*Astronomical and Astrophysical Transactions* (*AApTr*), 2021, Vol. 32, Issue 2, pp. 147–152,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

# Peculiar properties of abundances of some chemical elements in metal-rich field RR Lyrae variables

M.L. Gozha*, V.A. Marsakov, V.V. Koval'

*Southern Federal University, Rostov-on-Don, Russia*

*Received 1 March, 2020*

On the data of the author's catalog of spectroscopic determinations of the chemical element abundances in the atmospheres of galactic field RR Lyrae variables, it has been shown that the relative abundances of scandium, titanium and yttrium in metal-rich RR Lyraes ([Fe/H] $> -1.0$) are less, outside the error limits, than in field stars of similar metallicity. It is noted that the abundances of europium, zirconium and lanthanum are not determined in any metal-rich RR Lyraes. Errors in determining the abundances of these chemical elements are discussed. The possible causes of the peculiarities of the observed chemical composition in metal-rich RR Lyraes are analyzed.

*Keywords*: Stars: abundances; stars: variables: RR Lyraes

## 1 Introduction

RR Lyrae stars are radially pulsating variables of spectral class A or F that reside in the instability strip of the horizontal branch. The metallicities of the galactic field RR Lyraes vary widely. Unlike globular clusters, among RR Lyrae variables of the galactic field, there are those that have high metallicity and kinematic properties characteristic of disk subsystems. As studies show, although RR Lyrae variables are in the advanced stage of evolution, the abundances of most heavy chemical elements in their surface envelopes remain unchanged during star lifetimes (see, for example, [1]). Therefore, using the abundances obtained, we can infer the chemical composition of the matter from which these stars formed.

As we showed in our previous papers [2–4], the relative abundances of titanium in most RR Lyraes with [Fe/H] $> -1.0$ are significantly lower than in stationary field stars. The anomalous relative abundances of some chemical elements were also noted by the authors of several papers. In particular, in [1, 5, 6], the authors even attempted to explain the reasons for the lower relative abundances of not only titanium, but also scandium and yttrium in RR Lyraes with [Fe/H] $> -1.0$ compared to stationary stars of the same metallicity.

*Email: gozha_marina@mail.ru

As a result of a preliminary analysis of all published abundances of various chemical elements available to us, we identified those whose relative abundances in metal-rich RR Lyraes are anomalously low. These are scandium (iron peak element), titanium ($\alpha$-element, sometimes it is considered as iron group element) and yttrium (element of slow neutron capture process). In addition, we noticed that the abundances of $r$-process element, europium, as well as two $s$-process elements, zirconium and lanthanum, have not been determined for any metal-rich RR Lyrae variable.

## 2 Initial data

To analyze the behavior of the chemical elements listed above in galactic field RR Lyrae stars, we used spectroscopic determinations of the metallicity and relative abundances of titanium, yttrium, zirconium, lanthanum, and europium for 100 field RR Lyraes from our compiled catalog described in [2, 7]. To these data, we added the relative scandium abundance [Sc/Fe] for 77 RR Lyraes. The procedure for determining the relative scandium abundances is similar to that used to obtain abundances of other chemical elements from our catalog (see [8] for more details). For comparison, we used several samples of stars with known metallicities and relative abundances of scandium, titanium, and yttrium (see details below).

## 3 Errors in the determination of the relative abundances of chemical elements

In the spectra of RR Lyraes, the most symmetric and sharpest lines that are optimal for abundance studies are obtained close to the phase of minimum kinetic energy of the atmosphere and maximum radius of the star ($\phi \approx 0.35$), at which there are no shock waves in the atmosphere (e.g., [9]). Most of the spectra in the original papers were obtained close to this quiescent phase. However, it was shown that the relative abundances of most chemical elements, including those studied in this work, are practically phase independent (see [10] and references therein).

The relative abundances of scandium are known for 77, titanium for 83, and yttrium for 43 RR Lyraes. The average error calculated from the uncertainties given in the papers for these elements varies in the range (0.11–0.14) dex. The dispersion of the calculated weighted average values of the relative abundances for the cases of two or more determinations of the abundances of each element for any star, which gives an estimate of the external convergence of [el/Fe] determinations by different authors, is $\langle\sigma_{[\mathrm{el/Fe}]}\rangle$ = (0.05–0.07) dex. The deviation distributions of the calculated weighted average values from the author's determinations of abundances for scandium, titanium, and yttrium are studied. All the histograms are described by a normal law, so the errors can be regarded as random. This means that our weighted average abundances of scandium, titanium, and yttrium, as well as the individual determinations of the relative abundances of these chemical elements collected from the primary sources, can be considered reliable and suitable for analyzing the behavior of [el/Fe] in RR Lyrae variables.

## 4 Comparative analyses of the relative abundances of Sc, Ti, Y, in field metal-rich stars of different types

Figure 1 shows the dependences of the relative abundances of scandium, titanium, and yttrium on metallicity for RR Lyraes, Cepheids, and stationary field stars from several catalogs. 7066 nearby dwarfs and subgiants of disk subsystems from the catalog [11] are added to the panels (A–C). Almost all the stars of this voluminous catalog have [Fe/H] $> -1.0$. It can be seen that most metal-rich RR Lyraes lie below the region occupied by stationary stars.

The second column of Figure 1 clarifies the mutual positions of [el/Fe] ratios in comparison stars and field RR Lyraes in the metal-poor range. In Figure 1D, for comparison, [Sc/Fe] ratios were plotted for 171 nearby F-G dwarfs from the catalog [12] with distances up to 150 pc from the Sun, which in most cases belong to a thick galactic disk; only 15 of these stars are metal-poor. 781 field stars from the catalog [13] with a metallicity range similar to that of field RR Lyraes are added to Figure 1E, F. It can be seen from the figures that the positions of RR Lyraes and comparison stars coincide at [Fe/H] $< -1.0$. But at higher metallicity, the relative abundances of scandium, titanium, and yttrium in most RR Lyraes, outside the error limits, are smaller than in comparison stars.

Let us now consider the dependences of [Sc/Fe], [Ti/Fe], and [Y/Fe] on the metallicity for RR Lyraes as compared with the similar dependences for the field Cepheids, i.e. for another type of radially pulsating variable stars. 435 Cepheids from [14] are plotted on the panels (G–I) of Figure 1. Their positions in the figures are significantly higher than the area occupied by metal-rich RR Lyraes. For Cepheids, the average values are $\langle[\mathrm{Sc/Fe}]_{\mathrm{Cep}}\rangle = 0.33\pm0.01$, $\langle[\mathrm{Ti/Fe}]_{\mathrm{Cep}}\rangle = 0.13\pm0.01$, $\langle[\mathrm{Y/Fe}]_{\mathrm{Cep}}\rangle = 0.20 \pm 0.01$, whereas for RR Lyraes with the same high metallicity, $\langle[\mathrm{Sc/Fe}]_{\mathrm{RRL}}\rangle = -0.34 \pm 0.04$, $\langle[\mathrm{Ti/Fe}]_{\mathrm{RRL}}\rangle >= -0.08 \pm 0.04$, $\langle[\mathrm{Y/Fe}]_{\mathrm{RRL}}\rangle = -0.44 \pm 0.06$. Thus, the abundances in RR Lyrae variables with [Fe/H] $> -1.0$ and in Cepheids differs far beyond the limits of errors. It seems that such low relative abundances of the elements under consideration in metal-rich RR Lyraes are unlikely to be due to the fact that these stars are pulsating variables.

We noticed that in our catalog [2] there are no data on the abundances of lanthanum, zirconium, and europium for metal-rich RR Lyraes. But in other metal-rich variable stars, Cepheids, the abundances of Eu, Zr, and La are determined. What is the reason for the lack of these data? Perhaps the authors did not set the goal of determining them. Or metal-rich RR Lyraes contain such small amounts of Eu, Zr, and La that it is not even possible to establish their abundances. It is worth mentioning that the abundances of europium, zirconium, and lanthanum for some metal-poor RR Lyraes are known.

## 5 Attempts to explain the unique chemical composition of the metal-rich RR Lyraes

Let us review the explanations of the unique abundances of scandium, titanium, and yttrium that are given by the authors of the primary sources of our data on the abundances of the considered chemical elements. The authors of the work [1] were unable

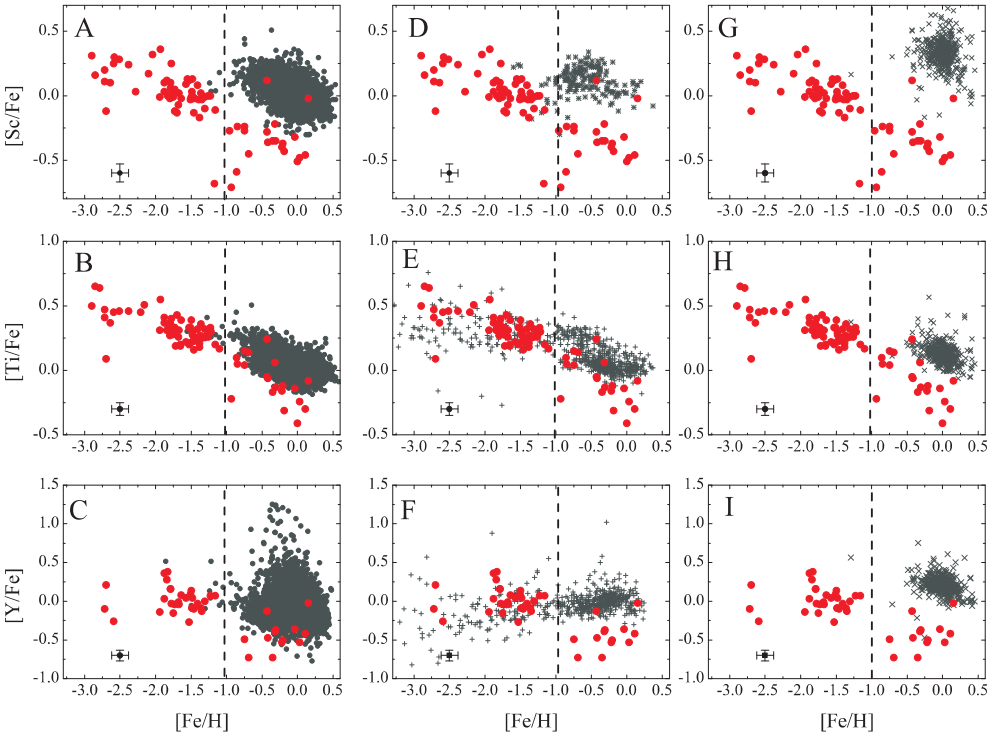



**Figure 1** Relative abundances of scandium, titanium, and yttrium as the function of metallicity for RR Lyrae variables of the galactic field (filled big red circles). Comparison stars are indicated by: (A–C) small gray dots, from [11]; (D) gray snowflakes, from [12]; (E, F) gray straight crosses, from [13]; (G–I) gray oblique crosses, Cepheids from [14]. The vertical dashed line at [Fe/H] = −1.0 divides the stars into two groups, metal-poor and metal-rich. The error bars of the weighted average values of [el/Fe] for RR Lyraes are shown.

to explain the underabundances of scandium and yttrium in metal-rich RR Lyraes by means of a nucleosynthetic argument or by combinations of atmospheric parameter errors. They suspected that low abundances of these elements are attributed to overionization in pulsating atmospheres of these variables. But the authors of the paper [5] considered this explanation to be unconvincing due to the lack of a similar effect in metal-poor RR Lyraes. Instead, they suggested that the deviations could be caused by differences in $\log g$ values for evolved RR Lyrae variables and unevolved dwarf stars. However, as our analysis has shown, other metal-rich variable stars, Cepheids, have surface gravities even less than RR Lyraes do, but their [el/Fe] ratios are slightly larger than for dwarfs and RR Lyraes. The authors of the work [6] consider that differences in the mechanisms of shock wave propagation in metal-rich and metal-poor RR Lyraes are related to differences in the atmospheric parameters of these stars, because the effective temperature and gravitational acceleration in their sample are greater in metal-rich RR Lyraes than in metal-poor ones. However, although $T_{\rm eff}$ and $\log g$ found by us for one hundred RR Lyraes [15] are on average slightly higher in

metal-rich stars, but within the error limits the values of these parameters coincide for both groups.

A possible explanation of the differences in the abundances in RR Lyraes and in comparison stars could be due to effects caused by deviations from local thermodynamic equilibrium (LTE). It is considered that giants are usually more affected by deviations from LTE than dwarfs [16]. However, there are giants among our comparison stars, but their [Sc/Fe], [Ti/Fe], and [Y/Fe] are much higher than for RR Lyraes of similar metallicity. Apparently, the uniqueness of the chemical composition of metal-rich field RR Lyrae stars cannot be explained by the deviations from LTE.

## 6 Conclusions

Thus, it is not possible to attribute anomalously low relative abundances of scandium, titanium, and yttrium in metal-rich RR Lyrae variables of the galactic field to errors in determining the abundances of these elements. It is not possible to explain them by the mechanisms occurring in the nonstationary atmosphere of these stars. The reason for the lack of data on the abundances of europium, zirconium, and lanthanum in metal-rich RR Lyraes is also unclear. It can be assumed that metal-rich RR Lyrae variables acquired just such under abundances of the elements listed above from the parent interstellar cloud, which experienced different chemical evolutionary history from that of the parent interstellar matter of most field stars close to the Sun.

## Acknowledgements

The research was financially supported by the Southern Federal University, 2020 (Ministry of Science and Higher Education of the Russian Federation).

## REFERENCES

[1] G. Clementini, E. Carretta, R. Gratton, et al., Astron. J. **110**, 2319 (1995).
[2] V. A. Marsakov, M. L. Gozha, and V. V. Koval', Astron. Rep. **62**, 50 (2018a).
[3] V. A. Marsakov, M. L. Gozha, V. V. Koval', and E. I. Vorobyov, Astrophysics **61**, 171 (2018b).
[4] V. A. Marsakov, V. V. Koval', and M. L. Gozha, Astrophys. Bul. **75**, 21 (2020).
[5] S. Liu, G. Zhao, Y.-Q. Chen, et al., Research in Astronomy and Astrophysics **13** (11), 1307 (2013).
[6] M. Chadid, C. Sneden, and G. W. Preston, Astrophys. J. **835**, 187 (2017).
[7] M. L. Gozha, V. A. Marsakov, and V. V. Koval', Astrophysics **61**, 41 (2018).
[8] M. L. Gozha, V. A. Marsakov, and V. V. Koval', Astrophys. Bul. **75**, 311 (2020).
[9] C. Sneden, B.-Q. For, and G. W. Preston, in *RR Lyrae Stars, Metal-Poor Stars, and the Galaxy*, ed. A. McWilliam, Carnegie Observatories Astrophys. Ser. **5**, 196 (2011).

[10] E. Pancino, N. Britavskiy, D. Romano, et al., Monthly Not. Roy. Astron. Soc. **447**, 2404 (2015).
[11] S. Buder, K. Lind, M. K. Ness, et al., A&A 624, A19 (2019).
[12] B. E. Reddy, D. L. Lambert, and C. Allende Prieto, Monthly Not. Roy. Astron. Soc. **367**, 1329 (2006).
[13] K. A. Venn, M. Irwin, M. D. Shetrone, et al., Astron. J. **128**, 1177 (2004).
[14] R. E. Luck, Astron. J. **156**, 171 (2018).
[15] V. A. Marsakov, M. L. Gozha, and V. V. Koval', Astron. Rep. **63**, 203 (2019).
[16] M. Asplund, ARA&A, **43**, 481 (2005).