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. Adopting such a circular velocity, the system of metal-poor RR Lyrae stars shows no significant net rotation in our Galaxy. The metal-rich RR Lyrae stars move like typical disk stars.

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 (gradual or sudden) 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 ε_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 $r_{\rm phot}$ (or equivalently photometric parallaxes $p_{\rm phot}$) 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 $p_{\rm Hipp}$ and the photometric parallax $p_{\rm phot}$ (based on S93) as a function of $p_{\rm phot}$ (also based on S93). The error bars show the mean measuring errors of $p_{\rm Hipp}$

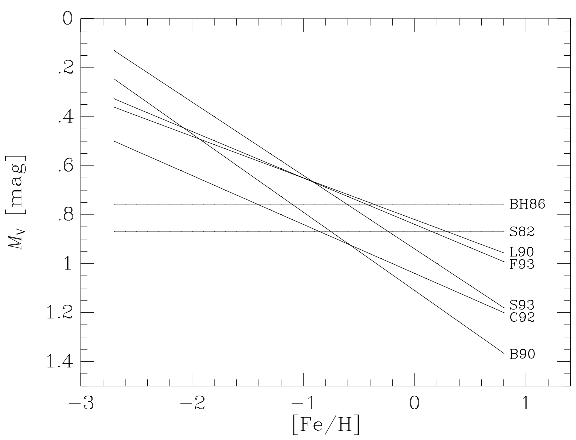

Figure 1. Photometric calibrations of the mean absolute magnitudes M_v of RR Lyrae stars as a function of the metallicity [Fe/H]. The following abbreviations are used: BH86: Barnes & Hawley 1986; S82: Sandage 1982; L90: Lee et al. 1990; F93: Fernley 1993; S93: Sandage 1993; C92: Cacciari et al. 1992; 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:

$$\Delta p = p_{\rm Hipp} - p_{\rm phot} = p_{0,f} + (f-1)\, p_{\rm phot} \qquad (1)$$

provides both a test of a possible zero-point error $p_{0,f}$ in $p_{\rm Hipp}$ as well as a global test of the photometric distance scale, where f is defined as:

$$p_{\rm phot,true} = f\, p_{\rm phot,used} \qquad (2)$$

or:

$$r_{\rm phot,true} = (1/f)\, r_{\rm phot,used} \qquad (3)$$

The RR Lyrae 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 [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 Lyrae stars for which we were able to determine photometric distances:

$$f - 1 = -0.02 \pm 0.10 \qquad (4)$$

or:

$$(1/f) = 1.02 \pm 0.10 \qquad (5)$$

The corresponding change in M_v is -0.04 ± 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, and 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-

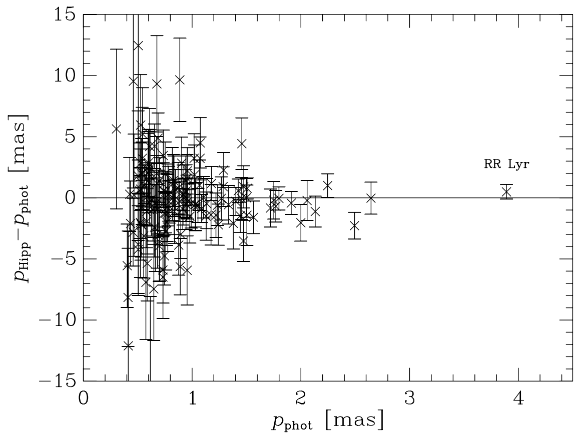

Figure 2. Test of the photometric parallaxes p_{phot} of RR Lyrae stars (based on S93) with the Hipparcos parallaxes $p_{\rm Hipp}$. The error bars represent the mean errors of $p_{\rm Hipp}$.

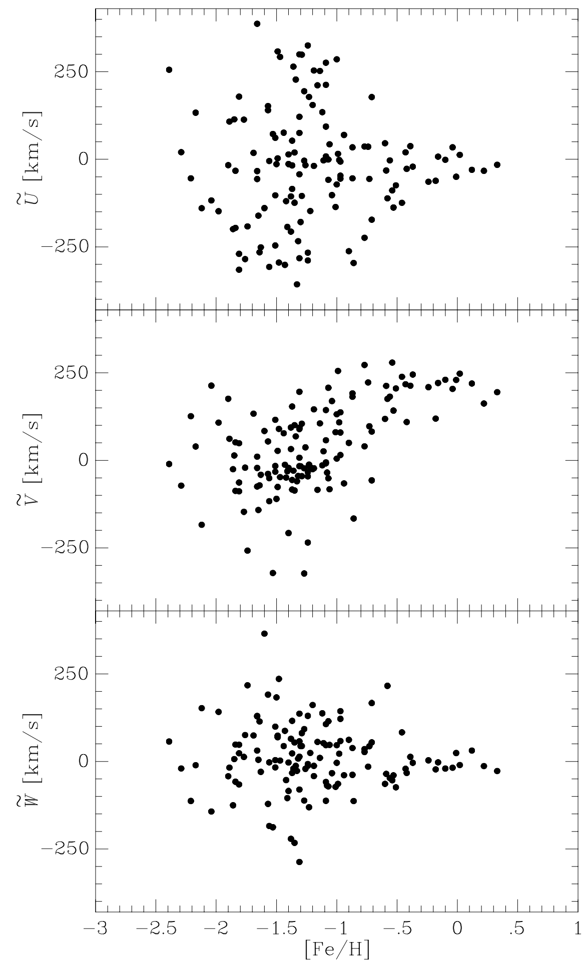

Figure 3. The components $\widetilde{U}, \widetilde{V}, \widetilde{W}$ of the galactic space velocities of RR Lyrae stars as a function of the metallicity [Fe/H].

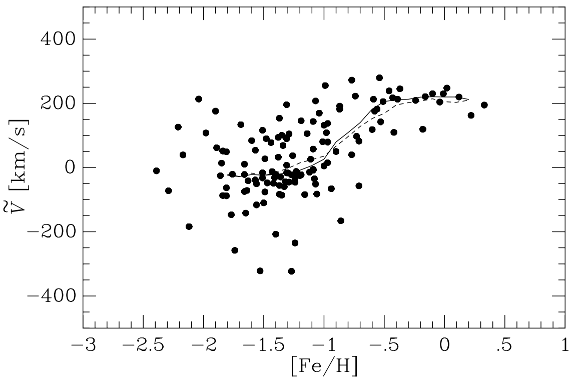

Figure 4. The velocity component $\widetilde{V}$ (in the direction of galactic rotation) of RR Lyrae stars as a function of the metallicity [Fe/H]. The solid curve represent a running median of $\widetilde{V}$, the dashed curve a running mean of $\widetilde{V}$ as a function of [Fe/H].

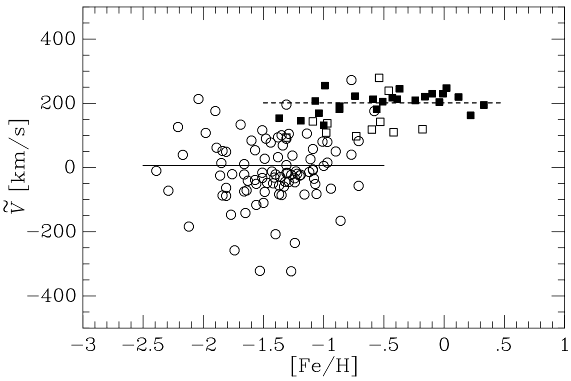

Figure 5. The velocity component $\widetilde{V}$ (in the direction of galactic rotation) of RR Lyrae stars as a function of the metallicity [Fe/H]. Open circles and open squares: halo objects; filled squares: disk objects. The lines represent the mean values of $\widetilde{V}$ for disk and halo objects. The open squares would be also classified as disk objects if we would enlarge the defining velocity ellipsoid by a factor of 1.5.

sition of the Sun, and W to the galactic north pole. The space motions with respect to the Sun have then be corrected for the peculiar solar motion, adopting $+9, +12, +7$ km s^{-1} in U, V, W (Delhaye 1965), and for a local circular velocity $V_{c,0} = 220$ km s^{-1}, using the IAU(1985) value (Kerr & Lynden-Bell 1986, Wielen 1986). Hence the space velocities are transformed into a frame in which the Galaxy should be at rest. Finally, the individual space motions are rotated around the spin axis of our Galaxy in such a way that the new $\widetilde{U}$ axis points from the position of the individual star towards the spin axis. In doing so, we assume for the galactocentric distance of the Sun the IAU(1985) value of $R_0 = 8.5$ kpc (Kerr & Lynden-Bell 1986, Wielen 1986). For our sample of 130 RR Lyrae stars, we show in Figure 3 these cylindrical components $\widetilde{U}, \widetilde{V}, \widetilde{W}$ as a function of the metallicity [Fe/H].

In Figure 4, we have fitted a smooth line to $\widetilde{V}$([Fe/H]). Table 1 presents the mean motions and the velocity dispersions of the RR Lyrae stars in four bins of metallicities. Both Figure 4 and Table 1 show that (1) the group of the most metal-deficient RR Lyrae stars does not show any significant galactic rotation ($< \widetilde{V} > \sim 0$, for $V_{c,0} = 220$ km s^{-1}), and (2) the most metal-rich RR Lyrae stars move like typical disk stars, e.g. the McCormick K and M dwarfs.

Many authors favour instead of a gradual transition from the halo to the disk a scenario with two kinematically very distinct populations, namely halo and disk, but with overlapping ranges of metallicities. In the spirit of this scenario, we have tried to subdivide our sample into two distinct subsets: halo and disk RR Lyrae stars. We call all those stars 'disk objects' which have metallicities [Fe/H] > -1.4 and have peculiar space velocities with respect to the circular velocity which are inside a velocity ellipsoid of $\widetilde{U} = 166$ km s^{-1}, $\widetilde{V} = 100$ km s^{-1}, $\widetilde{W} = 86$ km s^{-1}. The axial ratios of this velocity ellipsoid are taken from the McCormick K and M dwarfs (Wielen 1977). The other objects are assumed to be 'halo objects'. Of course, such a procedure cuts a 'hole' into a wing 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 $\widetilde{U}$, $\widetilde{V}$ (+constant), and $\widetilde{W}$.

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 $\widetilde{V}$ 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 $V_{c,0} = 220$ 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 $\widetilde{U}, \widetilde{V}, \widetilde{W}$ of RR Lyrae stars for four groups of metallicities [Fe/H].

[Fe/H] [dex]	n	$<\widetilde{U}>$	$<\widetilde{V}>$ [km/s]	$<\widetilde{W}>$	$\sigma_{\widetilde{U}}$	$\sigma_{\widetilde{V}}$ [km/s]	$\sigma_{\widetilde{W}}$
–2.4 to –1.5	35	–51 ± 29	–16 ± 19	+20 ± 19	172 ± 21	110 ± 14	112 ± 14
–1.5 to –1.0	55	+12 ± 25	+4 ± 13	+7 ± 13	183 ± 18	96 ± 10	98 ± 10
–1.0 to –0.5	25	–37 ± 25	+114 ± 22	+18 ± 16	121 ± 18	107 ± 16	78 ± 12
–0.5 to +0.4	15	–20 ± 11	+204 ± 11	–3 ± 7	41 ± 8	40 ± 8	24 ± 5

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

Component	n	$<\widetilde{U}>$	$<\widetilde{V}>$ [km/s]	$<\widetilde{W}>$	$\sigma_{\widetilde{U}}$	$\sigma_{\widetilde{V}}$ [km/s]	$\sigma_{\widetilde{W}}$
halo	106	–18 ± 17	+6 ± 11	+18 ± 10	176 ± 12	105 ± 8	101 ± 7
disk	24	–20 ± 8	+201 ± 7	–15 ± 6	39 ± 6	30 ± 5	25 ± 5

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