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On properties of metallicity function of F–stars in the galactic disk

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Abstract. We have constructed metallicity functions of disk stars with different ages, and investigated their properties proceeding from the statistically restored real altitude distributions of stars at the solar galactocentric distance. It is shown that the metallicity distribution of stars in each age range is not of Gaussian form, but it may be considered as a superposition of two normal distributions centered at $<$ [Fe/H] $>\approx -0.2$ and 0.0 dex. The maximum of the distribution function for stars younger than ≈ 3 Gyr is located near the solar metallicity, and it falls within the region of the second specific metallicity for older stars. A conclusion is drawn that the observed negative metallicity trend with age and the verical metallicity gradient are mainly due to the redistribution of the relative number of objects between these two specific metallicity values in the Galactic disk.

Key words: stars: F-stars – stars: abundances – stars: kinematics and dynamics

1. Introduction

The most important source of information concerning the history of enrichment of the interstellar medium is the distribution of stars of different age according to their abundancies of heavy elements. Thanks to the high stability of the relative abundance of chemical elements in cosmic objects of different nature, the abundance of heavy elements (i.e. the elements heavier than hydrogen and helium) is not infrequently judged by iron abundance (iron is the element, absorption lines of which are numerous in spectra of stars of spectral classes A — G). The quantity $[Fe/H] = \lg(Fe/H)_{star} - \lg(Fe/H)_{\odot}$ is called metallicity, where $(Fe/H)_{star}$ is the ratio of the number of iron atoms to the number of hydrogen atoms in a star and $(Fe/H)_{\odot}$ is the same ratio for the Sun. The [Fe/H] distribution of stars is called the metallicity function (MF). Even the first MF derived for a hundred and a half of stars nearest to the Sun revealed the "paradox of G dwarfs" (see van den Berg, 1962) which consisted in deficiency of metal-poor stars as compared to the "simple" model of chemical evolution of the Galaxy (suggesting continuous processes of interstellar medium enrichment and star formation and instantaneous turnover of matter (Audouze & Tinsley, 1976). A more detailed study of the MF from approximately five hundred F5 — K5 dwarfs and subdwarfs has shown that the distribution of heavy elements among stellar populations of the Galaxy is of discrete character (Marsakov & Suchkov, 1977). It has turned out that the halo objects are separated from the disk population by the range of values $[Fe/H] = -(0.5 \div 0.7)$ dex, where stars have been found to be essentially deficient. The same, but much less defined structural feature (dip in the MF) is observed in G dwarfs and red giants that lie in the direction of the galactic poles in the vicinity of $[Fe/H] = -(0.1 \div 0.2)$ dex (Marsakov & Suchkov, 1980). The stellar population of the disk finally turns out to be separated by metallicity into two groups. It is noteworthy that the groups of the disk population of different metallicity exhibit also a difference in kinematics and spatial location (Marsakov & Suchkov, 1977; 1978; 1980).

Based on the catalogue of fundamental astrophysical parameters of nearby stars that comprises about 5500 objects (Marsakov & Shevelev, 1995a), MF properties of F disk stars are investigated in this paper: distributions in metallicity of stars of different age are constructed and the structure of the MF at different distances from the Galaxy plane is considered. The fact, that in the sample of stars located in the vicinity of the Sun near the galactic plane there exists kinematic selection, was completely disregarded in the previous papers. The selection is caused by the higher vertical velocity component of older stars, because of which they stay near the Galaxy plane, when orbiting, a modest part of time and then move away to great distances. Hence the share of old (on average less metallic) stars in the sample from the circumsolar neighbourhood will be smaller. In order to take into account the selection effect described above, we employ in the present paper the procedure we have developed (Marsakov & Shevelev, 1995b) of statistical restoration of the real altitude distribution of objects at the solar galactocentric distance. Neither was previously taken into account the other type of selection related to metallicity. Indeed, stars located presently in the solar vicinity were most likely born near the apogalactic radii of their orbits (R_{max}), i. e. at distances usually much larger than their present location. Inasmuch at each moment of time in the galactic disk there exists a different from zero negative metallicity gradient (see e.g. Shevelev & Marsakov, 1993), we have taken into account this gradient ($d[Fe/H]/dR_{max}$) and reduced the values of [Fe/H] of the stars used here to the solar galactocentric distance.

2. Original data

We have made use of our sample of stars F2 — G2 (Marsakov & Shevelev, 1995a) where metallicities, isochronic ages, photometric distances and other parameters for about 5500 main sequence stars lying in the vicinity of 80 pc of the Sun are determined on the basis of uniform compilative *uvby* data and available positions and proper motions. For about one third of the stars for which we have managed to find the radial velocities in the literature, the elements of the galactic orbits have been computed. In our paper (Marsakov & Shevelev, 1995b) we gave a detailed grounding of the representativeness of the given sample concerning F stars of the disk subsystem. Moreover, within 50 pc from the Sun, the sample turned out to be nearly complete in the desired spectral range F2 — G2 (see the histogram in Marsakov & Shevelev, 1995b). In the same paper the representativeness is shown to be also preserved for the sample of stars with measured radial velocities, which, together with the tangential velocity components, make it possible to compute total velocities and orbit elements. For the sake of convenience in the calculations we have taken a cube 80 pc on edge with the Sun at the centre as the initial volume. The sample of F stars inside the cube is practically complete.

From the Revised Yale isochrones (Green et al., 1987) we have determined ages for all the stars mentioned here using an express-method that we developed in (Shevelev & Marsakov, 1993). Since particular values of individual ages of the stars (but only mean ages of the stellar groups) are not discussed in this paper, we considered it possible to use formal estimates of isochronic ages for stars located in the immediate vicinity of the zero-age main sequence as well. All these stars fall within the youngest group and therefore have no effect on physical characteristics computed from older samples of stars but only enhance the statistical reliability of the results for young stars. Analysis has shown that in the spectral range considered, both the youngest (located on the ZAMS) and the oldest disk stars (it is in the vicinity of G2 that the turn-off points of metall-rich and metal-poor stars are located, see Fig. 1 from (Marsakov et al., 1990) and the discussion in (Shevelev & Marsakov, 1993)) are represented. It has become possible for us to construct undistorted MFs for F disk stars of any age.

Any sample composed of stars of the nearest solar neighbourhood, as has already been noted, is burdened with the kinematic selection effect caused by predominant younger stars whose vertical velocity components are small, and the orbits lie near the galactic plane. For the objective of our work it is more correct to use MFs of stars located at the solar galactocentric distance in a sufficiently high vertical cylinder (so that all the objects of the investigated subsystem at the given distance fall within its volume). The radius of the base of the cylinder should be small so that the result could not be affected by the existing radial metallicity gradient. In (Marsakov & Shevelev, 1995b) we described a method of statistical restoration from the representative sample not only of the total number of stars in the vertical cylinder at the solar galactocentric distance but also their real altitude distribution. It is clear that the size of the initial sample must be large enough to make statistically grounded inferences. The idea of the method consists in the following. Among the stars that are presently located near the galactic plane there are representatives of any subsystem of the Galaxy. We believe that the complete sample of stars from the limited circumsolar vicinity is representative with respect to the subsystems of different age, that is, it is free of selection effects, but for the above mentioned kinematic effect. Therefore, in the course of time its MF will not change, although in the isolated volume one stars will be replaced by others.

Some time later, at an arbitrarily chosen moment, the stars of each subsystem will take a random position in their orbits. In the long run, at the solar galactocentric distance they will be distributed over the Z coordinate in exactly the same manner as the rest of the stars of the same subsystem are now distributed here. Owing to the fact that the meridional orbit of almost every disk star represents a filled "box" over a large number of revolutions (Fig. 4 in Marsakov & Shevelev, 1995b), any star moving along the orbit falls sooner or later at every point of a perpendicular to the galactic plane passing through the present-day star position. The length of the perpendicular is limited by the maximum distance of the orbit from the Galaxy plane, i.e. $|Z_{max}|$ (Fig. 4 in Marsakov & Shevelev, 1995b). As the probability of detecting a star near the Sun diminishes with increasing its Z_{max}, we assigned a weight to each star of the full sample equal to the ratio of the period of its revolution round the Galaxy centre to the time it stays during this period within ±40 pc from the galactic plane. In so doing we assumed the total number of stars on the perpendicular, which have the same astrophysical parameters (metallicity, age, velocity etc.) as those of the given star, to be equal to the weight assigned. Now, in order to reproduce the true distribution of the subsystem's stars over Z, one has to "spread" each star along the orbit from $-Z_{max}$ to $+Z_{max}$ in proportion with the probability density of finding it at different Z. The restored altitude distribution of the subsystem's stars can be derived if the probability densities of each sample star with the corresponding weights are summed up. For details on restoration over Z see (Marsakov & Shevelev, 1995b).

3. MF of different age disk stars

For comparison, Fig. 1 shows metallicity distributions of disk F stars in several age ranges derived for the total sample of stars in a sphere of 80 pc in radius around the Sun from (Marsakov & Shevelev, 1995a) (left panel of the figure) and for the sample of stars from the vertical column with a base of 80 × 80 pc restored by the above-described procedure (right panel). The radial metallicity gradient is taken into account in the latter case only. For the sample from the sphere of 80 pc the observed numbers of stars (n) are plotted on the ordinate, whereas for the restored sample percentage of stars in the total number of stars in the vertical column is given. The figure shows the same row distributions to be systematically different in structure. The employment of weight coefficients has increased the number of stars with large vertical velocity components. High-velocity stars, however, are generally of lower metallicity and older (Marsakov et al., 1990). That is why the MF of intermediate ($t = (3-5)$ Gyr) and old ($t = (5-12)$ Gyr) age stars have somewhat extended towards low metallicity (see corresponding pairs in Fig. 1). Accounting of the radial metallicity gradient (according to formula (1) from (Shevelev & Marsakov, 1995) increases the metallicity of stars with large apogalactic radii of the orbits, which have caused all MFs to be slightly positive-shifted in [Fe/H] and the objects inside each MF to be somewhat redistributed. The curves in the left column of Fig. 1 are approximations of the histograms by tenth power polynomials. The high polynomial power facilitates revealing structural details in the distributions. It is seen from the figure that even the initial MF in all age ranges demonstrate if only single-peaked distributions, but largely extended towards low metallicities, which cannot be described by a single Gaussian. After taking account of the above-mentioned selection effects, it turned out that beginning with the age of ≈ 3 Gyr the MF acquires a complex structure even at the centre of the distribution.

Let us dwell upon the method that permits us to estimate the statistical significance of approximation of the histograms by the sum of normal distributions. Represent the MF in Fig. 1 by the sum of Gauss curves:

$$p(m, \alpha_1, ..., \alpha_s, a_1, ..., a_s, \sigma_1, ..., \sigma_s) = \sum_{k=1}^{s} \frac{\alpha_k N}{\sqrt{2\pi}\sigma_k} \exp\left[-\frac{1}{2}\left(\frac{m-a_k}{\sigma_k}\right)^2\right], \quad (1)$$

where $m =$ [Fe/H], a_k and σ_k are the mean value and the dispersion of the k-th normal, respectively, α_k is the normalizing parameter of the k-th normal satisfying the condition $\sum_{k=1}^{s} \alpha_k = 1$, N is the total number of stars. The distribution parameters are found by the method of maximum likelihood, maximizing the likelihood function

$$L_s(m_1, ..., M_n, \alpha_1, ..., \alpha_s, a_1, ..., a_s, \sigma_1, ..., \sigma_s) = \prod_{i=1}^{l} p^{n_i}(m_i, \alpha_1, ..., \alpha_s, a_1, ..., a_s, \sigma_1, ..., \sigma_s),$$

where l is the number of bins in the investigated histogram, n_i the number of stars in the i-th bin, m_i the metallicity value in the middle of the i-th bin.

The s value can be found using the statistics

$$\lambda = -2ln\left(\frac{L_s}{L_{s+1}}\right),$$

where L_s and L_{s+1} are taken at the point of maximum. λ is known to be distributed by a law χ^2 with one degree of freedom (Martin, 1971). We are interested first of all whether the MF can be described by a normal law (zero hypothesis H_0: $s = 1$), or the metallicity distribution has a more complex structure (alternative hypothesis H_1: $s > 1$). Examine the region $-0.5 <$ [Fe/H] $< +0.2$. The Gaussian parameters and the corresponding values of λ determined by the method of maximum likelihood show that the probability to erroneously reject the hypothesis about the description of the distribution by one Gaussian against the alternative of its representation by the sum of two Gaussians for the stars of intermediate age turns out to be < 12 %, and < 13 % [1] for the oldest stars. In the above [Fe/H] range the descriptions of the two upper histograms of the right column by

[1] When applying the method of maximum likelihood, in expression (1) as the normalizing multiplier N we adopted the total observed number of stars used to derive the given distribution, but not the total restored number obtained from the former through its processing by weights. We have thus avoided the overestimated probability values.

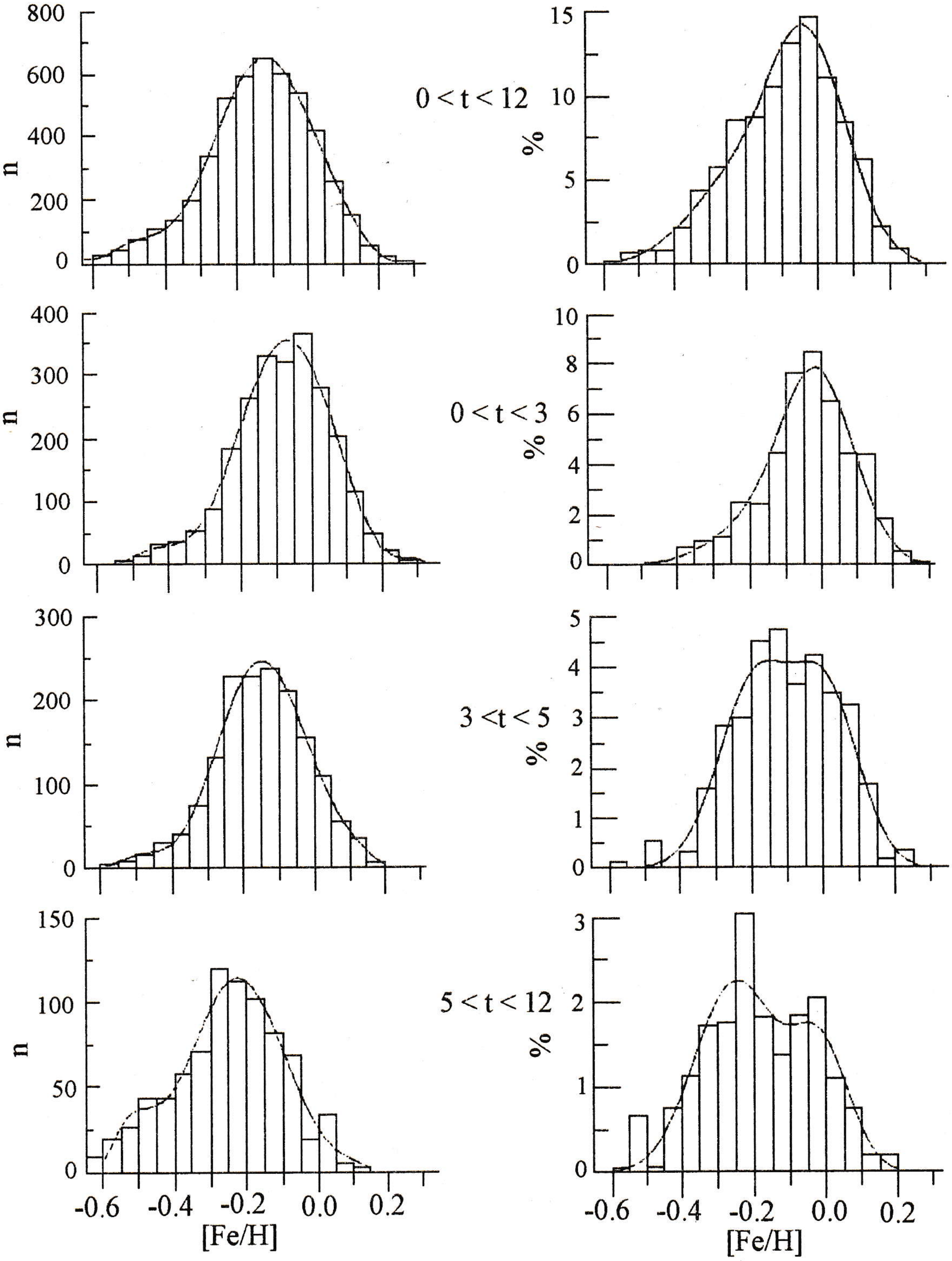

Figure 1: *The metallicity distribution of disk F stars in different age ranges: the left column — for the sample of stars within 80 pc around the Sun; the right part — for the restored complete sample at the solar galactocentric distance with allowance made for the radial metallicity gradient. t indicates the age ranges expressed in billions of years. The ordinata in the right part shows the percentage of stars with given metallicity in the restored complete sample. Curves represent approximations of the histograms by the tenth power polynomials (left) and by the sums of two Gauss functions (right).*

the sum of two Gaussians turned out very significant. This is due to the existence of extended metal-poor "tails". Thus we see that the MF of any age stars in this metallicity range is binormal. At the same time the statistical reliability of the hypothesis $s > 2$ is found to be extremely low in all cases. The approximations of the distributions by the sums of two Gaussians are shown in the right column of Fig. 1 by the solid lines.

4. Age-metallicity relation

Consider the disk age-metallicity relation derived from the complete sample of F stars in the restricted area of the circumsolar neighbourhood after allowing for the kinematic selection effect and the radial metallicity gradient. Fig. 2 displays the t—[Fe/H] relationship. To plot this relationship, our sample of F stars from the cubic volume of ±40 pc with correctly determined ages (i.e. we use the stars that have already slightly evolved from the ZAMS, beginning with $\sigma M_V > 0^m.3$) was divided in age into 8 ranges 1 Gyr each (but for the oldest range, which had to be increased to 4 Gyr because of the small number of stars). The bars indicate the metallicity dispersions in each age range. The determination errors of the mean [Fe/H] values, which were found from the real numbers (i.e. without regarding the weight coefficients that increase the initial number), lie in the range (0.01–0.03) dex and nearly always smaller than the difference between the neighbouring groups. As can be seen from the figure, the metallicity trend with age fits well into a straight line: the straight regression has the shape $[Fe/H = -(0.05 \pm 0.03)t + (0.11 \pm 0.02)$ with a correlation coefficient $r = 0.98 \pm 0.01$. A similar relationship derived from the sample of F stars with correct ages in the solar neighbourhood of 80 pc in radius (see Shevelev & Marsakov, 1993) is shown by the dashed line for comparison. In the latter case no correction for the kinematic selection and metallicity gradient has been applied. The relationship is seen to be slightly displaced, the slope being unchanged. The behaviour of the metallicity dispersion versus age described by Shevelev & Marsakov (1993) has also remained the same, i.e. the scatter of [Fe/H] in stars of the given age grows with increasing age up to ≈ 7 Gyr, and then drops again. This can be seen in Fig. 2 from the dispersion bars diminishing on both sides of this age and compared with the [Fe/H] scatter of stars in the narrow age ranges on the age—metallicity diagrams of Fig. 4 from (Shevelev & Marsakov, 1993).

5. MF of disk stars at different altitude above the galactic plane

Let us examine the MF of F stars at a Z altitude above the Galaxy plane for the complete sample and

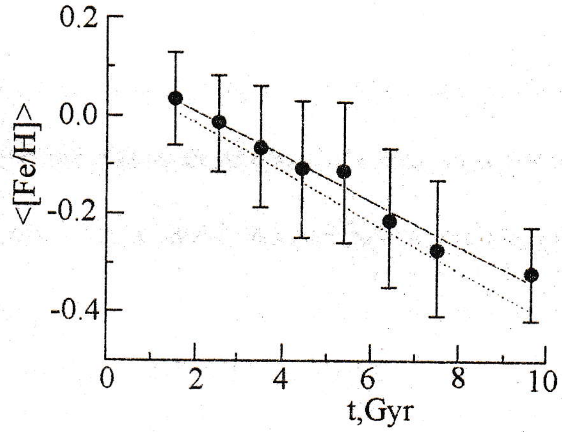

Figure 2: *The mean metallicity—age relationship derived from the complete restored sample with allowance made for the radial metallicity gradient. The bars are equal to the metallicity dispersions for the corresponding age bin. The central circle equals the mean error in the determination of < [Fe/H] > values. The solid line is the straight regression for the complete restored sample; the dashed line is that for the initial sample of F stars from the solar surrounding of 80 pc (without regarding of the radial metallicity gradient and the weight coefficients).*

for three narrow age ranges separately: ($t < 12$) Gyr, ($t < 3$) Gyr, ($3 < t < 5$) Gyr, and ($5 < t < 12$) Gyr. For this purpose we have plotted the metallicity distribution of stars in strips 10 pc wide from the complete restored sample in the vertical column at intervals of 50 pc up to Z=250 pc. (At larger Z the number of objects even in the complete sample is insufficient to obtain statistically reliable results.) As an illustration, Fig. 3 shows the distributions for three Z values, 0, 100 and 250 pc. Here we have also taken into account the age-dependent metallicity gradient, using formula (1) from Shevelev & Marsakov (1995). The solid curves are the approximations of the histograms by the sum of two Gaussians. The ordinate is the proportion of stars (as percentage) in the total number of the restored sample. (The character of drop in the number of stars with altitude Z is discussed in detail in (Marsakov & Shevelev, 1995b)). Analysis shows that the youngest stars up to 200 pc demonstrate reliably one-peaked distributions with maxima near [Fe/H]≈ 0.0, but having small "tails" towards low metallicities which grow with rising Z. (At larger Z the number of the youngest stars decreases sharply and the structure of the MF begins to be appreciably affected by the outliers on the histograms associated with the high weight coefficients of individual stars, as is seen, for instance, at Z=250 pc.) It is this "tail", as the appreciations of maximum likelihood show, that causes the failure (significance level $< 5\,\%$) to describe the distributions at Z=0 and 100 pc by one Gaussian against the alternative of approximating them in all the range of [Fe/H] characteristic of the disk by two Gauss curves displayed in Fig. 3. If we confine the metallicity range considered by the interval $[-0.25, +0.20]$ (i.e. discard the class intervals in the "tails" where the number of stars is small), it will then turn out that the central part of these distributions is better described by one Gaussian. In stars of intermediate age the MF structure is more complex, and beginning with $Z \approx 50$ pc, the distribution becomes clearly binormal. In particular, the approximation of the distribution displayed in Fig. 3 for 100 pc by one Gaussian is rejected by the criterion of likelihood ratio in favour of the alternative of describing it by the sum of two Gaussians at a significance level $< 17\,\%$ (see the curve on appropriate histogram of Fig. 3). The binormality is well seen at larger distances too (see the histogram for 250 pc), but it may unfortunately be assessed only at a qualitative level, since the number of objects here is insufficient to draw statistical conclusions. At length, the oldest stars demonstrate safely the binormality at the distribution centre even on the galactic plane. For Z=0 and 100 pc the statistical reliability of the normality of MF is about 13 % and 14 %, respectively. That is why it must be discarded in favour of the alternative (see the curves on the first two histograms of the lower row in Fig. 3). But even at Z=250 pc the MF assumes again the single-peaked character (the probability of erroneous rejection of the hypothesis of describing it by one Gaussian is $\approx 35\,\%$). It is noteworthy that the distribution maximum is displaced here towards low metallicities by about -0.2 dex (with respect to the MF maximum for the youngest stars), leaving a certain excess of objects on the metallicity wing. The upper row in Fig. 3 shows how the total MF of F stars of mixed ages of the disk subsystem changes with altitude above the galactic plane: at any Z its description by one Gaussian is turned down in favour of the sum of two Gauss curves (for the histograms exhibited in Fig. 3 the significance levels are $\approx 5\,\%$, $\approx 5\,\%$ and $\approx 27\,\%$, respectively. The general trend is as follows. The MF maxima of stars of mixed ages at all distances lie at approximately the same point, $[\mathrm{Fe/H}]=-(0.00-0.05)$ dex. However with increasing Z the proportion of stars grouped near $[\mathrm{Fe/H}]=-(0.20-0.25)$ dex grows and for Z=250 pc becomes comparable with the metal-rich group (the upper row in Fig. 3). At greater distances it is this group that begins to dominate (not shown in the figure). As a result, the mean metallicity decreases with growing Z, while the metallicity dispersion somewhat rizes first (till the number of stars in the metal-rich and metal-poor groups get equal) and then it drops again.

Note that the MF derived from the "stars" of the restored sample with no allowance made for the radial metallicity gradient, changes its shape with altitude in exactly the same manner, but all of them turn out to be displaced towards low metallicities by $d[\mathrm{Fe/H}]/dR \approx -(0.02-0.04)$ dex. Thus the properties of the MF of F stars suggest that there exist at least two standing out metallicity values that are predominantly possessed by the disk stars in the neighbourhood of the Sun.

6. Vertical metallicity gradient

Based on the complete sample from (Marsakov & Shevelev, 1995a), we determined in (Shevelev & Marsakov, 1995) the vertical metallicity gradients of disk population stars in several narrow age ranges from the observed metallicity values and the calculated maximum distances of their orbits from the galactic plane. The values of the gradients were found to systematically decrease when turning to older stars. It seems of importance to see what will happen to the computed vertical gradient value and how the character of its evolution with time will change after the kinematic selection effect is taken into account. For this purpose we have divided all the stars of the restored sample into 3 age ranges and derived for them the relationships between the mean metallicity and altitude Z. These relationships for the 3 narrow age intervals, as well as for mixed-age stars (i.e. for all the stars of the restored sample), are displayed in Fig. 4. The bars indicate the determination errors of $<[\mathrm{Fe/H}]>$ calculated from the real numbers of stars (i.e. without regarding the weight coefficients). It can be seen that all the relations can be described by straight lines derived by the least-squares method and shown in the figure. The tangent of the angle of the slope of such a line is numerically equal to the vertical metallicity gradient. For mixed-age stars it turned out to be equal to $d[\mathrm{Fe/H}]/dZ = -(0.17 \pm 0.02)\mathrm{kpc}^{-1}$ with a correlation coefficient $r = 0.98 \pm 0.02$. In (Shevelev & Marsakov, 1995) the similar value for all F stars from the 80 pc neighbourhood of the Sun was about 1.7 times as large. The difference is caused solely by taking account in the present paper of the kinematic selection effect near the galactic plane and using the probability altitude distribution of stars at the galactocentric distance instead of the maximum distance of the star's orbit, Z_{max}. The concurrent operation of the two factors (the former, in the main) have increased essentially the share of high-velocity (and hence more metall-poor) stars. As a result, at small Z the mean metallicity decreased, which reduced the gradient. The values of the vertical gradients have decreased in the narrow age ranges too, as com-

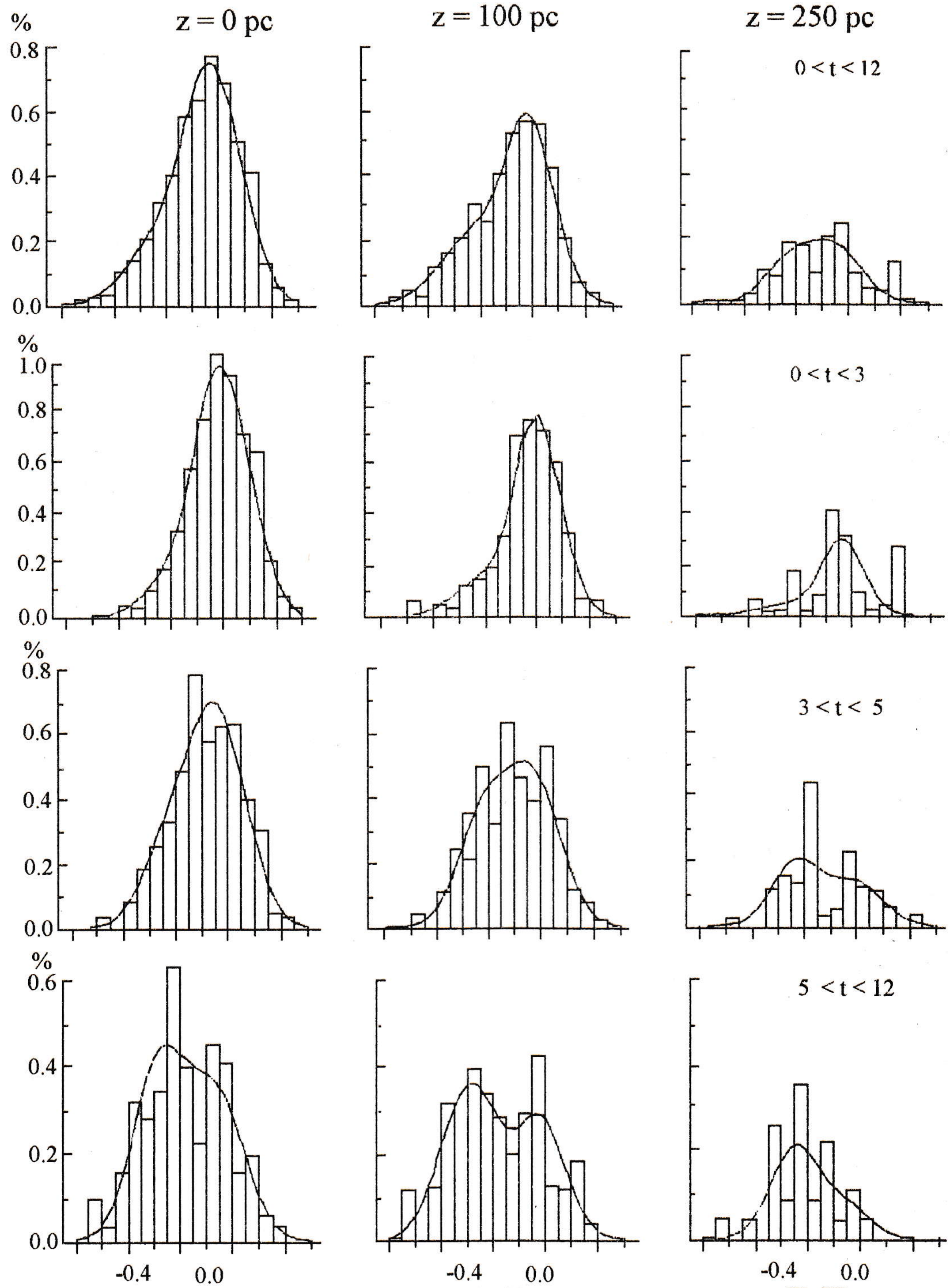

Figure 3: *The metallicity distribution of F stars of the restored sample in different age ranges at three distances from the galactic plane. The curves are the approximation of the histograms by the sum of two Gaussians. The ordinates are the percentage of these stars in the total restored number of stars.*

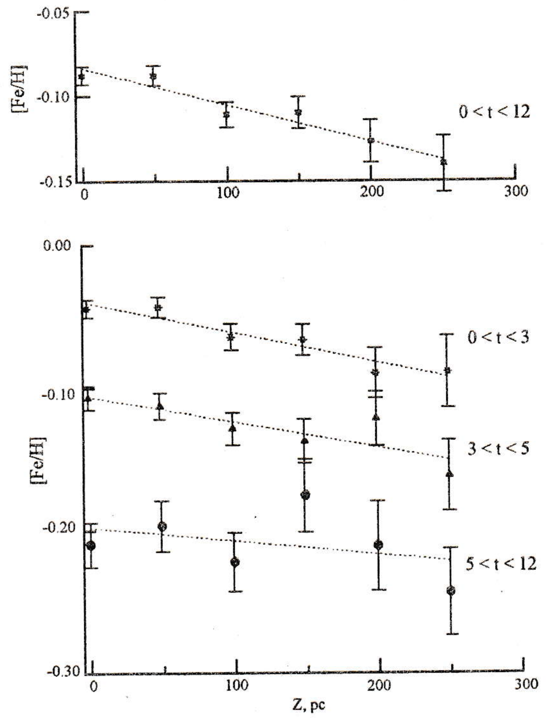

Figure 4: *The relationship between the mean metallicity and the distance from the galactic plane. The straight lines are the mean-square regressions, the bars are the errrors of the mean. The slopes of the lines determined the gradient values which are equal from top to bottom to:* $-(0.17 \pm 0.02)\,\mathrm{kpc}^{-1}$, $-(0.15 \pm 0.02)\,kpc^{-1}$, $-(0.12 \pm 0.06)\,kpc^{-1}$ *and* $-(0.11 \pm 0.09)\,\mathrm{kpc}^{-1}$.

pared with the results from (Shevelev & Marsakov, 1995) and become equal to $-(0.15 \pm 0.02)\,\mathrm{kpc}^{-1}$ with $r = 0.96 \pm 0.03$; $-(0.12 \pm 0.06)$ kpc^{-1} with $r = 0.7 \pm 0.2$; $-(0.11 \pm 0.09)$ kpc^{-1} with $r = 0.5 \pm 0.3$ for the youngest, medium and old groups of stars, respectively.

It can be seen that the metallicity gradient values for each group, small as they are, differ from zero beyond the errors. The correlation coefficients also satisfy this condition. The principal conclusion of (Shevelev & Marsakov, 1995), which consists in the fact that the vertical metallicity gradient decreases with increasing age of the stellar group, is not argued against either. The rate of the decrease (i.e. the value of the trend of the vertical gradient with age) becomes quite low and comparable with the uncertainties: $d[Fe/H]/dZ = 0.01t - 0.16$, where the distances are measured in kiloparsecs and the ages in Gyr. It will be recalled that the result has been obtained from the metallicities of stars corrected for the radial-metallicity gradient (i.e. reduced to the solar galactocentric distance). When using the observational values $[Fe/H]_{obs}$, the vertical metallicity gradient of stars of mixed ages proved to be $d[Fe/H]_{obs}/dZ = -(0.21 \pm 0.2\,\mathrm{kpc}^{-1}$, and the trend of the gradient with age to be $d[Fe/H]_{obs}/dZ = 0.03t - 0.26$, which is also smaller than the corresponding values obtained in the paper (Shevelev & Marsakov, 1995). The above formulae may turn to be useful in reduction of the metallicity of different age disk population stars to the metallicity in the disk plane at the solar distance, but only for ages < 6 Gyr, where interpolation holds. For larger ages one should, apparently, fix the numerical value of the gradient. Thus it can be concluded that at every moment of time there exists in the disk a negative metallicity gradient different from zero. Even though the absolute value of this gradient increases when turning to younger stars, its increase is quite insignificant. For the conclusion to be more reliable, it is necessary to repeat this kind of computations proceeding from the deeper sky observation to increase the radius of the complete sample by at least a factor of 1.5.

7. Conclusions

The present study of the properties of the complete restored sample of disk F stars at the solar galactocentric distance shows their MF to have a binormal structure, i.e. the metallicity distribution of stars is described with a higher reliability by the sum of two Gauss curves rather than one throughout the entire metallicity range characteristic of the disk. It turned out that stars of any age tend to concentrate at two specific metallicity values, $[Fe/H] = -(0.00 \div 0.05)$ dex and $-(0.20 \div 0.25)$ dex. Stars younger than ≈ 3 Gyr (which account for approximately half of all F stars in the disk) demonstrate a well defined one-peaked distribution with the maximum near zero and an essential "tail" towards low metallicities. The maximum of the oldest stars is located at the latter metallicity value, but their MF exhibits the "tail" on the metallicity side. Thus the observed negative trend of the main metallicity of disk population stars with age is basically caused by the redistribution of the relative number of objects between the two specific [Fe/H] values. The negative vertical metallicity gradient is due to a similar redistribution: at greater distances from the galactic plane the proportion of low-metallicity-group objects grows for stars of any age.

Taking into account the result of (Marsakov & Shevelev, 1994; 1995b), where stars of any age in the metal-poor group are shown to possess larger velocity dispersions and occupy a larger volume in the direction normal to the Galaxy plane than stars of the corresponding age in the metal-rich group, there are grounds to believe that the two disk subsystems exist concurrently. The metal-poor group is most likely to be formed from interstellar matter falling slowly onto the disk from the outskirts of the Galaxy. When such matter, deficient in heavy element content, proves to be within (600-900) pc from the disk plane, conditions favourable for star formation (it is at these Z_{max}, as follows from Fig. 6 of (Marsakov & Shevelev, 1995b), that the first metal-poor stars appear) are created. That is why, the velocity ellipsoids of the stars of the given group are likely to be close to an equilibrium configuration and depend only slightly on age. Things are different with the metal-rich group. Its stars, which occupy a smaller volume in depth ($Z_{max} \approx (400-600)$ pc), change essentially the shape of their velocity ellipsoid: from equilibrium in the oldest to extremely elongated in the youngest (for details see (Marsakov & Shevelev, 1994).

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