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STELLAR POPULATIONS OF THE GALACTIC DISK: METALLICITY DISTRIBUTION AND KINEMATICS

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Abstract. Metallicities and distances have been determined from *Vilnius* photometry for an *in situ* sample of nearly 650 stars in eight proper-motion fields at high Galactic latitudes. For half of these stars, radial velocities have been measured with the CORAVEL spectrometer, which allowed us to derive spatial velocities and Galactic orbits. In this contribution we present a status report on our results for the stellar content of the Galactic disk, with emphasis given to specific aspects of distinguishing the thick-disk stars from the old thin-disk population.

Key words: stars: abundances, kinematics – Galaxy: abundances, solar neighborhood, stellar populations

1. INTRODUCTION

Constraints on models of chemical and dynamical history of the Galactic disk come from observational investigations of metallicity distributions, kinematic properties and ages of constituent members of the disk populations. The oldest of these – the old thin disk and the Gilmore & Wyse thick disk – are particularly useful as probes of the early evolution of the Galaxy. Although the existence of the two disk populations seems well established, their descriptive parameters, such as metallicity distribution function, abundance and kinematic gradients and their trends with age, still remain poorly known. This may be due to difficulties in distinguishing between the old thin disk and the thick disk in the survey samples used.

One of the principal limitations is the fuzzy criteria for the identification of the thick-disk population. Such stars are often selected for kinematical study by their metallicity ([Fe/H] in the range –0.5 and –1 dex) or for chemical study by their kinematics (rotational lag behind the LSR taken to be 20–60 km s^{-1} and larger). However, there is strong evidence for both the extremely metal-week tail to [Fe/H] below –1.6 dex (Beers et al. 2002) and the high-metallicity tail extending to super-solar values (Bensby et al. 2003) in the distribution of the thick-disk field stars, which indicates that [Fe/H] is less discriminant than velocities to separate this population.

The immediate objective of this work was to provide photometric metallicities and kinematics for a new *in situ* sample of stars at high Galactic latitudes. Special care was taken to more precisely discriminate between the thin-disk and the thick-disk stars. This sample, free of any kinematical and metallicity bias, is used to look at trends in the properties of the two disk populations.

2. THE OBSERVATIONAL DATA

Nearly 650 stars have been observed photoelectrically in the *Vilnius* seven-color system in eight proper motion fields of 1.4 deg^2 each. The fields lie at Galactic latitudes $59° < |b| < 76°$, four fields each near the north and south Galactic poles. The observations, complete down to $V = 13$ mag, were performed using the 1 m Ritchey-Chrétien telescope at Maidanak Observatory in Uzbekistan (Bartašiūtė 1994, 1999, 2003). Absolute magnitudes, effective temperatures and metallicities [Fe/H] accurate to about ± 0.15 dex have been estimated, as well as interstellar reddening and distances accurate to within 20%, using calibrations of *Vilnius* photometry given by Bartkevičius & Sperauskas (1983), Bartkevičius & Lazauskaitė (1996) and Straižys et al. (1999).

Radial velocities were measured for 327 stars of the sample, using the CORAVEL spectrometer attached to five different telescopes: the 1 m at Maidanak Observatory, the 1.5 m at TUBITAK National Observatory in Turkey, and the Steward Observatory's 1.5 m (Mount

Lemmon), 1.6 m (Mount Bigelow) and 2.3 m (Kitt Peak) telescopes in Arizona (Bartašiūtė et al. 1993, Sperauskas et al. 2002).

Absolute proper motions for all of the sample stars with respect to galaxies were measured by Kharchenko (1987) using the second epoch plates taken with the Kiev long-focus astrograph. Nearly half of these stars enter also the ASCC-2.5 catalog compiled by Kharchenko (2001) from a number of the *Hipparcos-Tycho* family catalogs, which provides absolute proper motions to better accuracy than the original Kharchenko's catalog. In our calculations of spatial velocities and Galactic orbits, preference was therefore given to the ASCC-2.5 proper motions. For the non-ASCC-2.5 stars, astrometric data were taken from Kharchenko (1987) after reducing them to the *Hipparcos* system (Kharchenko 2004).

3. RESULTS AND DISCUSSION

Figure 1 shows the asymmetric drift (rotational lag) versus [Fe/H] plot for the sample of our survey stars. Two features can be noticed immediately in the diagram. First, there is no strong correlation between rotational velocity and metallicity, at least within the domain of disk populations. Second, we see that a number of metal-rich stars exists with thick-disk kinematics ($V_{\rm lag} \geq 50$ km s^{-1}). The scatter in [Fe/H] for the stars exhibiting the fastest Galactic rotation is also very large, due to the presence of a substantial fraction of metal-deficient stars. Indeed, we have to keep in mind that photometric [Fe/H] determinations for part of these stars can be affected by binarity.

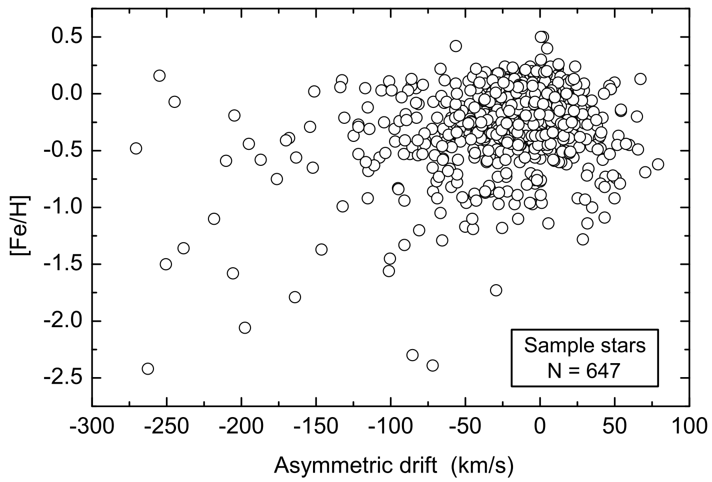

Fig. 1. Asymmetric drift versus [Fe/H] for the total 647 star sample.

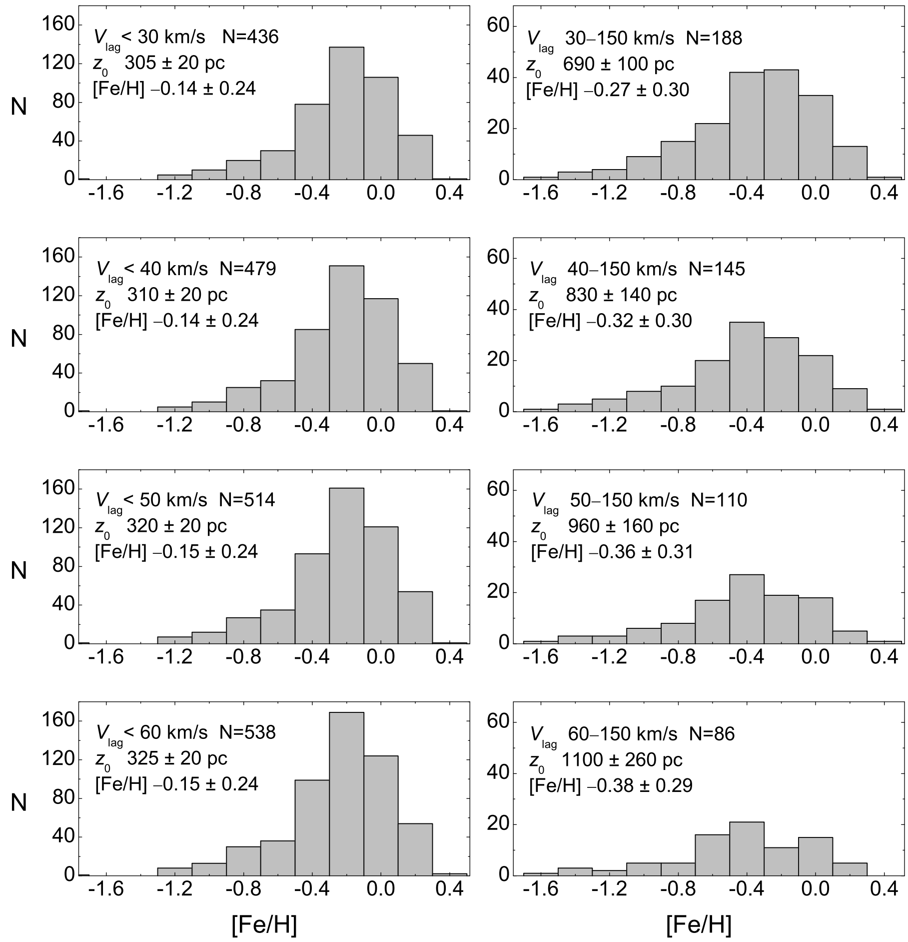

Fig. 2. Metallicity distributions for the two disk populations defined by different rotational lag criteria. The left-hand panels represent the thin disk, and the right-hand panels are for the thick-disk stars. Given in each panel are the mean [Fe/H] and $\sigma_{\rm [Fe/H]}$ of a Gaussian fit to the distribution and the derived scale height z_0.

The rotational properties of the thick disk are not yet well established, complicating the ability to isolate this component from thin-disk stars. We show in Figure 2 the metallicity distributions for stars admitted to the thin-disk and thick-disk samples according to different values of rotational lag. As it is apparent from the figure, a change of $10\ {\rm km\,s^{-1}}$ in $V_{\rm lag}$ leads on average to a change of only a few hundredths of dex in [Fe/H]. Under the assumption that metallicity within a single stellar population follows a Gaussian distribution, we obtain for the thin disk $\langle[{\rm Fe/H}]\rangle \sim -0.15$ and $\sigma_{\rm [Fe/H]} \sim 0.25$ dex. Meanwhile, the mean metallicity of the thick-disk stars is $\langle[{\rm Fe/H}]\rangle \sim -0.3$ or -0.4 dex, depending on the $V_{\rm lag}$ criteria used, and the spread in [Fe/H] ranges from +0.4 to –2.4 dex. It should be noted that the mean thick-disk metallicity found from our sample is significantly higher than that most frequently given in the literature, i.e. around –0.5 dex (Gilmore & Wyse 1985, Sandage & Fouts 1987, Carney et al. 1989, Schuster et al. 1993, Soubiran et al. 2003). On the other hand, our result is in close agreement with that of Bell (1996) who found from spectroscopic survey of thick-disk K giants in the Galactic rotation and anti-rotation directions a mean abundance of –0.35 dex.

To finally decide which of the $V_{\rm lag}$-criteria gives the best separation between the thin-disk and thick-disk populations, we also compared for each rotational lag interval the values of vertical velocity dispersion σ_W. For the thick-disk subsamples, σ_W is found to follow a gradual shift from 45±5 km s^{-1} (when the cutoff for $V_{\rm lag}$ is set at 30 km s^{-1}) to 59±7 km s^{-1} (when the cutoff is assumed at $V_{\rm lag}$= 60 km s^{-1}). Allowing for the uncertainties in the derived dispersions and V-velocities, we can accept $V_{\rm lag}$= 40 km s^{-1} as a reasonable lower cutoff for thick-disk membership. In this case, our thick-disk subsample has a W-velocity dispersion of 50±5 km s^{-1}, which is consistent, within the errors, with the upper σ_W values found in the literature (e.g., Bahcall et al. 1992, Schuster et al. 1993).

To isolate halo stars from the thick-disk sample, we accepted a somewhat arbitrary limit on rotational lag (150 km s^{-1}). We note that the bulk of our thick-disk sample cannot be significantly affected by halo contamination, as the relative number of halo stars within $\sim$2 kpc of the Galactic plane reached by our observations is still very small. Therefore, it appears safe to assume $40 < V_{\rm lag} < 150$ km s^{-1} as the criterion for selection of a final thick-disk sample. With this criterion, our total sample is comprised of 479 thin-disk stars, 145 thick-disk stars, and 23 possible halo members.

For the thick-disk stars, there appears to be a steady increase in σ_W (as noticed above), and, consequently, in scale height z_0 (see Figure 2) with decreasing rotation around the Galactic center. This fact provides evidence for the presence of a vertical gradient in the rotational velocity, which, if confirmed with additional work, may imply that a gradual heating of a precursor thin disk might have taken place. Such a kinematic gradient was found in the thick disk by Majewski (1992) and Chiba & Beers (2000), but was not observed by Soubiran et al. (2003) in their sample of *Tycho-2* stars at the north Galactic pole.

Our data show no strong correlation both between the Galactic orbital distance $R_{\rm med}$ and [Fe/H] and between $Z_{\rm max}$ and [Fe/H] for

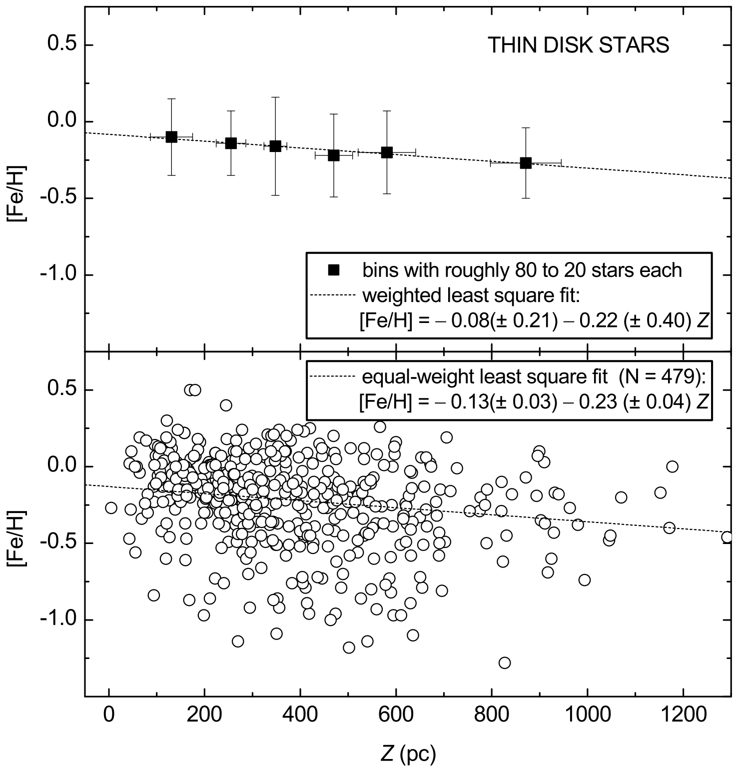

Fig. 3. Vertical abundance gradient for the old thin-disk stars. Error bars are the standard deviations about the mean values.

the thick-disk stars. This is in contrast to recent work of Ibukiyama & Arimoto (2002) who found a vertical [Fe/H]-$Z_{\max}$ gradient for this population extracted from the solar neighborhood *Hipparcos* stars. However, we find for the thick-disk stars a weakly pronounced vertical gradient in apparent z-distance, given formally by $d[\mathrm{Fe/H}]/dz = -0.07 \pm 0.05$ dex kpc^{-1}.

On the contrary to findings of Ibukiyama & Arimoto (2002) that show no indication of a thin-disk abundance gradient, we find clear evidence for both the vertical and radial metallicity gradients for the thin-disk stars. Our most unexpected result was the discovery of a rather steep apparent gradient in vertical direction: $d[\mathrm{Fe/H}]/dz = -0.23 \pm 0.04$ dex kpc^{-1} (Figure 3). This gradient can be in part or entirely determined by the age differences between the sample stars. The more metal-weak stars are most probably older, and it seems, therefore, plausible that there has been more time for them to heat up by one or more dynamical mechanisms during the evolution of the disk. Meanwhile, the maximum orbital heights $Z_{\max}$ and metallicities of the thin-disk stars show less pronounced relation (–0.11 dex kpc^{-1}). The radial metallicity gradient $d[Fe/H]/dR_{med}$ is found to be –0.05 dex kpc^{-1}. The existence of both the radial gradient and rather steep vertical metallicity gradient, if our finding proves to be correct, is important to constrain models of the disk chemical evolution.

In our high-Galactic-latitude sample a number of slowly rotating stars ($V_{lag} > 150$ km s^{-1}) have been found, which are supposed to kinematically belong to the halo population. We integrated their orbits backward and forward in time for 5×10^9 yr to see what kind of orbits such stars have. The orbits were calculated in a two-component (disk plus bulge and halo) model of our Galaxy by Kutuzov & Ossipkov (1989), using in these calculations Merson's method (described, e.g., by Ossipkov & Kutuzov 1994). These stars move along highly eccentric orbits (e between 0.7 and 0.9), some of them passing near the central 1 kpc of the Galaxy.

Most of the halo star orbits are inclined boxes or the simplest tubes inclined to the Galactic center, i.e. $z(R_{per}) < z(R_{apo})$. One orbit is found to be inclined to the opposite side. The orbit of the star KA 205-081 ([Fe/H] = –1.6) near the south Galactic pole is the most interesting. It fills a domain that is a superposition of a triangle box and a rectangle box, with folds on boundaries. Such boxes were called by Ossipkov, Kutuzov & Myllärri (2001) as 'peacock tails'.

4. CONCLUDING REMARKS

In this contribution we presented our first results that emerged from immediate analysis of the metallicity distribution and kinematics of a sample of 647 high-Galactic-latitude stars. There are two main points to notice. First, the thick-disk stars do have a large metallicity overlap with the thin-disk stars; their mean [Fe/H] values differ only by 0.2 dex. Second, there exists a rather steep vertical metallicity gradient (around –0.2 dex kpc^{-1}) for the thin-disk stars.

Our future contribution to this series will explore these observational data in greater detail by involving the age differences between the thin- and thick-disk stars and evaluating the affects of the most significant biases such as binarity, Malmquist bias, etc.

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