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Assessing SDSS Spectroscopy via Kinematics

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Abstract. A statistical-parallax analysis of the sample of (Chen et al. 2010), which the authors purport to consist mostly of red horizontal-branch (RHB) stars selected based on SEGUE spectroscopy, shows that the luminosities of the stars of this sample are overestimated, on average, by 1.5^m in terms of absolute magnitude. The correction is metallicity dependent and amounts to more than 2^m for metal-poor stars decreasing to 0.4^m for the metal-rich part of the sample. This result implies that the sample actually consists mostly of subgiants and turnoff stars and in its metal-poor part might be only slightly contaminated by horizontal-branch objects. Hence SDSS surface gravities in the temperature range of RHB stars appear not to allow proper separation of highly and moderately evolved stars, especially for metal-poor stars. There appears to be no problems with metallicities, because the metallicity dependence of the kinematical behavior of sample stars is consistent with what is observed for such bona fide distance indicators and kinematical tracers as RR Lyre variables.

1. Introduction

Due to their small luminosity range red horizontal branch stars (RHB) are very good distance indicators and, potentially, kinematical tracers. The main problem is that although they are easy to identify in more or less equidistant groups (globular clusters, external galaxies), their identification among field stars is a challenging task. So far, the largest sample of field RHB stars (5391 objects) is that of Chen et al. (2010), who selected these objects based on SDSS photometry and SEGUE spectroscopy using positions of stars on the metallicity-color and T_{eff}-log g diagrams. Here we test this sample by determining the average luminosities of its constituent stars. This test also serves to assess the suitability of stellar parameters inferred from SDSS (SEGUE) spectroscopy for identification of RHB stars as done by Chen et al. (2010). Although stars of the sample are too faint and distant to have their trigonometric parallaxes measured with satisfactory accuracy, they are nevertheless ideal objects for the method of statistical parallax, which allows one to simultaneously estimate the kinematical parameters of the population studied and adjust the zero point of the adopted distance scale and thereby estimate their true luminosities.

2. The data

The sample of Chen et al. (2010) contains all the data needed to apply the method of statistical parallax:

1. Provisional distances (photometric distances determined from metallicity-luminosity relation $M_g = 0.492 \times$ [Fe/H] + 1.39 derived by Chen et al. (2009).
2. Radial velocities taken from SDSS DR7 catalog (Abazajian et al. 2009)
3. Absolute proper motions from SDSS DR7 catalog.

3. The method

Here we use the statistical parallax method in its maximum-likelihood version (Murray 1983; Hawley et al. 1986; Strugnell et al. 1986; Layden et al. 1996; Dambis 2009), which allows one to simultaneously determine the kinematical parameters of the sample [its mean velocity components with respect to the Sun (U_0, V_0, W_0) and velocity dispersion along Galactocentric radius (σV_R) and transversal velocity dispersion (σV_T] as well as the average absolute-magnitude correction ΔM (in our case, ΔM_g).

4. Results

Table 1 summarizes the results obtained for the entire sample. The inferred average velocity in the direction of Galactic rotation (the reflex solar motion with respect to the sample stars), V_0=-111 ± 2 km/s, and Galactocentric and transversal velocity dispersions, σV_R=105 ± 1 km/s and σV_θ=80 ± 2 km/s, indicate that the stars considered represent either a population intermediate between the Galactic halo and thick disk (with typical V_0 values of ~ -220 and ~ -45 km/s and velocity dispersion components of $\sigma V_R \sim 170$ ± and ~ 50 km/s and $\sigma V_\theta \sim 80$ and 50 km/s, respectively, see, e.g., Dambis (2009)), or a mixture of two or more populations. However, the most important result is the strong evidence for a factor-of-two distance-scale reduction implying a factor-of-four reduction of their luminosities, which casts doubt on the very horizontal-branch nature of most of the objects.

Table 1. Kinematical parameters and the average *g*-band absolute-magnitude correction for the entire sample.

U_0	V_0	W_0	σV_R	σV_θ	ΔM_g	Distance
			km/s			correction factor
+2	-111	+3	105	80	+1.53	0.49
± 1	± 2	± 2	± 1	± 2	± 0.05	0.01

To identify the actual nature of stars included into the list and see whether they represent a more or less homogeneous intermediate population or a mixture of several populations, we subdivided the entire sample into nine subsamples by grouping stars by metallicity. The resulting metallicity-based subsamples can also be viewed as representing stars of different intrinsic colors, because the first criterion that Chen et al. (2010) used to select their RHB candidates was for them to obey very closely the metallicity-color relation $(g - r)_0 = 0.829 + 0.343 \times$[Fe/H] (Chen et al. 2009). Table 2 and Figs. 1–4 summarize the results obtained for these subsamples.

The behavior of kinematical parameters with metallicity is more or less consistent with that demonstrated by such bona fide distance-scale indicators and kinematical tracers as RR Lyrae type variables (Dambis & Rastorguev 2001), thereby corroborating

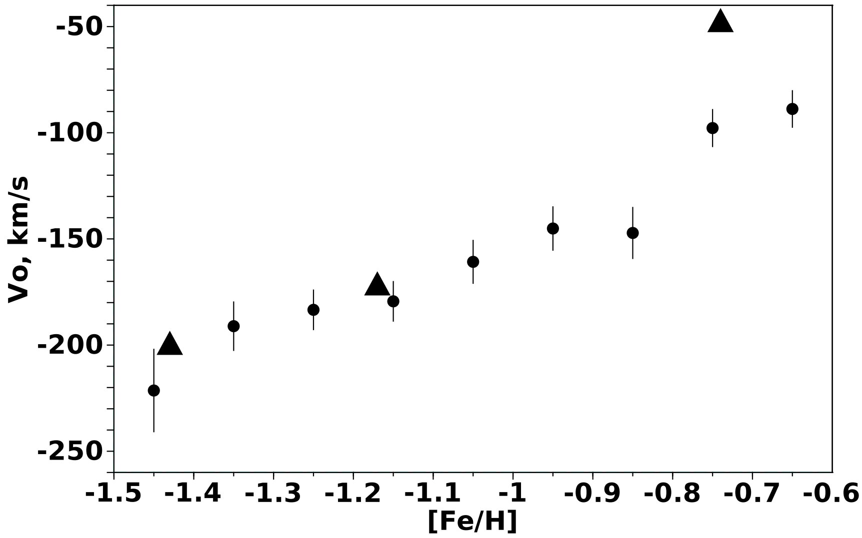

Figure 1. Average velocity in the direction of Galactic rotation as a function of metallicity. The dots and triangles correspond to the results of this study (stars of the sample of Chen et al. (2010)) and local RR Lyrae type variables (Dambis & Rastorguev 2001), respectively.

Table 2. Kinematical parameters and the average *g*-band absolute-magnitude correction for metallicity- (color-) binned subsamples.

$<[Fe/H]>$	U_0	V_0	W_0	σV_R km/s	σV_θ	ΔM_g	Distance correction factor
-1.45	-21	-221	+10	121	72	+2.08	0.38
	± 10	± 19	± 9	± 8	± 8	± 0.20	0.03
-1.35	-17	-191	-2	126	81	+1.98	0.40
	± 7	± 11	± 7	± 5	± 6	± 0.14	0.03
-1.25	-5	-183	-1	125	78	+2.09	0.38
	± 6	± 9	± 5	± 4	± 5	± 0.11	0.02
-1.15	-5	-179	-4	126	76	+1.88	0.42
	± 6	± 9	± 6	± 5	± 5	± 0.12	0.02
-1.05	-2	-161	+1	124	87	+1.64	0.47
	± 7	± 10	± 6	± 5	± 6	± 0.14	0.03
-0.95	6	-145	+8	106	88	+1.37	0.53
	± 7	± 10	± 6	± 5	± 7	± 0.16	0.04
-0.85	16	-147	+6	88	106	+0.63	0.75
	± 8	± 12	± 8	± 5	± 10	± 0.20	0.07
-0.75	-3	-98	+13	89	83	+1.23	0.57
	± 7	± 9	± 7	± 5	± 7	± 0.19	0.05
-0.65	6	-89	+16	69	76	+0.44	0.82
	± 5	± 9	± 6	± 4	± 8	± 0.23	0.08

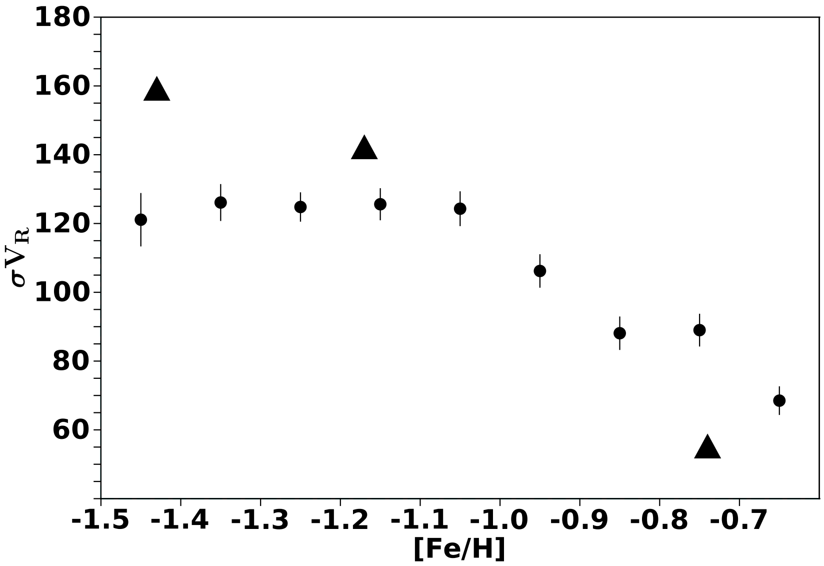

Figure 2. Velocity dispersion along the Galactocentric direction as a function of metallicity. The dots and triangles correspond to the results of this study (stars of the sample of Chen et al. (2010)) and local RR Lyrae type variables (Dambis & Rastorguev 2001), respectively.

the suitability of SDSS (SEGUE) stellar metallicities. The results, however, show conclusively that the sample considered is kinematically inhomogeneous and consists of a mixture of both halo and thick-disk populations with the former dominating the metal-poor domain ([Fe/H] < -1.0) and contaminating appreciably the metal-rich part of the sample ([Fe/H] > -1.0). Furthermore, the distances (and hence luminosities) of stars appear to be highly understimated at low metallicities with degree of underestimation decreasing toward the metal-rich part of the sample.

To better present the result of our "tomography" of the sample, we plot them on the $(B-V)_0$-M_V color-magnitude diagram. To this end, we first convert the average metallicities $< [Fe/H] >$ of each subsample into the corresponding average intrinsic colors $< (g-r)_0 > = 0.829 + 0.343 \times < [Fe/H] >$ (Chen et al. 2009), which we further transform into the $(B-V)_0$ intrinsic colors using the relation $(B-V)_0 = 0.98 \times (g-r)_0 + 0.22$ (Jester et al. 2005), and then determine the average g-band absolute magnitude of each subsample by adding the corresponding ΔM_g absolute-magnitude correction to the initial metallicity-based absolute-magnitude estimate $M_g = 0.492 \times < [Fe/H] > + 1.39$ (Chen et al. 2010), and convert the resulting $< M_g >$ values into V-band absolute magnitudes via the relation $M_V = M_g$ - $0.58 \times (g-r)_0$ - 0.01 (Jester et al. 2005). We show the resulting CMD in Fig. 1, where the $(B-V)_0$-M_V data points corresponding to our subsamples are superimposed on the 12-Gyr Padova isochrone.

Our "sequence" lies slightly above the turnoff point and the subgiant sequence, and only its red tip (metal-rich) might reach the lower part of the red horizontal branch. This implies that the sample should consist mostly of turnoff and subgiant stars and maybe

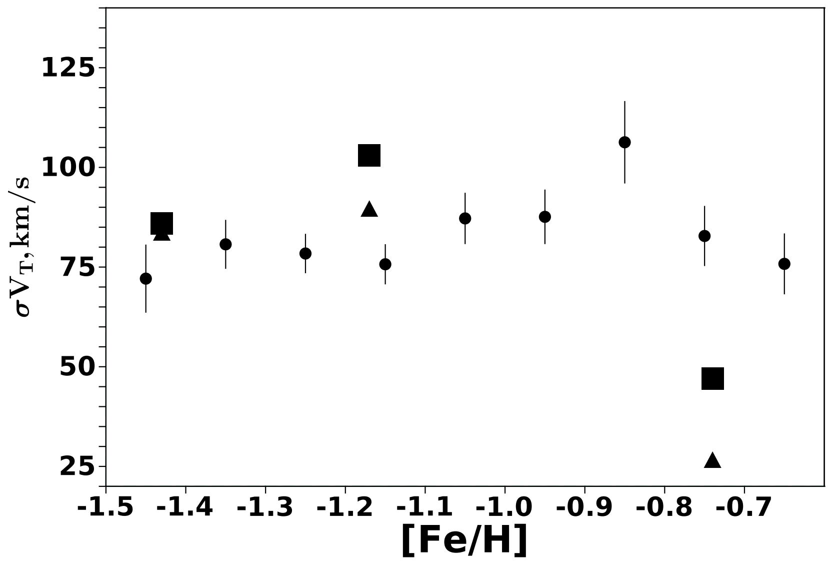

Figure 3. Transversal velocity dispersion as a function of metallicity. The dots correspond to the results of this study (stars of the sample of Chen et al. (2010)). The squares and triangles show the velocity dispersion components in the directions ϕ and θ, respectively, in the Galactocentric spherical system for local RR Lyrae type variables (Dambis & Rastorguev 2001).

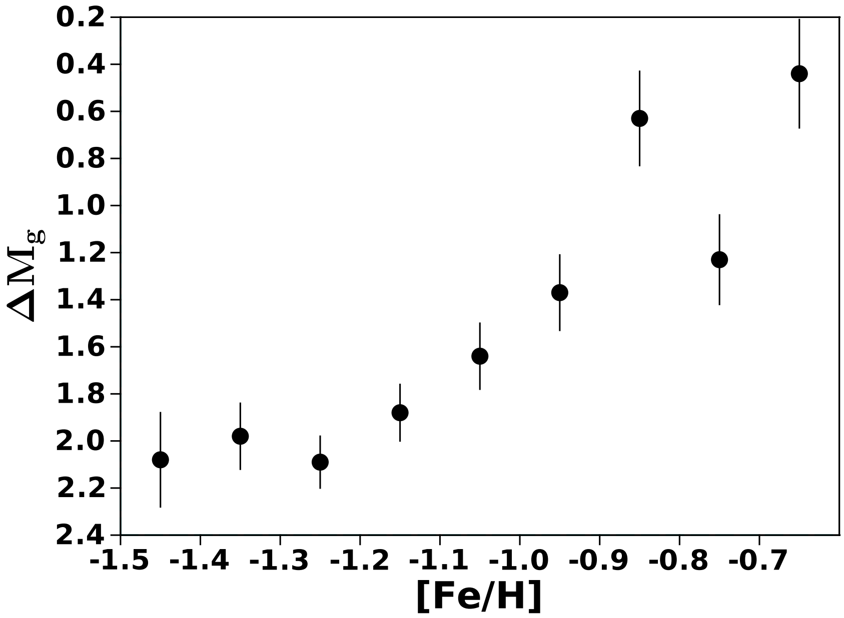

Figure 4. Absolute-magnitude correction as a function of metallicity.

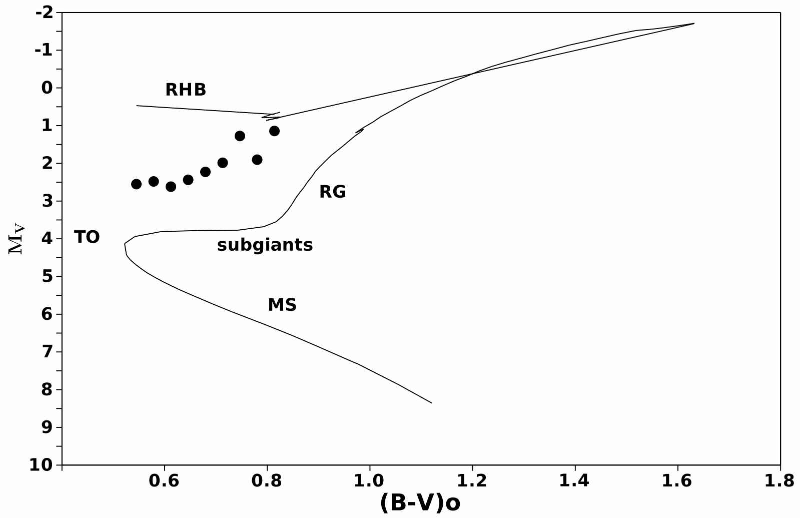

Figure 5. The inferred average positions of subsamples from Table 2 (the dots) on the $(B-V)_0$–M_V color - absolute magnitude diagram. Also indicated are the loci of main-sequence (MS), turnoff (TO), red-giant (RG), and RHB stars, and the $Z = 0.004$ 12-Gyr Padova isochrone (Girardi et al. 2002).

only slightly contaminated by RHB stars, except for the metal-richest part, which indeed appears to consist mostly of horizontal-branch objects.

5. Conclusions

Hence the stellar parameters provided by SDSS pipeline do not allow proper separation of RHB stars from other populations of similar color, especially in the case of metal-poor objects, which should be mostly turnoff and subgiant stars with the distances almost by about a factor of three shorter than adopted in the original list, and all the scale heights and scale lengths inferred should be adjusted accordingly. This result is in sharp contrast to that obtained for the blue horizontal-branch star sample by Xue et al. (2008) whose absolute magnitudes are found to be consistent with their classification (Dambis 2010). The situation appears to be better for the metal-rich part of the sample., for which substantially smaller absolute-magnitude corrections are inferred. The metallicity dependence of the average velocity component in the direction of Galactic rotation (V_0) and radial (σV_R) and transversal (σV_T) velocity dispersions are consistent with what is known based on bona fide kinematical tracers and distance indicators, such as, RR Lyrae variables (Dambis 2009), suggesting that SDSS metallicities for the stars of the sample are, unlike surface gravities, quite satisfactory.

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