw $V_{\rm Hip}$ magnitudes were converted to fluxes and then phased using the period from the GCVS (Kholopov et al. 1985). The period was then optimised and the resulting light curve fitted to a Fourier Series. This analysis was done using the program PULSAR (Skillen 1985). The mean flux was then converted back into a magnitude and transformed onto the Johnson system using the equations given by the Hipparcos project. Comparing these intensity mean magnitudes with those listed by Liu and Janes (1990a) shows, for 13 stars in common, a mean difference of 0.003 mag and an rms scatter of 0.007 mag.

3. Reddenings were taken from Burstein and Heiles (1982). The de-reddened stars were then used to determine period-colour relations which were in turn used to estimate the reddening for the stars at low galactic latitudes.

4. The parallaxes are from Hipparcos. Only one star, RR Lyrae itself, has a well-determined parallax, 4.38±0.59 mas. For the remaining stars the parallaxes are smaller (mean value = 0.8 mas) and the standard errors larger (mean value = 2.6 mas).

5. The proper motions are also from Hipparcos. In Figure 1 we compare these proper motions with ground-based measurements as given in Layden et al. (1996). It can be seen that overall the agreement is good, the main difference is that the Hipparcos standard errors are lower than the ground-based ones, σ_μ = 2.2 mas/yr compared to 5.6 mas/yr.

6. The radial velocities are from the literature. The radial velocities typically have a standard error of 3 km/s which, at the mean distance of the RR Lyraes of 1250 pcs (= 0.8 mas in parallax), translates into an error of 0.55 mas/yr.

7. The metallicities are also taken from the literature.

3. TRIGONOMETRIC PARALLAXES

As discussed in the previous section only one star, RR Lyrae itself, has a well-determined parallax, 4.38±0.59 mas. With $V_J = 7.76$ and E(B-V) = 0.06 this gives $M_v = 0.78 \pm 0.29$. For the remaining stars the parallaxes are too uncertain to give any useful information, either individually or collectively.

No Lutz-Kelker correction (Lutz & Kelker 1973, Hanson 1979) was applied to the derived absolute magnitude of RR Lyrae since the selection criterion was not the parallax (there are 13 other RR Lyraes for which Hipparcos gives a parallax greater than it) but the standard error on the parallax (RR Lyrae has $\sigma_\pi =$ 0.59 mas whereas the remaining stars all have $\sigma_\pi \geq$ 0.90 mas). It should be noted that the correction is in any case small, from Hanson (1979) we estimate the correction is 0.07 mag in the sense that the derived magnitude would be brighter.

4. STATISTICAL PARALLAX

Using the program described in Hawley et al. (1986) and the data described in Section 2 we obtained the solutions shown in Table 1. It is important in the Statistical Parallax method to isolate a dynamically homogeneous sample of stars. In the present context this means separating the Halo and Old Disk components and we have done this by making a cut in metallicity. Based on previous work (e.g. Layden et al. 1996, Figure 4) it is clear that below [Fe/H] = -1.3 the stars are almost entirely Halo and above [Fe/H] = -0.8 they are almost entirely Old Disk. Unfortunately there are insufficient stars with [Fe/H]≥ -0.8 to obtain a useful solution and so we have run instead a metal-rich solution which contains all stars with [Fe/H] ≥ -1.3. This sample is therefore not dynamically homogeneous in that it contains both Halo and Old Disk stars (as of course does the solution for all stars).

Table 1. Absolute magnitudes from statistical parallaxes.

Sample	No Stars	[Fe/H]	M_v
All RR Lyraes	144	-1.32	0.76 ± 0.13
Halo RR Lyraes	84	-1.66	0.77 ± 0.17
Metal-Rich RR Lyraes	60	-0.85	0.69 ± 0.21

These results are very similar to those from previous studies (Hawley et al. 1986, Strugnell et al. 1986, Layden et al. 1996) which used ground-based proper motions. However, as noted in the previous section, the Hipparcos and ground-based proper motions for RR Lyraes are in good agreement, the main improvement with Hipparcos is the lower error.

5. THE ABSOLUTE MAGNITUDE CALIBRATION

If we write:

$$M_v = \alpha[\mathrm{Fe/H}] + \beta \tag{1}$$

then we are concerned with determining the zero-point, β, and slope, α, using the Hipparcos results given in this paper and previously published work.

Zero-Point β: the Baade-Wesselink work on RR Lyraes (Fernley 1994 and references therein) gives values for both the slope and zero-point. The slope is still the subject of debate and so to derive a zero-point in the least controversial way we have firstly, updated the metallicity values in Fernley (1994) and then we have simply taken the mean values of the metallicity and magnitude for the 15 stars listed by Fernley that have $-1.0 \leq$ [Fe/H] ≤ -2.0 (for reasons discussed in that paper we have excluded SS Leo). This gives $M_v = 0.66 \pm 0.08$ at [Fe/H] = -1.50. The Baade-Wesselink work is subject to systematic errors from several sources and these are estimated as ±0.12 mag (Fernley et al. 1989), to give a final error on the Baade-Wesselink zero-point of ±0.14.

Combining the results from the Baade-Wesselink work with those from the Trigonometric Parallax of RR Lyrae ($M_v = 0.78 \pm 0.29$ at [Fe/H] = -1.39) and the Statistical Parallax solution for the pure halo sample ($M_v = 0.77 \pm 0.17$ at a mean metallicity of [Fe/H] = -1.66) and inversely weighting by the square of the error we obtain $M_v = 0.72 \pm 0.10$ at [Fe/H] = -1.52. The small error on M_v reflects the remarkably good agreement between the three independent methods used to determine the zero-point.

Slope α: this is a subject of some controversy and has most recently been discussed by Fernley et al. (1997b). Based on both the Baade-Wesselink results referred to previously and the observations by Fusi Pecci et al. (1996) of globular clusters in M31, they estimate a slope of 0.18±0.03. Adopting this value we obtain:

$$M_v = 0.18 \pm 0.03([\mathrm{Fe/H}] + 1.52) + 0.72 \pm 0.04 \tag{2}$$

6. DISTANCE TO THE LMC

There are observations of RR Lyraes in 5 LMC Clusters (Walker 1992, Reid & Freedman 1994) and combining the data from the clusters gives a mean dereddened magnitude m_v of 18.98 and a mean [Fe/H] of -1.8. From Equation 2 we obtain a distance modulus $(m - M)$ of 18.31 and in Table 2 we compare this with other recent determinations.

It can be seen that the distance modulus derived from the RR Lyraes, which as noted earlier is based on three independent methods of calibration, is ~0.37 less than the distance modulus derived from the Cepheids, which in turn is based on two independent methods of deriving the zero-point of the P-L relation (Gieren et al. use Baade-Wesselink methods and Feast & Catchpole use the recently published Hipparcos trigonometric parallaxes). The uncertainty in

Table 2. LMC Distance Moduli.

Method	$(m-M)$
RR Lyraes (this paper)	18.31
SN1987A Ring - Gould(1995)	18.37
SN1987A Ring - Panagia et al. (1997)	18.58
Cepheids - Gieren et al. (1993)	18.65
Cepheids - Feast & Catchpole (1997)	18.70

the distance modulus obtained from SN1987A means that it cannot usefully discriminate between them.

Given the weight of evidence behind both the RR Lyrae and Cepheid LMC distance scales it seems natural to look for an alternative explanation for the disagreement. A possibility is that there are depth effects in the LMC. The observed diameter of the cluster is 7.7 degrees and if the depth is comparable to the width this would be equivalent to ± 0.14 in $(m-M)$. Assuming the Cepheids, which are young objects, are in the central region then the LMC would have to be more than twice as deep as it is wide and all the RR Lyraes would have to be at the near edge. This seems unlikely since the 5 clusters used to determine m_v are spread evenly across the face of the cluster (Walker 1992).

Another possibility is that, for some reason, RR Lyraes in clusters are not the same as RR Lyraes in the field. Liu and Janes (1990b) did Baade-Wesselink analyses of 4 RR Lyraes in the Globular Cluster M4 ([Fe/H] ~ -1.4) and Storm et al. (1994) did Baade-Wesselink analyses of 2 RR Lyraes in M5 ([Fe/H] ~ -1.5) and 2 in M92 ([Fe/H] ~ -2.1). For the 8 stars the mean difference between the absolute magnitudes found by these authors and the value given by Equation 2 is only 0.03 mag, in the sense the calculated values stars are brighter than the predicted values.

A further possibility is the sensitivity of the zero-point of the Cepheid P-L relation to metallicity effects. If we write:

$$\Delta M_v = \alpha \Delta[\mathrm{Fe/H}] \qquad (3)$$

then Gould (1994), from an analysis of Cepheids in different regions of M31, has argued that $-0.88 \leq \alpha \leq -0.56$. More recently Sekiguchi & Fukugita (1997) have used the high quality abundances derived for 23 galactic Cepheids by Fry & Carney (1997) to show that the residuals from the Cepheid P-L relation are strongly correlated with metallicity, specifically $\alpha = -2.15 \pm 0.44$.

Assuming the Cepheids in the LMC are slightly metal-poor compared to Galactic Cepheids (Feast & Catchpole 1997) then the metallicity sensitivity of the Cepheid P-L relation appears to be the most promising explanation for the difference between the RR Lyrae and Cepheid distance scales.

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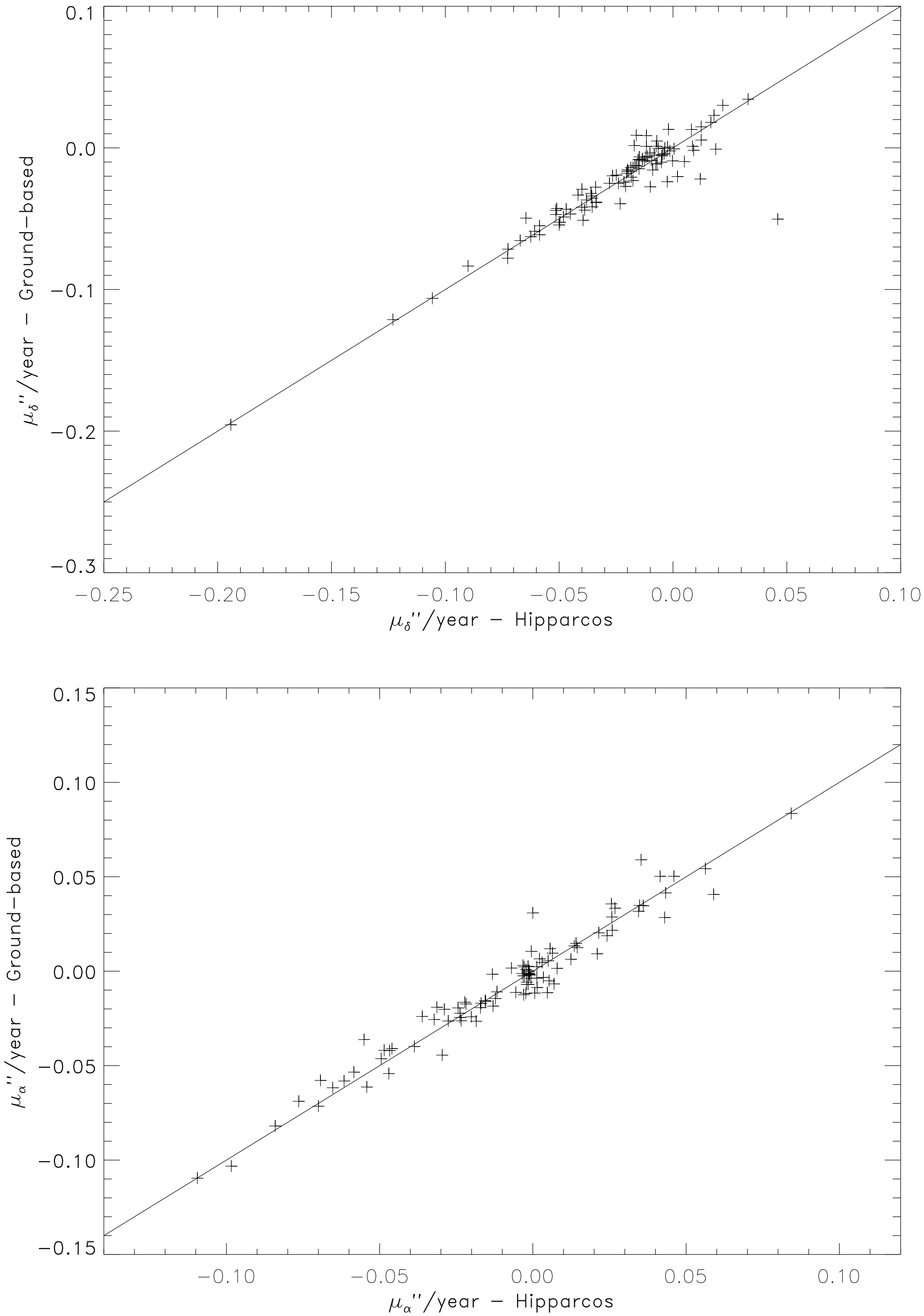

Figure 1. A comparison between the Hipparcos and ground-based proper motions (98 stars). The upper panel is for declination, the lower panel for right ascensions. In both cases the solid line has slope unity.