KINEMATICS OF RR LYRAE STARS
BASED ON HIPPARCOS PROPER MOTIONS

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ABSTRACT
We have derived the galactic space velocities of 130 RR Lyrae stars, using proper motions measured by Hipparcos. The distances of the stars are taken from a photometric calibration which is confirmed by Hipparcos parallaxes. We present the mean velocities and the velocity dispersions of the RR Lyrae stars as a function of the metallicity [Fe/H]. The data do not allow to decide safely whether the kinematical properties of halo and disk objects show a smooth transition or whether halo and disk stars belong to two distinct populations. The difference in the mean motions of metal-poor and metal-rich RR Lyrae stars is in good agreement with a circular velocity of about 220 km/s at the Sun. A smaller fraction of RR Lyrae stars behaves more like objects of the old galactic (thick or thin) disk. This gives us the opportunity to study the transition from the halo to the disk.

Photometric distances used by Hipparcos cannot be used for this purpose in most cases, since their relative errors are too large. Most of the RR Lyrae stars observed by Hipparcos have distances \( r \) from the Sun between 0.5 kpc and 2 kpc, which correspond to parallaxes \( p \) between 2 mas and 0.5 mas, while the mean error \( \varepsilon_p \) of the Hipparcos parallaxes is larger than 1 mas (except for RR Lyr itself). Hence we have to use photometric distances for the RR Lyrae stars, which should have relative errors of 10 to 20 per cent in our sample.

From the sample we remove all those stars for which we have indications that they are binaries, either visual or astrometric ones. The additional data which we need for calculating photometric distances and space velocities (i.e. photometry, metallicities, radial velocities) have been taken from the literature (see Rockman 1995). Mostly we work with a sample of 130 RR Lyrae stars which have complete and accurate data.

Key words: RR Lyrae stars; galactic kinematics; galactic dynamics; galactic evolution; galactic halo; galactic disk; Hipparcos Catalogue.

1. INTRODUCTION

RR Lyrae stars are very important for studies in galactic kinematics and dynamics, since most of these variables are easily identifiable members of the halo of our Galaxy and absolutely rather bright. A smaller fraction of RR Lyrae stars behaves more like objects of the old galactic (thick or thin) disk. This gives us also the opportunity to study the transition from the halo to the disk.

The ESA astrometry satellite Hipparcos has observed more than 170 RR Lyrae stars. They are essentially a magnitude-limited sample of RR Lyrae stars, brighter than the limiting magnitude of Hipparcos of about 12 mag in \( V \). The proper motions of RR Lyrae stars given in the Hipparcos Catalogue (ESA 1997) are the most accurate ones available at present, both with respect to the individual accuracy and to the absence of systematic errors.

For deriving space motions from the proper motions, we need the individual distances of the stars. Unfortunately, the trigonometric parallaxes of RR Lyrae stars measured by Hipparcos cannot be used for this purpose in most cases, since their relative errors are too large. Most of the RR Lyrae stars observed by Hipparcos have distances \( r \) from the Sun between 0.5 kpc and 2 kpc, which correspond to parallaxes \( p \) between 2 mas and 0.5 mas, while the mean error \( \varepsilon_p \) of the Hipparcos parallaxes is larger than 1 mas (except for RR Lyr itself). Hence we have to use photometric distances for the RR Lyrae stars, which should have relative errors of 10 to 20 per cent in our sample.

From the sample we remove all those stars for which we have indications that they are binaries, either visual or astrometric ones. The additional data which we need for calculating photometric distances and space velocities (i.e. photometry, metallicities, radial velocities) have been taken from the literature (see Rockman 1995). Mostly we work with a sample of 130 RR Lyrae stars which have complete and accurate data.

2. PHOTOMETRIC DISTANCES USED

We have used photometric distances \( r_{\text{phot}} \) (or equivalently photometric parallaxes \( p_{\text{phot}} \)) which are based on various photometric calibrations of the mean absolute magnitudes \( M_v \) of RR Lyrae stars (Rockman 1995). Many of the calibrations include a dependence of \( M_v \) on the metallicity [Fe/H] of the RR Lyrae stars. The various calibrations are shown and referenced in Figure 1.

3. TEST OF PHOTOMETRIC DISTANCES

Although most of the Hipparcos parallaxes of RR Lyrae stars are individually not very accurate, they are still very valuable for testing the various photometric calibrations of RR Lyrae stars statistically by using our whole sample.

An example of such a test is shown in Figure 2 for the calibration S93 (Sandage 1992). We plot the differences between the Hipparcos trigonometric parallax \( p_{\text{Hipp}} \) and the photometric parallax \( p_{\text{phot}} \) (based on S93) as a function of \( p_{\text{phot}} \) (also based on S93). The error bars show the mean measuring errors of \( p_{\text{Hipp}} \).
Photometric calibrations of the mean absolute magnitudes $M_v$ of RR Lyræe stars as a function of the metallicity $[\text{Fe/H}]$. The following abbreviations are used: BH86: Barnes & Hawley 1986; S82: Sandage 1982; L90: Lee et al. 1990; F93: Fernley 1993; S93: Sandage 1993; C92: Cacciari et al. 1992; B90: Buonanno et al. 1990, recompiled by Fernley 1993.

only. As discussed by Wielen et al. (1994), a linear fit of the data in such a diagram:

$$\Delta p = p_{\text{Hipp}} - p_{\text{phot}} = p_0 + f - 1 \, p_{\text{phot}}$$

(1)

provides both a test of a possible zero-point error $p_0$ in $p_{\text{Hipp}}$ as well as a global test of the photometric distance scale, where $f$ is defined as:

$$p_{\text{phot}, \text{true}} = f \, p_{\text{phot}, \text{used}}$$

(2)

Or:

$$r_{\text{phot, true}} = (1/f) \, r_{\text{phot, used}}$$

(3)

The RR Lyræe stars alone do not allow to determine $p_0, f$ reliably. We therefore assume, in accordance with other information, $p_0, f = 0$. We also adopt the same slope of $M_v$ with $[\text{Fe/H}]$ as used in S93. The points in Figure 2 follow closely a horizontal line (i.e. $f - 1 = 0$ or $f = 1$). A least-squares solution with appropriate weights gives for 149 RR Lyræe stars for which we were able to determine photometric distances:

$$f - 1 = -0.02 \pm 0.10$$

(4)

or:

$$(1/f) = 1.02 \pm 0.10$$

(5)

The corresponding change in $M_v$ is $-0.04 \pm 0.22$ mag. Hence the photometric distances based on S93 are statistically in good agreement with the Hipparcos parallaxes and will be used without any correction. Many of the other calibrations, however, are also statistically acceptable (except for S82 and BH86).

4. GALACTIC KINEMATICS OF RR LYRAE STARS

From the data mentioned above and the calibration S93, we have calculated space velocities $U, V, W$ with respect to the Sun. $U$ is parallel to the direction from the Sun towards the galactic center; $V$ points to the direction of galactic rotation at the po-

Figure 1. Photometric calibrations of the mean absolute magnitudes $M_v$ of RR Lyræe stars as a function of the metallicity $[\text{Fe/H}]$.

Figure 2. Test of the photometric parallaxes $p_{\text{phot}}$ of RR Lyræe stars (based on S93) with the Hipparcos parallaxes $p_{\text{Hipp}}$. The error bars represent the mean errors of $p_{\text{Hipp}}$.

Figure 3. The components $\tilde{U}, \tilde{V}, \tilde{W}$ of the galactic space velocities of RR Lyræe stars as a function of the metallicity $[\text{Fe/H}]$. 
of the velocity distribution of the halo stars. However, the bias in the results for the halo seems to be small. Therefore, we have not corrected for this bias, although this would be possible by assuming that the velocity distribution of the halo stars is symmetric in \( \vec{U}, \vec{V} \), and \( \vec{W} \).

Figure 5 and Table 2 show our results for the two distinct groups of halo and disk RR Lyrae stars. Again, the halo objects do not show a net rotation, while the disk RR Lyrae stars behave like typical old disk stars. Clearly, the details depend on our somewhat arbitrary separation of disk and halo objects.

5. CONCLUSIONS

The difference in the mean \( \vec{V} \) velocities of the (extreme) halo and disk RR Lyrae stars is in good agreement with a local circular velocity \( V_{c,0} \) of about 220 km s\(^{-1}\).

The space velocities of RR Lyrae stars, based on Hipparcos proper motions, confirm that the system of the most metal-poor RR Lyrae stars shows no rotation, if we use a local circular velocity of \( V_{c,0} = 220 \text{ km s}^{-1} \). The velocity dispersions of these (extreme) halo objects are quite accurately determined here. The most metal-rich RR Lyrae stars move like typical disk stars.

The data presented here do not allow to decide safely whether there is a smooth transition in the kinematical behaviour of halo and disk objects or whether the halo and disk are very distinct populations without any transitional phase.
Table 1. Mean values (⟨⟩) and dispersions (σ) of the components of the galactic space velocities $\tilde{U}, \tilde{V}, \tilde{W}$ of RR Lyrae stars for four groups of metallicities [Fe/H].

<table>
<thead>
<tr>
<th>[Fe/H]</th>
<th>n</th>
<th>$&lt;\tilde{U}&gt;$</th>
<th>$&lt;\tilde{V}&gt;$</th>
<th>$&lt;\tilde{W}&gt;$</th>
<th>$\sigma_{\tilde{U}}$</th>
<th>$\sigma_{\tilde{V}}$</th>
<th>$\sigma_{\tilde{W}}$</th>
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<tr>
<td>-2.4 to -1.5</td>
<td>35</td>
<td>-51 ± 29</td>
<td>-16 ± 19</td>
<td>+20 ± 19</td>
<td>172 ± 21</td>
<td>110 ± 14</td>
<td>112 ± 14</td>
</tr>
<tr>
<td>-1.5 to -1.0</td>
<td>55</td>
<td>+12 ± 25</td>
<td>+4 ± 13</td>
<td>+7 ± 13</td>
<td>183 ± 18</td>
<td>96 ± 10</td>
<td>98 ± 10</td>
</tr>
<tr>
<td>-1.0 to -0.5</td>
<td>25</td>
<td>-37 ± 25</td>
<td>+114 ± 22</td>
<td>+18 ± 16</td>
<td>121 ± 18</td>
<td>107 ± 16</td>
<td>78 ± 12</td>
</tr>
<tr>
<td>-0.5 to +0.4</td>
<td>15</td>
<td>-20 ± 11</td>
<td>+204 ± 11</td>
<td>-3 ± 7</td>
<td>41 ± 8</td>
<td>40 ± 8</td>
<td>24 ± 5</td>
</tr>
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</table>

Table 2. Mean values (⟨⟩) and dispersions (σ) of the components of the galactic space velocities $\tilde{U}, \tilde{V}, \tilde{W}$ of RR Lyrae stars for halo and disk objects.

<table>
<thead>
<tr>
<th>Component</th>
<th>n</th>
<th>$&lt;\tilde{U}&gt;$</th>
<th>$&lt;\tilde{V}&gt;$</th>
<th>$&lt;\tilde{W}&gt;$</th>
<th>$\sigma_{\tilde{U}}$</th>
<th>$\sigma_{\tilde{V}}$</th>
<th>$\sigma_{\tilde{W}}$</th>
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<td>halo</td>
<td>106</td>
<td>-18 ± 17</td>
<td>+6 ± 11</td>
<td>+18 ± 10</td>
<td>176 ± 12</td>
<td>105 ± 8</td>
<td>101 ± 7</td>
</tr>
<tr>
<td>disk</td>
<td>24</td>
<td>-20 ± 8</td>
<td>+201 ± 7</td>
<td>-15 ± 6</td>
<td>39 ± 6</td>
<td>30 ± 5</td>
<td>25 ± 5</td>
</tr>
</tbody>
</table>

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