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HAFNIUM ABUNDANCES IN FGK DWARF OF GALACTIC DISK

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ABSTRACT. In this work we present new observational data for hafnium (72). Hf is an important element that is between the lightest rare-earth elements (e.g., La, $Z = 57$) with elements of the third r-process peak (Os, Ir, Pt, $Z = 76-78$). Hafnium is the heaviest ($Z = 72$) stable element represented by low-excitation (<1.5 eV) ionized lines in the spectra of the cool stars (Lawler et al., 2007). This element is important as a stable reference element for nucleocosmochronometry, and also to study of the sources of its production and enrichment with n (neutron)-capture elements of Galactic disc. We provide the analysis of the spectra of 126 FGK dwarfs in metallicity range from $-1.0 < [\text{Fe}/\text{H}] < +0.3$ that were taken from our starting sample of 276 stars (Mishenina et al. 2013). The observed stars belong to the substructures of the Galaxy disc. The observations were conducted using the 1.93 m telescope at Observatoire de Haute-Provence (OHP, France) equipped with the echelle type spectrographs ELODIE and SOPHIE. The results are based on analyses of spectra that have a typical $S/N \sim 100-300$ and a resolution of 42 000 (ELODIE) and 75 000 (SOPHIE). The hafnium abundance was derived by comparing the observed and synthetic spectra in the region of two Hf II line ($\lambda 4080.437 \text{ \AA}$ and $\lambda 4093.155 \text{ \AA}$), making use of the LTE approximation. The obtained hafnium abundance decrease with increasing metallicity in both discs, and have a big scatter at all metallicities. The dependence of our Hf abundance on metallicity and their comparison with those of other authors is presented. It corresponds to typical behavior of the elements behind the iron peak, the elements formed in the processes of neutron capture. The sources of the Hf enrichment of Galactic disc are considered.

Keywords: stars: abundances – stars: late-type – Galaxy: disc – Galaxy: evolution – abundances, nucleosynthesis

РЕФЕРАТ. У цій роботі ми представляємо нові спостережні дані для гафнію (72). Hf є важливим елементом, який знаходиться між найлегшими рідкоземельними елементами (наприклад, La, $Z = 57$) та елементами третього піку r-процесу (Os, Ir, Pt, $Z = 76-78$). Гафній – це найважчий ($Z = 72$) стійкий елемент, представлений іонізованими лініями з низьким потенціалом збудження (<1.5 eV) у спектрах холодних зір (Lawler et al., 2007). Цей елемент важливий як стійкий еталонний елемент для нуклеокосмохронометрії, а також вивчення джерел його виготовлення та збагачення елементами захвату нейтронів галактичного диску. Ми провели аналіз спектрів 126 FGK-карликів ($-1.0 < [\text{Fe}/\text{H}] < +0.3$). Зорі в нашій вибірці належать до підструктур

диска Галактики. Спостереження проводилися за допомогою телескопа 1,93 м на Обсерваторії Верхнього Провансу (ОHP, Франція), оснащеного ешельними спектрографами ELODIE та SOPHIE. Результати базуються на аналізі спектрів, що мають типовий $S/N \sim 100-300$ та роздільну здатність 42 000 (ELODIE) і 75 000 (SOPHIE). Вміст гафнію було отримано шляхом співставлення спостережуваних та синтетичних спектрів в області двох ліній Hf II ($\lambda 4080.437 \text{ \AA}$ та $\lambda 4093.155 \text{ \AA}$), з використанням наближення Локальної Термодинамічної Рівноваги (ЛТР). Отриманий вміст гафнію зменшується зі збільшенням металічності для обох дисків і має великий розкид на всіх металічностях. Представлено залежність наших значень вмісту Hf від металічності та їх порівняння з даними інших авторів. Вона відповідає типовій поведінці елементів, що утворюються в процесах захоплення нейтронів. Розглядаються джерела збагачення Hf галактичного диска.

Ключові слова: зорі: вміст – зорі: пізній тип – галактика: диск – галактика: еволюція – вміст, нуклеосинтез

1. Atmospheric parameters

The effective temperatures T_{eff} , the surface gravities $\log g$, the microturbulent velocity V_t , and metallicities of the studied stars were determined earlier in our paper (Mishenina et al., 2013). Effective temperatures T_{eff} were estimated by the line depth ratio method (Kovtyukh et al., 2003). Surface gravities $\log g$ was determined by two methods: parallaxes and ionization balance of iron.

The microturbulent velocity V_t was derived considering that the iron abundance $\log A(\text{Fe})$ obtained from the given Fe I line is not correlated with the EW of that line.

The metallicity $[\text{Fe}/\text{H}]$ accepted as the iron abundance obtained from Fe I lines.

2. Abundances

In the solar spectrum we found two Hf II lines to be good abundance indicators: $\lambda 4080.44$ and $\lambda 4093.15$. The $\log gf$ source was the Vienna Atomic Line Database (VALD, Kupka et al., 1999). Determination of the Hf abundances was made by new version of STARS LTE spectral synthesis code (Tsymbal, 1996). We used lines, which are weak and do not require to take into account the hyperfine or isotopic structure. The examples of comparison of synthetic and observed spectra for Hf II are shown in Fig. 1(a,b).

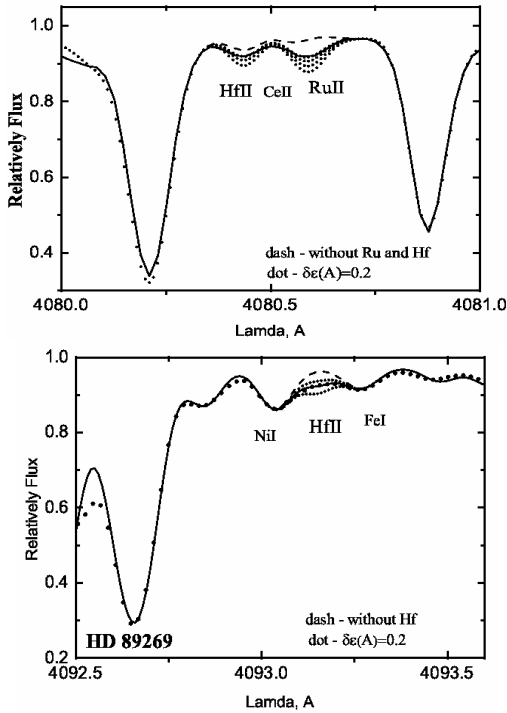


Figure 1(a,b): Comparison of synthetic and observed spectra in the region of Hf II lines. Dotted line: observations; solid black lines marked the spectra calculated for the resulted abundances. The dashed line shows the synthetic spectra without taken into account the contribution from Hf.

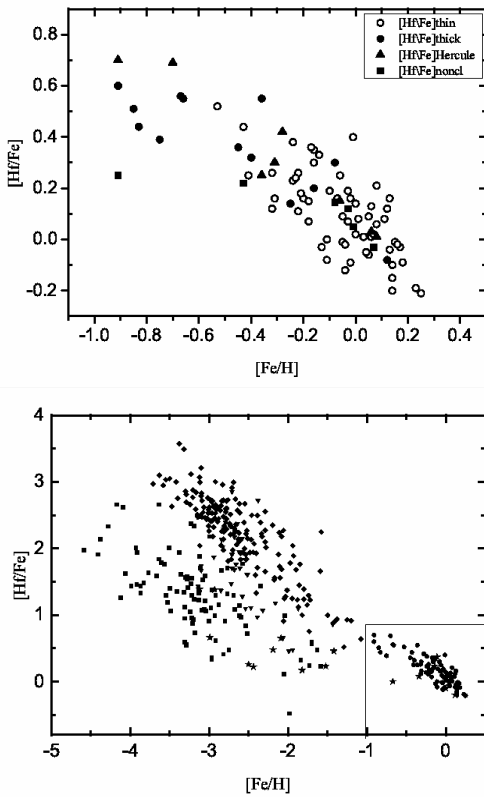


Figure 2(a,b): a) Dependences of [Hf/Fe] on [Fe/H] for the stars of the thick disk (filled symbol), of the thin disk (open circle), the Hercules stream (open triangles), and unclassified stars (square), b) comparison with those of other authors.

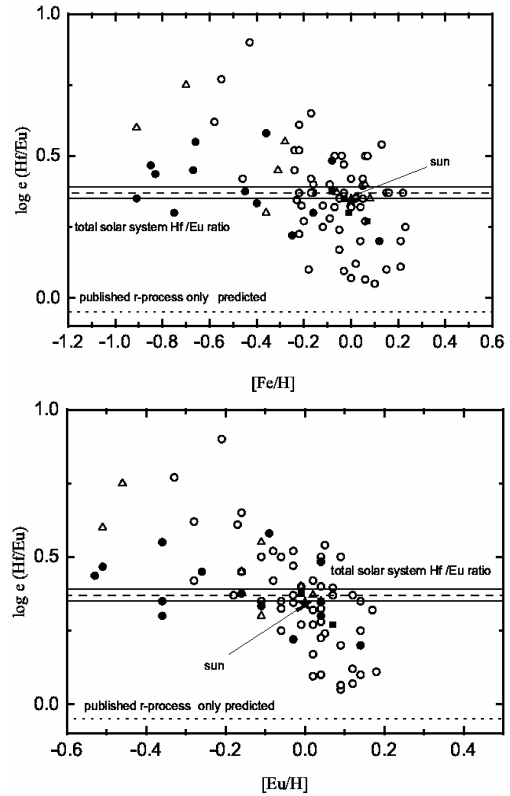


Figure 3(a,b): Abundance comparisons of $\log \epsilon(\text{Hf}/\text{Eu})$ vs. [Fe/H] and [Eu/H]. The dotted lines define the range of the solar system r-process only, the dashed line is the total solar system ratio (see in details, Lawler et al. 2007) and the solid line is the mean ratio of the stars in our sample.

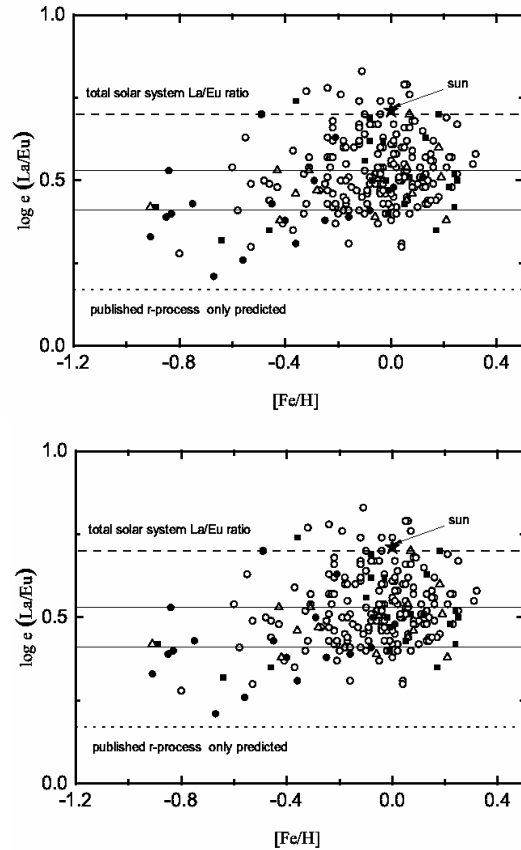


Figure 4(a,b): Abundance comparisons of $\log \epsilon(\text{La}/\text{Eu})$ vs. [Fe/H] and [Eu/H]. the notation is the same as in Fig. 3.

3. Results

We have determined the abundance of hafnium for 126 stars. As can be seen from Fig. 2a, the hafnium abundance decrease with increasing metallicity in both discs. The dependence of our Hf abundances on metallicity and their comparison with those of other authors (Lawler et al., 2007; Roederer et al., 2014) are presented in Fig. 2b. This is the typical behavior of the elements behind the iron peak, the elements formed in the processes of neutron capture.

To estimate the contribution of the s- (slow), and r- (rapid) processes to the Hf abundance, we compare La и Hf, which are predominantly an s-process element in solar system, with the element Eu (Fig. 3,4), having the prevailing contributions of the r- processes. The dotted lines define the range of the solar system r-process only values based on the published deconvolution of the solar system abundances (Simmerer et al., 2004), and the dashed line is the total solar system ratio based on the stellar value for the r-process (see in details Lawler et al., 2007).

4. Conclusions

We obtained the hafnium abundance for 126 FGK dwarfs belonging to different Galactic substructures. The behavior of Hf abundance with metallicity like as other

elements of n-capture. The observed stellar abundance ratios of Hf/Eu and La/Eu are coincident with previous estimates of the solar system s-, r-processes. The comparison of Hf abundance with those of La (s-element) and Eu (r-element) support that Hf is s-element.

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