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The kinematics and zero point of the $\log P - \langle M_K \rangle$ relation for galactic field RR Lyrae variables via statistical parallax

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Abstract. The kinematical parameters of the local field RR Lyrae population and the zero point of the $\log P$–$\langle M_K \rangle$ relation for these variables are inferred by applying the statistical parallax (maximum-likelihood) technique to a sample of 379 RR Lyrae stars with known periods, radial-velocities, metallicities, K-band photometry, and absolute proper motions on the ICRS system. Hipparcos, Tycho-2, SPM, UCAC1 and NPM1 were used as the sources of proper motions. The K-band magnitudes were adopted from the 2MASS All-Sky Data Release. The parameters of the velocity distribution are found to be ($U_0 = -13 \pm 9$, $V_0 = -41 \pm 7$, $W_0 = -19 \pm 4$) km s^{-1}, ($\sigma_U = 66 \pm 9$, $\sigma_V = 47 \pm 7$, $\sigma_W = 23 \pm 5$) km s^{-1} and ($U_0 = -11 \pm 10$, $V_0 = -224 \pm 8$, $W_0 = -8 \pm 6$) km s^{-1} ($\sigma_U = 158 \pm 9$, $\sigma_V = 95 \pm 5$, $\sigma_W = 88 \pm 5$) km s^{-1} for the thick-disk (the purest disk sample, 56 stars) and halo (the purest halo sample, 264 stars) objects, respectively. The zero point of the infrared PL relation of Jones et al. (1992 – based on the results obtained using the Baade-Wesselink method) is confirmed: we find $\langle M_K \rangle = -2.33 \cdot \log P_F - 0.89 \pm 0.09$, which is only $0\overset{m}{.}01$ brighter than found using the Baade-Wesselink method (Jones et al. 1992). A conversion of the resulting $\log P$–$\langle M_K \rangle$ relation to V-band luminosities yields the metallicity-luminosity relation $\langle M_V \rangle = +1.12 + 0.18 \cdot [\mathrm{Fe/H}] \pm 0.10$. Our results imply a solar Galactocentric distance of $R_0 = 7.8 \pm 0.4$ kpc and an LMC distance modulus of $DM_{\mathrm{LMC}} = 18.17 \pm 0.10$ (cluster RR Lyraes) or $DM_{\mathrm{LMC}} = 18.10 \pm 0.10$ (field RR Lyraes), thereby favoring the so-called short distance scale.

1. Introduction

RR Lyrae variables are objects of prime importance for determining the distances to old stellar systems both in our Galaxy and beyond. In this paper we use the infrared K-band photometry of Galactic-field RR Lyrae stars adopted from the 2MASS All-Sky Data Release combined with absolute proper motions, radial velocities, metallicities, and interstellar extinction values to constrain the zero point of the infrared period-luminosity relation ($\log P_F$ - $\langle M_K \rangle$) and estimate the kinematical parameters of the halo and thick-disk RR Lyr populations using the method of statistical parallax in its rigorous form as described by Murray (1983) and Hawley et al. (1986). We use the results obtained to estimate the distances to the Galactic center and the LMC.

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2. The data

We adopted the periods and pulsation modes from the General Catalog of Variable Stars (Kholopov et al. 1985–1987). The fundamental-mode periods P_F for first-overtone pulsators (RRc type variables) were computed as $\log P_F = \log P + 0.127$ (see Frolov & Samus 1998). Our source of radial velocities, [Fe/H], and interstellar extinction, E_{B-V}, was the work of Beers et al. (2000). We adopted K-band magnitudes from a single source: the 2MASS Second All-Sky Data Release. We adopted the absolute proper motions of RR Lyrae variables from the Hipparcos (ESA 1997), Tycho-2 (Hog et al. 2000), SPM (Platais et al. 1998), UCAC1 (Zacharias et al. 2000), and NPM1 (Hanson et al. 1994) catalogs. We reduced the proper motions from the NPM1 catalog to the TYCHO-2 (ICRS) frame field-by-field using NPM1 plate logs provided by Klemola (2003). For a number of stars, we computed the proper motions from the 2MASS minus AC 2000.2 (Urban et al. 2001) position differences or from 2MASS minus (earliest-plate) USNO-B1.0 Catalog (Monet et al. 2003) position differences.

3. Initial distances

Here we determined the initial distances to the RR Lyrae stars of our sample based on the infrared PL relation by Jones et al. (1992) based on the application of Baade-Wesselink method to field RR Lyrae stars:

$$\langle M_K(\text{Jones})\rangle = -2.33 \cdot \log P_F - 0.88. \tag{1}$$

4. Results

4.1. Period-Luminosity and Period-Metallicity relations

We applied the method of statistical parallax to a subsample of 350 RR Lyrae variables, from which we removed 17 stars at heliocentric distances greater than 7 kpc and 12 apparent kinematic outliers – most likely due to large proper-motion errors. The results are summarized in Table 1. Halo-1,2,3/Disk-1,2,3 indicate the names of the halo/disk subsamples according to the three partitions of the entire sample as used by Layden et al. (1996) and Dambis & Rastorguev (2001): for statistical parallax method to operate correctly, it should be applied to kinematically homogeneous samples. Here N is the number of stars in the subsample; (U_0,V_0, W_0) and (σ_U, σ_V, σ_W) are the mean heliocentric velocity and velocity dispersion components of the corresponding subsample, respectively; and ΔM is the absolute magnitude correction to the PL relation given in eq. 1.

The resulting absolute magnitude correction $\Delta M = -0.01 \pm 0.09$ (based on the most homogeneous Halo-3 sample) implies a final PL relation of:

$$\langle M_K\rangle = -2.33 \cdot \log P_F - 0.89 \pm 0.09. \tag{2}$$

This relation can be converted into the following [Fe/H]-$\langle M_V\rangle$ relation:

$$\langle M_V\rangle = +1.12 + 0.18 \cdot [\text{Fe/H}] \pm 0.16 \tag{3}$$

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Table 1. Kinematical parameters and K-band absolute magnitude correction of Galactic field RR Lyrae variables

Sample	N	$\langle[Fe/H]\rangle$	U_0	V_0	W_0	σ_U	σ_V	σ_W	ΔM
					km s^{-1}				
Halo-1	277	-1.59	-11	-217	-8	154	96	86	+0.00
			± 130	± 8	± 5	± 8	± 5	± 5	± 0.09
Halo-2	294	-1.56	-11	-206	-9	151	103	84	+0.00
			± 9	± 8	± 5	± 8	± 6	± 5	± 0.09
Halo-3	264	-1.60	-11	-224	-8	158	95	88	-0.01
			± 10	± 8	± 6	± 9	± 5	± 5	± 0.09
Disk-1	73	-0.71	-12	-40	-21	68	45	35	-0.19
			± 8	± 6	± 5	± 9	± 6	± 65	± 0.23
Disk-2	56	-0.58	-13	-41	-19	66	45	23	-0.05
			± 9	± 7	± 4	± 9	± 7	± 5	± 0.24
Disk-3	86	-0.81	-11	-51	-20	67	49	35	-0.29
			± 8	± 6	± 5	± 8	± 6	± 5	± 0.20

based on 241 stars with both K-band and photoelectric V-band photometry. We use the photoelectric V-band photometry adopted from Layden et al. (1996) and our own observations for 60 stars (Vozyakova 2003).

4.2. The Distances to the Galactic Center and the LMC

Our zero point of the infrared PL relation for RR Lyr stars virtually coincides with that of Jones et al. (1992). We thus corroborate the solar Galactocentric distance of $R_0 = 7.8 \pm 0.4$ kpc estimated by Carney et al. (1992) based on the IR photometry of 58 RR Lyrae stars in the Galactic bulge and the PL relation of Jones et al. (1992).

Our [Fe/H] - $\langle M_V\rangle$ relation (converted from the $\log P_F - \langle M_K\rangle$ relation) yields a mean distance modulus of $DM_{\mathrm{LMC(cluster)}} = 18.17 \pm 0.10$ for RR Lyrae stars of seven LMC globular clusters (based on the data adopted from Walker (1992)) and $DM_{\mathrm{LMC(field)}} = 18.10 \pm 0.11$ for field RR Lyrae stars (based on OGLE survey data from Udalski (2000)).

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Discussion

Bono: We have recently published a paper in which we collected all the BW data available for field RR Lyrae stars and we found the metallicity term is empirically supported. If you account for this term, the distance to the Cluster Reticulum become ≈18.50.

Dambis: No, this is not so. In our case the effect of the metallicity term is approximately equal to the difference between the metallicity of the cluster in question (Reticulum), which is equal to −1.7, and the mean metallicity of the sample (≈ -1.5) – Δ [Fe/H] = $[\mathrm{Fe/H}]_{Reticulum} - < [\mathrm{Fe/H}] >_{Sample} \sim -0.2$ multiplied by a small factor (+0.1 or -0.23) – and hence does not exceed 0.05 in absolute value. If our formula is correct, we have $\Delta M_K = -0.36 - 0.23 \cdot (-1.7) = +0.04$ ($\sim -0.23 \cdot (-0.2) = +0.05$) and $\mathrm{DM}_{Reticulum}$(CORR)= 18.26 ± 0.09. If we adopt a slope of +0.1 (i.e., $\Delta M_K = +0.1\cdot$ [Fe/H]) we obtain $\Delta M_K = +0.1 \cdot (-0.2) = -0.02$ and $\mathrm{DM}_{Reticulum}$(CORR)= 18.32 ± 0.09.

Jerzykiewicz: The parallaxes you derived are called secular parallaxes. The term "statistical parallax" is reserved for the case when you use the so-called z component of proper motion and mean value of peculiar redial velocity to get mean parallax.

Dambis: The method used was the maximum-likelihood version by Murray (1983) (see also Hawley et al. 1986), which is actually a combined generalisation of the methods traditionally called "secular" and "statistical" parallax; this now is commonly referred to as "statistical parallax".

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