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Chemical and kinematic properties of the population classical cepheids in the Galaxy

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It is found that the abundances of α-elements and elements of rapid and slow neutron capture in Cepheids increase at increasing galactocentric distance and decrease at increasing metallicity, as well as in dwarfs and giants of the thin disk. However these abundances do not depend on spatial velocity. At the same time as a whole the ratios $[\alpha/Fe]$ for Cepheids are lower outside the error limits, but $[r/Fe]$ and $[s/Fe]$ are higher than for dwarfs and giants. The assumption is made that after the interstellar medium of the thin disk has reached approximately solar metallicity, the most massive stars no longer exploded as Type II supernovae which enriched the interstellar medium with α-elements mainly. As a result in the next generations of stars, there is a deficiency of the relative abundances of α-elements and also a small excess of r-process elements which are ejected into the interstellar medium by less massive (8–10 $M_{\odot}$) Type II supernovae. An excess of s-process elements in Cepheids can be explained by production of the part of s-elements in a weak component of s-process within massive stars which, probably, can shed the upper parts of their envelopes without explosion like AGB stars. Since exploding as SNe II such massive stars enriched the interstellar medium with also a significant amount of iron atoms, in their absence the ratios $[s/Fe]$ (as well as $[r/Fe]$) have to increase in the next generations of stars.

Keywords: Stars: cepheids, galactic disk

1 Introduction

Due to the fact that masses, luminosities and ages of Cepheids can be calculated from their variable periods, which are easily determined from observations, these stars play a leading role in the research of our own and other galaxies. Since the classic long-period Cepheids are massive B-stars advanced in their evolution, they are very young and their ages are within ≈20–200 million years, so using them it is convenient to track the degree of heterogeneity of the chemical composition within the regions of recent star formation in our Galaxy (Lepine et al., 2011; Gozha and Marsakov, 2013).

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However quite high space velocities uncharacteristic of the thin galactic disk as well as anomalous relative abundances of some chemical elements are given in the published catalogs for some Cepheids. Therefore, it is interesting to analyze all these deviations taking into account errors of determination of the corresponding parameters for each star.

So far sufficient amounts of precision astrometric and spectroscopic data are collected to make complex statistical researches of chemical and kinematic properties of classical Cepheids in our Galaxy for the testing of degree of homogeneity of this population. The global goal of such research is to detail the history of star formation in the thin galactic disk.

2 Initial data

We have taken the spatial positions, kinematic data and periods for 276 classical Cepheids from Berdnikov et al. (2003) catalog. Accurate equatorial coordinates of Cepheids from the HIPPARCOS catalog, the values of proper motions from the TYCHO-2 catalog, and radial velocities from literature are used in this catalog, but distances were defined on the basis of the variability periods received by authors. We calculated the ages of these stars from the formula $\log t = 8.50 - 0.65 \log P$, where t is the age in years, and P is the Cepheid period in days (Efremov, 2003).

As the goal of this paper is to study the chemical evolution of the thin disk of the Galaxy, we have restricted the use of the abundances of only those chemical elements which, according to modern views, have almost no changes related to the nuclear processes in the atmospheres of the studied stars. In particular such elements are α-elements (O, Mg, Si, and Ca), iron peak elements (Fe), elements of the slow (Ba, La, and Ce) and of the rapid neutron capture (Eu) (see rationale for choosing below). We have added homogeneous data on the abundances of the above-mentioned nine chemical elements produced in the various processes of nuclear synthesis for 221 Cepheids to kinematic data from the papers of one group of authors (see Andrievsky et al., 2013 and references therein to earlier papers). The high accuracy of the received atmospheric parameters and the abundances of chemical elements in the atmospheres of Cepheids were provided using high–resolution spectra with a signal-to-noise ratio >100 in those papers. Determination accuracy of the abundances for the elements having more than 10 lines (e. g., iron) reaches 0.05–0.10 dex, whereas the error increases to 0.15–0.20 dex in the case of five lines or less. The authors analyzed the NLTE effects in the abundances of some chemical elements and came to the conclusion that the resulting distortions of the abundances never exceed error of their determination stated above.

For comparison, we have involved data on the abundances of the same elements in 212 dwarfs and in 171 ascending-branch giants and the clump-giants which are close to the evolutionary status of Cepheids received by a group of authors, using a similar technique (Mishenina et al., 2006, 2007, 2013). Errors in determining the abundances of all the elements in these stars do not exceed 0.15 dex. The uniformity of approaches to determining the abundances of chemical elements in the Cepheids, dwarfs and giants is provided by using everywhere the unified system of solar oscillator

strengths, the uniform list of spectral lines and the uniform grid of the atmospheric models of Kurucz.

3 The statistical relationship between various characteristics

Figure 1a shows the relation between the galactocentric distance and metallicity for Cepheids of our sample. Linear regression based on the points of the diagram indicates the existence of a highly significant correlation ($r = 0.71 \pm 0.03$). Since the galactic disk rotates differentially, there is a quite understandable decrease in the azimuthal component of the velocity at increasing galactocentric distance, which the Cepheids demonstrate in Fig. 1b. The correlation coefficient for the sample with errors of tangential velocities < 40 km s^{-1} is $r = 0.34 \pm 0.08$, whereas the probability of chance occurrence of the same correlation for the same number of points is $P_N << 1\,\%$, that is, the correlation is highly significant. It is possible to expect correlation between the azimuthal velocity and metallicity from the fact of existence of two previous correlations. However, as can be seen from Fig. 1c, this correlation is not significant for the Cepheids ($P_N > 5\,\%$). As our check showed, the radial and vertical components of the velocity of Cepheids do not correlate either with metallicity or with galactocentric distance.

The relation between age and metallicity is the subject of separate studies in the thin galactic disk (see below). Unfortunately, the range of ages of the Cepheids is extremely limited, and, in principle, such correlation shouldn't be shown. However, it is seen in Fig. 1d, and also the correlation coefficient differs from zero outside the limits of $3\sigma (r = 0.22 \pm 0.06)$, and the probability of chance occurrence of the correlation is $P_N << 1\,\%$. It should be noted that the large spread of metallicities significantly reducing the correlation is observed for stars with age about 50 million years. The reason for this effect is connected with selection, which can be seen in Fig. 1e. The whole field of points in the diagram can be limited above by two inclined lines. In this case, the oldest Cepheids lie near the solar radius of the orbit, while the Cepheids with ages of $\sim$50 million years are observed in a very wide range of the distance. It is clear, these stars, as the most massive and bright, are far visible. For illustration of this effect, Cepheids which are closer than 2 kpc from the Sun are marked by open circles in Fig. 1d. The reason for the observed correlation between age and metallicity is most likely the fact that, according to theoretical calculations, lower–metallicity Cepheids, having lower mass at the same temperature, enter the instability strip at a higher age.

Figure 1f shows the age–azimuthal velocity diagram. As we see there is no correlation among them. And approximately the same spread of velocities is observed for the stars of any age. The other two components of the spatial velocity also show no correlation. This means that the high velocities observed even for the Cepheids with minimal errors of velocities are not connected with the relaxation processes in the galactic disk. Otherwise velocity dispersion would have to increase with age.

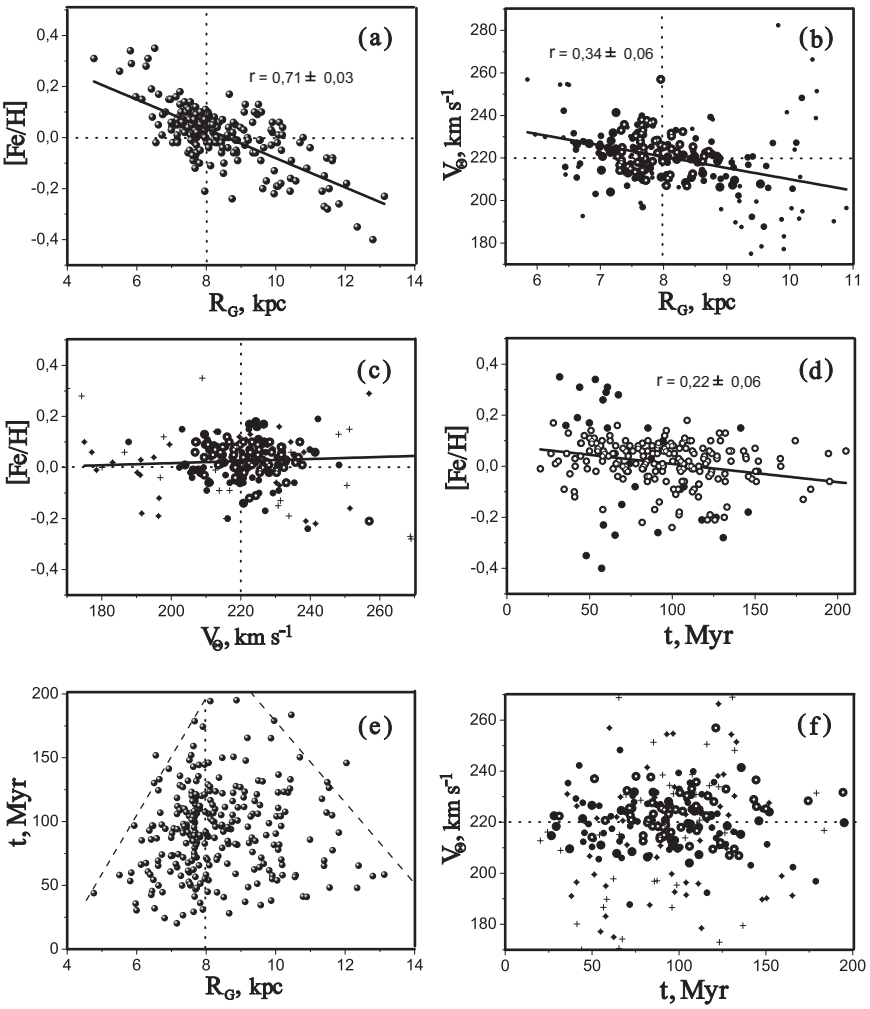


Figure 1 The diagrams of (a) galactocentric distance vs metallicity; (b) galactocentric distance vs azimuthal component of velocity; (c) azimuthal component of velocity vs metallicity; (d) age–metallicity; (e) galactocentric distance vs age; (f) age vs azimuthal component of velocity. In panels (b, c, f) stars with velocity errors <40 km s^{-1}, <20 km s^{-1}, <10 km s^{-1} are marked with filled circles with increasing sizes, stars with errors < 5 km s^{-1} are indicated by open circles, crosses are all the other stars of the sample. Open circles in panel (d) are Cepheids located closer than 2 kpc from the Sun. The solid inclined lines in some panels are linear regressions, and correlation coefficients are shown at the tops (see text for details).

4 Dependences of the relative abundances of various chemical elements on metallicity

According to modern views, the basic processes of nuclear synthesis, which produced isotopes of all chemical elements, take place in stars of a certain mass. In particular, the bulk of α-elements are synthesized in the interiors of massive ($>10M_{\odot}$) stars at

the late stages of their evolution and are ejected into the interstellar medium as a result of outbursts as Type II supernovae (see, for example, Timmes et al., 1995). At that stage only oxygen and magnesium are produced exclusively in these stars, while other α-elements can be synthesized in SNe Ia in small amounts. At the same time, for dwarfs of the disk, the relative abundances of two more α-elements, silicon and calcium, change with increasing metallicity like oxygen and magnesium, i.e. the contribution to their abundance from SNe Ia is insignificant (Mishenina et al., 2013). The abundances of these elements are practically unchanged in the atmospheres of stars at advanced stages of evolution too, that is, in red giants, which contain a core of burning helium in core (see Mishenina et al., 2006).

It is believed that the synthesis of the bulk of atoms of rapid neutron capture elements takes place directly during outbursts of SNe II with the masses $8 < M/M_{\odot} < 10$ (Woosley et al., 1994). When SNe II explode, some of the atoms of iron–peak elements are also formed. The bulk of elements of iron peak are produced in the explosions of SNe Ia which are the final stage of the evolution of close binary stars with masses $<8_{\odot}$ (Thielemann et al, 1986; Travaglio et al., 2011).

Chemical elements, which are produced in the process of nuclear synthesis in stars of different masses, are ejected into the interstellar medium in different time. So time of the evolution of massive stars (SNe II progenitors), enriching the interstellar medium with α-elements, the r-process elements, and a small amount of iron, is not more than about 30 million years, and the mass outbursts of supernovae SN Ia, making the major contribution to the enrichment of the interstellar medium with iron group elements, come after $\approx$1–1.5 Gyr (Matteucci and Greggio, 1986; Yoshii, 1996). Therefore, the relative abundances of $[\alpha/Fe]$ and $[r/Fe]$ will decrease at increasing metallicity for the new generations of stars. This fact is useful for studying the history of star formation in the star–gas system. A feature of the study of dependence of chemical element abundances on the metallicity in Cepheids is that the range of their $[Fe/H]$ because of the youth of these stars is so small, that it is not much larger than the errors of individual determinations. Therefore, $[\alpha/Fe]$–$[Fe/H]$ and $[r/Fe]$–$[Fe/H]$ correlations, arising due to the above, should not appear for them. However, some regularities are observed (see, e. g., Kovtyukh et al., 2005). It is possible to reveal statistically significant existing correlations only with the help of a sample of Cepheids of sufficiently large volume.

Slow neutron capture elements are also produced in stars of different masses. The bulk of them at solar metallicity are produced as a result of thermal pulsations in the atmospheres of asymptotic branch giants (AGB-stars) with masses $M < 4M_{\odot}$ (main component of the s-process) and falls into the interstellar medium by the shell ejection (Gallino et al., 1998). According to theoretical calculations, peak of the yield is formed near $[Fe/H] \approx -0.2$ and the ratio $[s|Fe]$ decreases at a further increasing metallicity (Cristallo et al., 2009). Some additional amount of atoms the s-process elements are produced at high temperatures in the interiors of massive stars; this is the weak component of s-process (Woosley et al., 1994, Pignatari et al., 2010). Recent estimates (Travaglio et al., 1999; Serminato et al., 2009) show that the abundances of heavy s-elements in the Sun (80–90% of barium, 60–65% of lanthanum, 99% of cerium and samarium) are provided with the main component of the s-process, i. e., with AGB-stars. We used three heavy s-process elements, namely Ba, La and Ce, for the analysis.

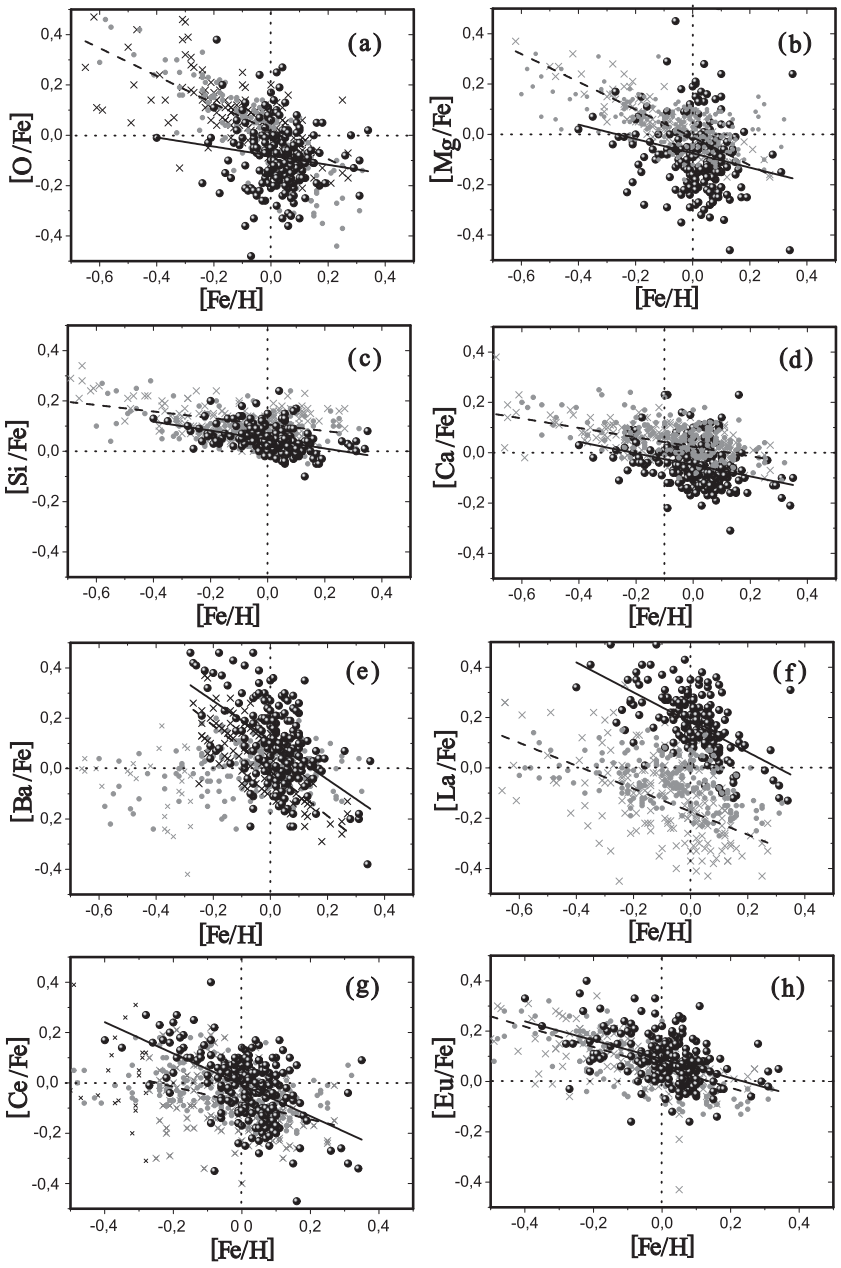


Figure 2 Dependences of relative abundances of eight chemical elements on metallicity in Cepheids (large filled circles), red giants (crosses) and field dwarfs (small dark gray circles). The solid inclined lines are linear regression for Cepheids, and dashed ones are for giants.

Figures 2a–d show dependences of the relative abundances of four α-elements on metallicity. Similar dependences for red giants are marked by crosses; and those for

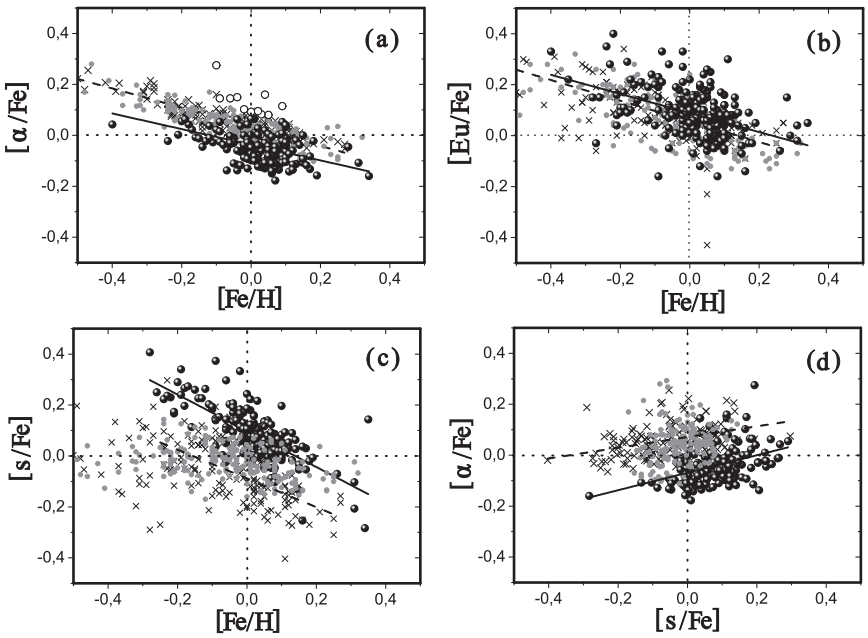


Figure 3 Dependences of the relative abundances of (a) α-elements, the elements of (b) the rapid and (c) slow neutron captures on metallicity. Panels (d) show cross-correlations of the relative abundances of elements produced in different processes. Symbols are the same as in Fig. 2.

dwarfs are shown by small dark gray circles. The abundances of all listed elements in Cepheids are obtained in the LTE approximation from equivalent width of their lines. Calculation of silicon and calcium abundances in the dwarfs and giants is also produced from the equivalent widths in the LTE approximation, whereas the oxygen is from the synthetic spectrum, and magnesium is from the calculated line profiles taking into account the deviations from LTE. Dispersions of the relative abundances of oxygen and magnesium for Cepheid, as seen on the first two panels of Fig. 3, are substantially greater than for the other types of stars. At the same time there are significant deficiencies of average abundances of both elements in comparison with the other stars; even if to limit the range of metallicity of all objects to the value $[Fe/H] = \pm 0.15$ (there are 85% Cepheid in it), then $\Delta[O/Fe] = -0.08 \pm 0.02$ and $\Delta[Mg/Fe] = -0.07 \pm 0.02$. Despite large errors, in Cepheids, both elements exhibit weak tendency to decrease of the relative abundances with increasing metallicity ($r = 0.14 \pm 0.07$ and 0.20 ± 0.07 respectively, at $P_N < 5\,\%$). For dwarfs and giants, analogous dependencies are narrower; slopes are greater; and correlations are much more significant. The relative abundances of silicon and calcium in Cepheids steadily decrease with a small spread at increasing metallicity in the same way as the other two types of stars ($r = 0.4 \pm 0.1$ and 0.3 ± 0.1 respectively, at $P_N << 1\,\%$). But as well as for two previous α-elements, both dependences lie on $\Delta[Si/Fe] = -0.06 \pm 0.01$ and $\Delta[Ca/Fe] = -0.07 \pm 0.01$ below, than for giants. As discussed systematic underestimation of the abundances of each element in Cepheids, in general, can turn

out because of not accounting for deviations from LTE, which can be the greatest for Cepheids. But it is doubtful whether these deviations of all the elements have the same sign. Besides oxygen abundances in dwarfs and giants can also be obtained without LTE approximations (as they are insignificant for oxygen lines), and the silicon and calcium abundances are generally determined by an identical methodology for all stars. To compensate slightly for possible systematic deviations in determinations of the abundances of each element, we will investigate further the behavior of the average abundances of all four α-elements.

Dependences of the abundances of three heavy s-elements, viz. Ba, La and Ce, on the metallicity are shown in Figs 2e–g. Barium abundances in Cepheids and dwarfs are determined with synthetic spectra of several lines in NLTR approximation, and so in giants are in LTE approximation with synthetic profile of strong line of ionized barium. Despite the difference in methods, for Cepheids and giants, the slope of dependences of $[Ba/Fe]$ on $[Fe/H]$ within the error limits in the typical for Cepheids metallicity range ($[Fe/H] > -0.30$) are the same, but the sequence of Cepheids lies up by $\Delta[Ba/Fe] = +0.12 \pm 0.02$. But dwarfs practically show no slope. And, near the solar metallicity, relation $[Ba/Fe]$ in dwarfs and giants is approximately solar one, that is, the same barium excess in Cepheids is observed with respect to both types of stars. Lanthanum and cerium abundances in all stars are received from measured equivalent width of lines in LTE approximation. As can be seen in the figure, the values of the relative abundances of these s-elements also decrease at increasing $[Fe/H]$ (in both cases, $P_N << 1\,\%$). In this case, both elements also show increased abundances in comparison with giants and dwarfs. Moreover, for Cepheids and the giants, the slopes of the dependences of $[La/Fe]$ on $[Fe/H]$ within the errors are the same, and the excess for Cepheids is very large ($\Delta[La/Fe] = +035 \pm 0.02$). The slope of the dependence of cerium abundance outside the error limits for Cepheids is more, than for giants; and the excess is less than for the previous two s-elements on $\Delta[Ce/Fe] = +0.07 \pm 0.02$. For dwarfs, the slopes for all elements even in a limited range of metallicity differ only slightly from zero. Thus, regardless of the method used, the relative abundances of each element of s-process in Cepheids are always high. As all listed elements of slow neutron capture in Cepheids behave approximately equally relative to the giants, further we will use the average value for all three heavy elements of s-process.

The behavior of europium, a typical element of rapid neutron capture, is shown in Fig. 2h. Europium abundances in Cepheids are defined in LTE approximation with the equivalent widths, while in dwarfs and giants are defined with the method of synthetic spectrum taking into account the hyperfine structure. The probabilities of chance occurrence of all correlation are $P_N << 1\%$. Despite the difference in methods, the slopes of the $[Eu/Fe]$–$[Fe/H]$ dependences for all three types of stars are practically the same, finding on the average shift ($\Delta[Eu/Fe] \approx +0.05 \pm 0.01$) in the direction of greater relative abundance in Cepheids in comparison with giants. Thus, the relative abundances of all investigated α-elements in Cepheids show in varying degrees lower ratios of $[\alpha/Fe]$, than in other field stars (including the Sun). Instead, the relative abundances of all studied elements of s- and r-processes in Cepheids are overestimated in comparison with field stars. Besides all elements show decrease of the relative abundances with increasing metallicity.

5 Connection of relative abundances of chemical elements of different processes with other parameters

The first three panels in Fig. 3 shows the dependence of the relative abundances of the α-elements, rapid and slow neutron capture elements on the metallicity for Cepheids, giants and dwarfs. For each star, the errors of different signs in the determinations of the abundances of elements produced in a single process are compensated a little at such averaging. As can be seen, the relative abundances of the elements produced in α- and r-processes decrease approximately identically for all objects with increasing metallicity. Besides the sequences for dwarfs and giants are practically the same, while the sequence of α-elements for Cepheids is below beyond 3σ ($\Delta[\alpha/Fe] = -0.07\pm0.01$), than for giants and dwarfs, and the sequence of r-process element is above outside of the error ($\Delta[Eu/Fe] = +0.03 \pm 0.01$). The slope of the dependence of $[s/Fe]$ on $[Fe/H]$ for Cepheids is about the same as for giants with the same metallicity (i. e. $[Fe/H] > -0.30$). But at that point Cepheids are much above ($\Delta[s/Fe] = +0.19 \pm 0.01$). Note that the nature of the dependence of s-elements and the other two types of elements on metallicity is different. If the yield of s-elements decreases at increasing metallicity of their parent stars (e. g, Serminato et al., 2009), then the relative abundances of α- elements and r-process elements decrease in the following more metallicity generations of stars due to later advent of era of mass ejections of iron from SNe Ia.

Figure 3d shows the dependences between the element abundances obtained in two neutrons capture processes of nuclear synthesis and the existence of the correlation between the elements of the s- and r-processes in Fig. 3f is a surprise. As noted above the fact is that, with the solar metallicity, low-mass ($< 4M_{\odot}$) giant of asymptotic branch contribute mainly to the enrichment of s-process elements. Some of these stars, being close binaries, then explode as a SN Ia, enriching the interstellar medium with iron. That is, both processes go consistently in one and the same stars, and so the relative number of atoms of the s-process elements ejected them into the interstellar medium should not depend on metallicity. However, both the Cepheids and field stars show approximately identical close dependences between the elements of the slow and rapid neutron captures, although a little displaced from each other. The existence of correlations is likely due to the fact that the yield of the relative amount of s-process elements decreases with increasing metallicity of AGB stars in which atmospheres their formation happens (see, e. g., Cristallo et al., 2009). As a result, as shown in the top panels of Fig. 3, dependences of the relative abundances of the s-elements on metallicity for all stars were very similar to the analogous dependences of the relative abundances of α- and r-element; the reason for their appearance is related to the sequence of enrichment of the interstellar medium with these elements and iron.

Figures 4a,b,c show the dependences of the abundances of elements of the same processes in the Cepheids on their galactocentric distance (R_G). We see that the relative abundances of α-elements and r-process elements significantly (for all $P_N << 1\,\%$) increase with increasing metallicity. As for Cepheids, reliable negative gradient of metallicity is observed (Fig. 1a), and the relative abundances of the elements of both processes decrease with the increase of metallicity (Fig. 3a,b), then the relative abundances of α- and r-elements should be higher at large galactocentric distances where the metallicity is less. In Fig. 4c the relative abundances of the s-process

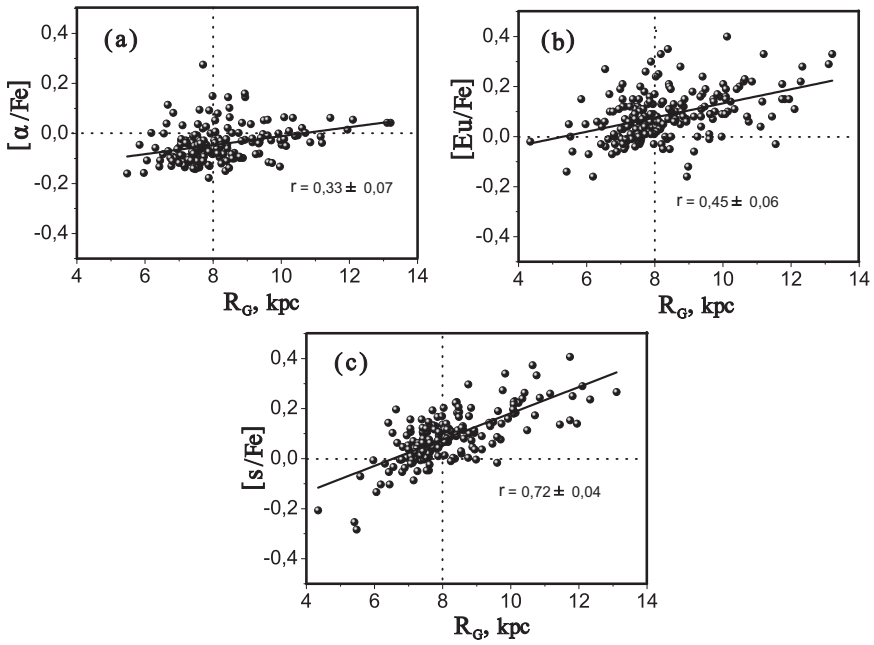


Figure 4 Radial gradients of the abundances of (a) α-elements, (b) r-elements and (c) s-elements in Cepheids.

elements also increase with increasing galactocentric distance, but as already noted, this is due not to the chemical evolution of the interstellar medium, but to the internal processes happening in stars in which these elements are synthesized. Let's notice that the absolute abundances $[el/H]$ of all elements discussed here (except barium) in Cepheids show negative radial gradients in the galactic disk (Andrievsky et al., 2013). In Fig. 4 the relative abundances of all elements, including barium, show reliable increase at increasing galactocentric distance.

According to our analysis, all components of the spatial velocity are not correlated with the chemical elements of three discussed processes. It means that, in contrast to the open clusters (Gozha et al., 2012a, b), the field Cepheids are formed by the common process, stimulating the star formation in the galactic disk most likely under the influence of spiral density waves.

6 Discussion

Change of the relative abundances of some chemical elements $[el/Fe]$ with increasing metallicity can be interpreted within the framework of chemical evolution of a stellar–gaseous system only in case if the total abundance of heavy elements in it increases on the average over time, that is, if metallicity is the statistical indicator of age. However, the study of metallicity in the thin galactic disk shows that a wide scatter of the abundances of heavy elements, that prevents the detection of dependence between age and metallicity in the subsystem, exists among stars of any age. In a recent

paper (Marsakov et al., 2011), we made the complete sample of F–G-dwarfs of the thin disk located around 70 pc of the Sun on the basis of the catalog (Holmberg et al., 2009); we analyzed the selection effects, the systematic effects of random errors in the determination of ages and the effects of radial migration of stars. We showed in it that the interstellar matter in the thin disk demonstrated really on average about the same amount of heavy elements ($< [Fe/H] > \approx -0.2$) and low homogeneity in the first few billion years of the formation of the thin disk; but with age, metallicity dispersion continuously decreased from $\sigma[Fe/H] \approx 0.22$ to ≈ 0.13. However about 4–5 billion years ago average metallicity began to increase systematically, keeping dispersion invariable. The paper suggested that the rate of star formation, low in the initial stages of formation of the thin galactic disk, increased suddenly about 4–5 billion years ago. Therefore it is possible to consider metallicity in the thin disk in the last 5 billion years as time parameter and to explain observed distinctions in the relative abundances of α- and r-elements in Cepheids in comparison with other field stars within the framework of chemical evolution of interstellar matter.

We noted above that the decrease in the relative abundances of the α-elements and r-process elements with metallicity, observed in Fig. 3a,b for Cepheids and field stars was due to the later emission into the interstellar medium of bulk of the iron group atoms. As the metallicity in the thin disk is an age indicator and the range of ages for the giants and dwarfs are much longer than the evolution time of the progenitor of SN Ia, that such dependences have an evolutionary meaning for these stars. In contrast to dwarfs and giants, Cepheids are very young stars, and dependences of $[\alpha/Fe]$ on $[Fe/H]$ and of $[r/Fe]$ on $[Fe/H]$ observed for them testify not to their sequential birth, and only to the lack of homogeneity of the chemical composition of the interstellar medium in which star formation took place. From Fig. 3a, it would be visible that widths of dependences for them under the given metallicity are slightly less than total spread of the relative abundances of α- and r-elements. However, the correlations are significant, and dependences in both panels are parallel but they are spaced from each other outside the error limits. Parallelism means that all stars were formed from the matter that experienced the same history of enrichment with chemical elements. Apparently, the star formation rate had omitted some kind of regions of interstellar matter, and only then the young stars, which representatives are present Cepheids, were formed out of them. As a result, existence of the dependences for Cepheids testifies to a weak mixing of interstellar matter and "delayed" star formation in some areas, when the stars with different abundances of heavy elements are formed at the same time not far from each other (see also Lepine et al., 2011; Gozha and Marsakov, 2013). Note that stars with ages, typical for Cepheids, are practically absent among our near dwarfs and giants, so a significant gap in ages between the Cepheids and other stars is observed.

Thus, the relative abundances of α-elements systematically increased and decreased abundances of r-process elements in Cepheids compared with dwarfs and giants of the field can be explained by the fact that very massive stars stopped to explode as supernovae when the interstellar medium reached about solar metallicity, and as a result the number of atoms of α-elements ejected into the interstellar medium decreased sharply. In view of the fact that large mass supernovae also produced a significant amount of iron-group elements during outbursts, the ratio $[r/Fe]$ increased in the interstellar medium, but the final values $[\alpha/Fe]$ still decreased. Subsequently

the Cepheids observed now were formed from this medium. This assumption is supported also by the observational fact, being that all Type II supernovae progenitors studied in other galaxies do not exceed the maximum of masses ≈20 solar masses (see Smartt et al., 2009; Kochanek et al., 2008).

The excess of *s*-process elements in Cepheids can also be explained by the ending of outbursts of massive SNe II, which enriched the interstellar medium also with a significant amount of iron–group elements except α-elements. But in the atmospheres of massive stars, some amount of the *s*-elements is also produced in the weak component of the *s*-process. It is likely that these stars can shed the upper parts of their envelopes also without an explosion, like AGB stars, increasing as before the relative abundances of the *s*-elements in the next generation of stars. As a result, the ratio $[s/Fe]$ in young stars, epheids, could be high. But the parallelism of dependencies $[s/Fe]$ on $[Fe/H]$ for the Cepheids and the giants shows that AGB stars, whose ratio $[s/Fe]$ in the output depends on their metallicity, remain the main supplier of these elements. This dependence also explains the increase of the relative abundances of *s*-elements in Cepheids at increasing galactocentric distance, i. e. at decreasing metallicity.

Certainly the expressed assumption can be true only if the discussed distinctions between the relative abundances of various chemical elements in Cepheids, dwarfs and red giants are not due to undetected systematic errors in the determinations of these abundances in Cepheids. Otherwise, it is necessary to reconsider the approach to determination of the chemical element abundances in the evolutionarily advanced stars, namely Cepheids. For testing conclusions of this work, it is desirable to investigate the behavior of the abundances of the same elements in open star clusters, as young as Cepheids.

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