The Absolute Magnitudes of RR Lyrae Stars

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Abstract.

We have used HIPPARCOS proper motions and parallaxes to estimate the absolute magnitude of RR Lyr stars using the parallax of RR Lyr itself and the method of statistical parallax. The two results are in excellent agreement with each other and give $M_v=0.77\pm0.15$ mag at $[\text{Fe/H}]=-1.53$. This zero-point is in good agreement with that obtained recently by several groups using Baade-Wesselink methods, i.e., $M_v=0.73\pm0.14$ mag at the same $[\text{Fe/H}]$. Taking the HIPPARCOS based zero-point and a value of $0.18\pm0.03$ for the slope of the $M_v,[\text{Fe/H}]$ relation from the literature, we find the distance modulus of the LMC to be $18.26\pm0.15$ mag.
1. Introduction

RR Lyraes are one of the primary distance indicators. In the present paper we use HIPPARCOS trigonometric parallaxes to estimate their $M_V$ directly and HIPPARCOS proper motions to estimate it using the method of statistical parallax. These results are used to determine the distance to the LMC to compare the RR Lyr distance scale with that from other primary distance indicators. Our results are discussed more extensively in Fernley et al. (1997a).

2. The Data

In this section we summarize the data used in the analysis.

Proper motions and parallaxes were provided by the HIPPARCOS project for 180 stars identified as RR Lyraes. We rejected 36 for various reasons, leaving 144 for our analyses. For illustrative purposes, we note that the mean parallax of our sample is $0.0008 \pm 0.0026$ (s.d.) arcsec. Similarly, the mean absolute value of the proper motion components is $0.0262 \pm 0.0022$ (s.d.) arcsec per year, which may be compared with the same value for these stars from a recent ground based study, $0.0264 \pm 0.0056$ (s.d.) arcsec per year (Layden et al. 1996).

HIPPARCOS provided photometry on the Hipparcos system for all our stars, typically 120 points per star. The photometry was converted into fluxes and phased using periods optimized with the program PULSAR (Skillen 1985). The phased fluxes were fitted to a Fourier Series, typically of order 6. The mean flux so found was converted into a magnitude which was then transformed to the Johnson V system using relations given by the HIPPARCOS project.

We estimated $E(B-V)$ values from the Burstein and Heiles (1982) maps. For the low latitude stars not covered by these maps the reddening was estimated by combining the (V-K) color and [Fe/H] values with the intrinsic Period-(V-K)-[Fe/H] relations from Fernley (1993) and the ratio $E(B-V)=0.35E(V-K)$ from the same source. We took a value of $R=A_V/E(B-V)=3.1$.

Radial velocities and iron abundances were newly determined for many of these stars using spectra from McDonald Observatory, Sutherland Observatory, and Observatorio de Calar Altar (Fernley and Barnes 1997, Solano et al. 1997). These were combined with values from the literature to determine systemic velocities and metallicities.

3. Trigonometric Parallaxes

One star, RR Lyr itself, has a reasonably well determined parallax from HIPPARCOS, $\pi=0.00438 \pm 0.00059$ arcsec, i.e., $\sigma_\pi/\pi=0.13$. The other RR Lyr stars in the sample are at least a magnitude fainter with smaller parallaxes and larger errors, $\sigma_\pi/\pi \geq 0.30$. These stars are close to the measurement limit of HIPPARCOS and were not useful in our analysis. For RR Lyr itself, we obtain $M_V=0.78 \pm 0.29$ mag. RR Lyr has [Fe/H]$=-1.39$.

No Lutz-Kelker correction (Lutz and Kelker 1973, Hanson 1979) has been applied to this result as RR Lyr was selected for its small standard error, not for its large parallax.
4. Statistical Parallax

Using HIPPARCOS proper motions and the data described above, we determined statistical parallaxes with the program described by Hawley et al. (1986). 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, which we have done by making a cut in metallicity. We have run a halo solution for stars with \([\text{Fe/H}] < -1.3\) and a metal-rich solution for stars with \([\text{Fe/H}] \geq -1.3\). The latter sample is not dynamically homogeneous in that it contains a mixture of both old disk and halo stars (Layden et al. 1996). We prefer the solution for the halo RR Lyrae as it is dynamically homogeneous. Our results are given in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>No Stars</th>
<th>([\text{Fe/H}])</th>
<th>(M_v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All RR Lyraes</td>
<td>144</td>
<td>-1.32</td>
<td>0.76 ± 0.13</td>
</tr>
<tr>
<td>Halo RR Lyraes</td>
<td>84</td>
<td>-1.66</td>
<td>0.77 ± 0.17</td>
</tr>
<tr>
<td>Metal-Rich RR Lyraes</td>
<td>60</td>
<td>-0.85</td>
<td>0.69 ± 0.21</td>
</tr>
</tbody>
</table>

These results are very close to those from previous studies which used ground based proper motions (Layden et al. 1996, Hawley et al. 1986, Strugnell et al. 1986).

5. The \(M_v, [\text{Fe/H}]\) Calibration and Implications for the Distance Scale

Combining the results from the trigonometric parallax of RR Lyr and the halo statistical parallax solution, we obtain \(M_v = 0.77 ± 0.15\) mag at \([\text{Fe/H}] = -1.53\). The slope of the \(M_v, [\text{Fe/H}]\) relation has recently been discussed by Fernley et al. (1997b) who estimate a value of 0.18±0.03. Thus we adopt

\[
M_v = 0.18 ± 0.03([\text{Fe/H}] + 1.53) + 0.77 ± 0.15
\]

(1)

Recently several groups have worked on Baade-Wesselink analyses of RR Lyr stars (Liu and Janes 1990, Jones et al. 1992, Cacciari et al. 1992, Skillen et al. 1993 and Fernley 1994) and results of the different groups are reasonably consistent. Taking a simple mean gives

\[
M_v = 0.20 ± 0.04[\text{Fe/H}] + 1.03 ± 0.14
\]

(2)

where the error on the zero-point comes from both the random error, ±0.06 mag, and the estimated systematic errors in the Baade-Wesselink method, ±0.12 mag. At \([\text{Fe/H}] = -1.53\), eqn(2) predicts \(M_v = 0.73 ± 0.14\) mag, which is in excellent agreement with the zero-point derived from the HIPPARCOS data in eqn(1), which is itself based on two independent methods. This agreement in the zero-point among three completely independent methods of analysis strongly suggests that the absolute magnitudes of field RR Lyr stars are reasonably well understood.

A convenient venue for comparison of the RR Lyr distance scale with other distance scales is the Large Magellanic Cloud. There are observations of RR
Lyrae in 5 LMC clusters (Walker 1992, Reid and Freedman 1994). Combining the data from the clusters gives a mean dereddened magnitude $m_v=18.98$ and a mean [Fe/H] = $-1.8$. From eqn(1), we obtain a distance modulus for the LMC of $(m-M)=18.26\pm0.15$ mag.

We show in Table 2 some recent determinations of the distance modulus of the LMC.

<table>
<thead>
<tr>
<th>Method</th>
<th>$(m-M)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR Lyraes - HIPPARCOS data (this paper)</td>
<td>18.26±0.15</td>
</tr>
<tr>
<td>RR Lyraes - Baade-Wesselink (see text)</td>
<td>18.31±0.14</td>
</tr>
<tr>
<td>Cepheids - Field Stars HIPPARCOS data (Feast and Catchpole 1997)</td>
<td>18.70±0.10</td>
</tr>
<tr>
<td>Cepheids - Open clusters (Feast 1995, HIPPARCOS Pleiades scale)</td>
<td>18.33±0.10</td>
</tr>
<tr>
<td>Cepheids - Baade-Wesselink (Gieren et al. 1997)</td>
<td>18.49±0.05</td>
</tr>
<tr>
<td>Cepheids - Baade-Wesselink (Gieren et al. 1993)</td>
<td>18.65±0.10</td>
</tr>
<tr>
<td>Miras - HIPPARCOS data (van Leewuen et al. 1997)</td>
<td>18.54±0.18</td>
</tr>
<tr>
<td>SN1987A Ring - Gould and Uza (1997)</td>
<td>18.37±0.04</td>
</tr>
<tr>
<td>SN1987A Ring - Sonneborn et al. (1997)</td>
<td>18.43±0.10</td>
</tr>
<tr>
<td>SN1987A Ring - Panagia et al. (1997)</td>
<td>18.58±0.03</td>
</tr>
<tr>
<td>SN1987A Ring - Lundqvist and Sonneborn (1997)</td>
<td>18.67±0.08</td>
</tr>
</tbody>
</table>

6. Summary

Using HIPPARCOS data we obtain the following estimates of the zero-point of the RR Lyr $M_v$, [Fe/H] relation: firstly, $M_v=0.78\pm0.29$ mag at [Fe/H] = $-1.39$ from the HIPPARCOS trigonometric parallax of RR Lyr itself and secondly, $M_v=0.77\pm0.17$ mag at [Fe/H] = $-1.66$ from the method of statistical parallax and HIPPARCOS proper motions for 84 Halo field RR Lyraes. These two estimates are in excellent agreement and give a final value of $M_v=0.77\pm0.15$ mag at [Fe/H] = $-1.53$. This in turn is in very good agreement with the zero-point derived recently by several groups using Baade-Wesselink methods, namely $M_v=0.73\pm0.14$ mag at [Fe/H] = $-1.53$. This level of agreement, among three completely independent methods, gives us great confidence that we do understand the distance scale for Galactic field RR Lyr stars.

Taking the HIPPARCOS zero-point and a value of $0.18\pm0.03$ for the slope of the $M_v$, [Fe/H] relation from the literature, we find the distance modulus of the LMC to be $18.26\pm0.15$ mag. Comparing this value with recently published estimates from other standard candles, shows that there remain unresolved problems in the distance scale.

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References

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