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Posted Date: 6 June 2024

doi: 10.20944/preprints202406.0332.v1

Keywords: Solar System, element abundances, exoplanets, astromineralogy planets

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Astromineralogy of the Nearby Exoplanetary Systems I: A Comparative Analysis of the Stellar and the Averaged Solar Mg/Si and Fe/Si Molar Ratios

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Abstract: This study was based on the corresponding elemental abundances of carbonaceous - chondrites and the Solar photospheric elemental abundances [1]. The comparative analysis between the average magnesium, silicon and iron abundances of the Solar System and the abundances of these elements in potential nearby planetary systems was based on the Mg, Si and Fe abundances of host stars, which are in the Galactic thin disk within 25 parsecs distance from the Sun. The stellar abundance data had been taken from the Hypatia Catalog, which contains high precision data of chemical elements. We show that in general there are no significant differences between the molar Mg/Si and Fe/Si ratios of the most examined stars and the corresponding elemental ratios of the Solar System. However, the comparative study also shows that a significant fraction of the nearby extrasolar terrestrial planets may have higher bulk Mg/Si ratio than Solar, but the Solar Fe/Si ratio can relatively be frequent. We conclude that the medium - sized metallic cores can relatively be common in the rocky planetary interiors, while the mantle mineralogy for most of the rocky exoplanets in the Solar neighborhood may differ from that of Earth.

Keywords: solar system element abundances; stellar element abundances; astromineralogy; rocky planets

1. Introduction

The transit detection methods combined by the spectroscopic observation techniques allow the discovery of low-mass terrestrial exoplanets: ~1 Earth– mass (ME), and so – called super – Earths (1 - 10 ME). The discoveries of Kepler mission confirm that the low-mass exoplanets are very common in the Galaxy. The discovery of hundreds of rocky planets around F –, G -,K-, and M – stars raises new questions about the diversity of planetary compositions estimating the abundances of compositionally different planet types. It is generally thought that the surface of approximately 1 Earth's – mass rocky planets orbiting the habitable zones of the G-, K- and M-spectral type main – sequence stars, can be the most suitable places for hosting complex life as known in Earth. The geological activity and the long – time plate tectonics are essential factors to sustain the planetary habitability. Plate tectonics depends on the physical conditions of the mantle convection. It is known that the planetary composition, the mantle mineralogy may strongly affect the efficiency of mantle dynamics and the properties of the lithosphere. Therefore, the mineralogy of rocky planets has a great importance in the astronomical, cosmochemical research as well as in the Planetary Sciences. The bulk mineralogy of rocky planets crucially depends on the average C/O, Mg/Si and Fe/Si ratios of the protoplanetary disks, in which they had been formed.

Certain oxides, (SiO_2, MgO, FeO) and silicates, (such as $MgSiO_3$, and $CaSiO_3$) are the major components in the composition of bulk silicate Earth, and likely in rocky planets characterized by similar bulk C/O and Mg/Si mineralogical ratios than that of the Earth. Hence, it is necessary to clear that whether the Earth's bulk chemical composition and mineralogy is rare amongst the rocky planets

 doi:10.20944/preprints202406.0332.v1

around G – and F – type stars in the Solar neighborhood, or not. The chemical properties and mineralogy of exoplanets are not directly observable, however the stellar abundances of the key terrestrial planet – building elements are adopted for modeling the planetary bulk compositions. The stellar abundances of these elements correlate with a relatively good approximation with the bulk chemistry and bulk mineralogy of the rocky planets, which may potentially be orbiting them. Note that the mineralogy of these rocky planets not only depends on the average key planet – building abundances of the system, but also the bulk mineral compositions depend on the location of the planetary body formation inside the protoplanetary disc and on the planetary chemical differentiation. The knowledge of the bulk Earth chemical composition is based on the petrological and mineralogical analysis of different kinds of meteorites, crustal and mantle – derived rocks, respectively.

For Fe, Mg and Si, the averaged Solar System and the chondritic abundances are being nearly consistent with abundances of these refractory elements of the Solar photosphere [2–3]. In this manner, observation of the elemental compositions of the host stars provides information from the exoplanetary compositions. The C/O, Mg/Si and Fe/Si abundance ratios play a determining role in the formation of building blocks, the bulk chemistry, and interior structure of rocky planets [4]. The Galactic chemical evolution may play an important role in the planetary structures and compositions [5]. The C/O and Mg/Si elemental ratios indicate the distribution of carbides and silicates in planetary systems [6]. The abundances of these two ratios in Solar – type host stars with low – mass planets are like those found in the Sun [7].

Adibekyan et al (2021) [8] find that the iron abundances of the host stars and the iron mass fraction of rocky exoplanets correlate with each other. The bulk planet Fe/Si ratio may refer to the size of the metallic core and the value of this elemental ratio in terrestrial planetary bodies depends on the iron content of the mantle minerals. The stellar Fe, Mg and Si abundances have been appeared as proxies for the planetary bulk composition and interior structure constraining the relative size of the planetary cores and mantles [3,9]. Silicates are the most abundant building minerals of rocky planets, which determine rocky planet's mantle and crustal composition. The two major types of the cosmic silicate mineral grains are the groups of the olivines (Ol) and the pyroxenes in the interstellar medium (ISM) and protoplanetary disks (PPDs). Spectroscopic observations of the cosmic dust confirm that the silicates are Mg – rich in the ISM [10]. According to the results of laboratory analysis, it is shown that the silicates in the materials of the Solar System are also mostly Mg–rich minerals. The elemental abundances of chondritic meteorites refer to that the abundance of Mg–silicates is higher than that of the abundances of Fe-, Ca-, Al-silicates. The mineral composition of the Earth's lower crust and mantle is dominated by Mg – rich silicates.

The chemical composition of the carbonaceous chondrites is the closest to the solar and the average Solar System composition neglecting the ratio of volatile elements. The bulk elemental composition of major rock – forming elements (O, Mg, Si, Fe) in the inner rocky planets slightly differ from the average Solar System element ratios due to the chemical conditions at the location of the formation in the solar nebula during their accretion, the major planetary differentiation and fractionation processes (core formation, partial melting), respectively. In the Earth's lower mantle, the Mg/Si ratio is lower while the Fe/Si ratio is higher relative to the upper mantle composition. Geophysical evidence implies that the Earth's core build up mostly of iron and that it contains light elements, which decrease the bulk density below that of the pure iron [11] .

The differences between the solar Mg/Si (1.05) [1] and the molar values of calculated bulk Mg/Si abundances of the Earth [12,13] are within 20 % in the most studies. Accordingly, a good approximation to the bulk elemental composition of the terrestrial exoplanets is to assume that the compositions of the host stars for rock–forming elements are close to the bulk elemental compositions of their rocky planets [9]. The results of space–and ground - based observations show that the low–mass exoplanets (super Earths and smaller rocky planets) have a high occurrence rate among exoplanets in the Milky Way galaxy. According to the determinations of stellar abundances in our galactic neighborhood imply that in most cases there are no substantial differences in Mg/Si and Fe/Si ratios of the low–mass stars compared to the corresponding solar values. As opposed it, the

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mineralogical composition of the galactic population of rocky planets can likely be more diverse than previously thought. The elemental abundances of carbonaceous chondrites (CCs) are consistent with the average Solar System composition. As is well known the average Solar System composition of key planet–building elements of rocky planets (O, Fe, Mg, Si) are consistent with the Solar photospheric abundances of these elements. Consequently, the average abundances of key rock–forming elements in exoplanetary systems stars are consistent with the elemental composition of their host stars.

Based on the spectroscopic examinations of PPD materials and exoplanet host stars, most of the terrestrial exoplanets had been accreted from Mg–rich materials and having a chondritic–like Mg and Fe elemental composition. Spaargaren et al. [14] found that the bulk Mg/Si ratio of the Earth's mantle is below the average of bulk-silicate Mg/Si for planets in the galactic neighborhood. Small – sized planets (RPlanet< 4 REarth) can be formed around host stars with a wide range of metallicities [15]. Buchhave et al. [16] found that the planetary composition and structure have been regulated according to the host star metallicities. Based on the cosmochemical and geochemical arguments, it is commonly thought that the Earth's core is composed primarily of iron [17]. The largest fraction of the Earth's Fe budget is concentrated in the metallic core, which is thought to consist of light element-bearing (such as S, Si, C) high-pressure iron-nickel alloy. It is also very likely that the Fe budget is mainly presented in the metallic cores of rocky planets in the most planetary systems formed during the planetary accretion and differentiation.

The size of the metallic planetary cores depends on the bulk planet (BP) Fe/Si ratio, the thermal history and chemical differentiation of the planets. Moreover, the size of the cores of terrestrial planets depends upon their collisional history in the early evolutionary stage of the planetary system. The mantle mineralogy of a significant fraction of the exoplanets may be controlled by core formation [18]. Consequently, the Fe/Si is also very important elemental ratio because it may have a determining role in the bulk chemistry and mineralogy of rocky planets.

Many previous studies have been focused on the plausible bulk mineral composition of rocky exoplanets [6,19-21]. Amongst them, Delgado Mena et al. [6] attempt to compare the chemical properties of our Solar System with the chemical properties of the observed nearby stars, which are known to host terrestrial planets, or they may have rocky planets. The relative elemental abundances of Fe, Mg and Si are similar among the Sun, Earth, Mars, Moon and the meteorites (carbonaceous chondrites) [22,23].

It has been known that planetary bulk and stellar abundances of Mg/Si and Fe/Si are very similar during the planet formation [24,25] owing to that refractory elements Fe, Mg and Si condense in similar temperature ranges at distances of ~1 AU to the host stars [9]. At the same time, the observed wide variety in the key planet-building elements of stars shows that a diverse range of terrestrial planets may exist in the exoplanetary systems [24]. We therefore thought that it would be useful to compare the Mg/Si and Fe/Si abundances of the potential planet–harboring stars of our galactic neighborhood with the average solar occurrence of these key rock – forming elements.

O, Mg, Si and the Fe are the major mineral–forming elements and the variations of their abundances play a key role in the formation of the mineral assemblage of bulk silicate planets (BSP). The investigations of the abundances of rock–forming elements in the stellar photospheres are important steps for better understanding the mineralogy of the Solar System terrestrial planets and of the rocky exoplanets around other Solar–like stars. Accordingly, a comparison between the observable bulk Mg/Si and Fe/Si ratios in the neighboring planetary systems and the relevant Solar elemental ratios can help to answer that how typical our Solar System is.

1.1. The stellar Mg/Si and Fe/Si elemental ratios and the bulk mineralogy of planetary materials

Amongst the carbonaceous chondrite–groups, the elemental composition of CI – chondrites are closest to the Solar photospheric abundances (Table 1.).

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Table 1. The bulk molar Mg/Si and Fe/Si ratios of the Solar photosphere, CI and CV – type sub- groups of carbonaceous chondrites, Earth and Mars. (1. Asplund et al. [1].; 2. Alexander, C.M.O. [41].; 3. Wolf and Palme [50]; 4. Dauphas et al. 2015 [13]; 5. McDonough [2]; 6. Yoshizaki and McDonough [51].

Elemental ratio	Solar photosphere	CI-chondrites	CV-chondrites	Earth	Mars
Mg/Si	1.05[1]	1.05[1] ; 1.03[2]	1.077[3]	1.16[4]	0.99[4]
Fe/Si	0.87[1]	0.87[1] ; 0.87[2]	0.74[3]	1.00[5]	0.69[6]

However, the H, He, C, N, O and the noble gas abundances of CI – chondrites have been neglected [26]. The solid materials had been formed at different distances from the Sun. At the same time, the planetary building blocks, although having different condensation histories inside the system, could exhibit similarities in their elemental and isotopic compositions. Moreover, a large terrestrial planet will not retain the pristine chemistry of its chondritic building blocks owing to the transformation of materials, which could occur by the pressure, the temperature, the reaction with water and by magmatic fractionation [26]. The groups of carbonaceous and ordinary chondrites distinct from Earth's isotopic composition [27], while enstatite chondrites are isotopically identical to the Earth [28]. Interestingly, not known chondrite group, which satisfies the Earth's elemental and isotopic composition because it is likely that the Earth had been formed from a variety of different materials [27]. The resulted unique composition inside the terrestrial formation zone of the Solar System could substantially contribute to the chemical composition and the formation of habitability of the Earth.

Although, the chemistry of major rock–forming elements in the planetary bodies of the Solar System are poorly known, we have numerous good estimates for the element abundances of several type objects, by analyzing spectroscopically planetary materials and meteorite samples, which are fragments of asteroids. Many meteorite types are known to be derived from differentiated asteroids: iron–meteorites from the core material, stony – iron meteorites are from the fragments of the core–mantle boundary zone, while the basaltic meteorites are derived from the crust of the parent asteroids. Carbonaceous chondrite parent asteroids are thought to be accreted from rock and ice [29]. The variations of Mg/Si ratio are about 20 % within the most common groups of chondritic meteorites [30]. In general, the differences between bulk Mg/Si and Fe/Si ratios of the differentiated terrestrial–type planetary bodies in the Solar System are smaller than 20 percent in many cases.

It is very likely that, the chemically primitive chondritic materials have played a key role in planet formation during the early evolution of the System. Owing to the similarities with the bulk elemental composition of Earth, chondrites have generally been used in the research as important materials from which the Solar System terrestrial planets formed [27, 31,32]. In conclusion, the material of chondritic meteorites belonging to different meteorite groups in general can be considered as building blocks for terrestrial planets. Accordingly, it can be extrapolated to the consistency between the abundances of the key rocky planet–building elements in the terrestrial planetary building blocks and in the photospheres of the host stars. The metallicity and the abundances of key rock–forming elements varies in time and location of the Galaxy. In this manner, the formation efficiency, structure and composition of terrestrial–type planets depend on the time and place in the Galaxy and on the chemical conditions of the environment in which they form [33].

The relative abundances of several heavy elements and determined elemental ratios (C/O, Mg/Si and Fe/Si) in stars orbited by planets have great importances for controlling the internal structure and compositions of terrestrial planets [9,24,25]. The mantle mineralogy may have a crucial impact on the efficiency of mantle dynamics sustaining plate tectonics and long – time geological activity, which are important factors for the formation and maintenance of the planetary habitability as known on Earth. Therefore, the investigation of possible mineralogical composition of approximately Earth–mass rocky planets have a great relevance in the exploration of our galactic neighborhood and the search of potential life – hosting planets. The comparative analyses for planet– building element abundances between stellar samples and Solar abundances of the relevant elements may provide key information for better understanding the chemical evolution of Solar System. The Mg/Si and Fe/Si

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ratios are the most important elemental ratios for the formation of the internal structure of terrestrial planets [9].

1.1.1. The Mg/Si ratio

The most of the observed stars with known planets have C/O ratios lower than 0.8 [6,7], silicon presents mainly in silicates and the silicate mineralogy has been controlled by Mg/Si ratio. More than half of these relatively low–C/O stars have Mg/Si ratios between 1 and 2. In this case, silicates presented in olivine and pyroxenes in the condensation sequence produce terrestrial planets with bulk silicate composition being similar that of Earth. A significant fraction of planetary host stars exhibit relatively low Mg abundances compared to Si. If the Mg/Si ratio is lower than 1, the silicate composition of the forming rocky planets will be dominated by pyroxenes, olivine presents only in a small amount. As observed in F - , G –, and K–type stars, stellar Mg/Si ratios > 2 are very rare. The mantles of the high–Mg/Si planets are expected to be magnesium – rich, which are dominated by olivine and the excess Mg build in MgO.

1.1.2. The Fe/Si ratio

Fe is the one of the most important rock–forming elements. The core mass fraction of the differentiated planetary bodies strongly depends on the Fe/Si ratio of the planetary building blocks, whereby the Fe/Si ratio plays basic role in the formation of the internal structures of terrestrial planets. The final size of the metallic planetary cores is not only depending on the average Fe/Si ratio of the planetary systems and of initial planet–building materials but post–accretion processes and other conditions also affect the core formation. At the same time, the observed variations of Fe/Si in host stars implies that a wide variety of core mass fractions of terrestrial planets.

2. Methods

To analyze the characteristics of stellar element abundances in the Solar Galactic neighborhood, we use the Hypatia Catalog [34], which includes high precision data and a broad range of chemical elements. Precise elemental abundance analysis can be performed by using Hypatia Catalog to obtain excellent approaches from the exoplanet mineralogy. The abundance data of Mg, Si and Fe has been taken from the catalog by focusing on the photospheric composition of G–and F-spectral type main–sequence stars located in the Galactic thin disk inside 25 parsec distance from the Sun. The analyzed stars are in the metallicity range of $-0.9 < [Fe/H] < +0.5$ for G – stars and $-0.6 < [Fe/H] < +0.4$ for F – stars.

The elemental abundance data were taken from the Hypatia catalog as being solar normalized logarithmic values. All selected values are expressed in dex (decimal exponent) being related to the Solar abundances. The measured data for each elements have been collected from the catalog and we then computed the Mg/Si and Fe/Si ratios from the data set of 408 (G–stars) and 216 (F- stars) stellar abundances for Mg, Si and Fe elements. The Mg/Si ratios with the Fe/Si ratios can be calculated in 136 cases from the datasets for G–stars and in 72 cases for F-stars. The Mg/Si and Fe/Si ratios are expressed as molar ratios throughout this study. The resulting data of stellar Mg/Si ratios have been plotted against the Fe/Si ratios and the obtained abundance patterns of the nearby stars are being compared to that of the Sun (Figures 1a and b).

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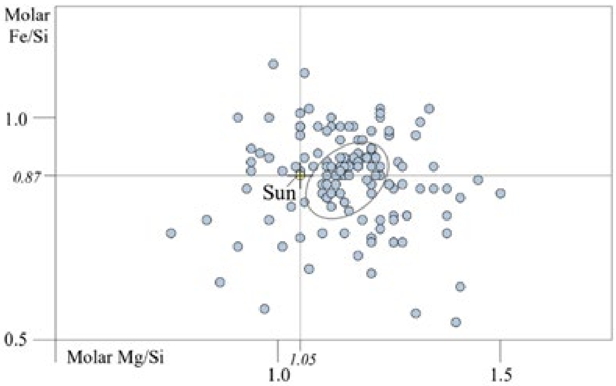
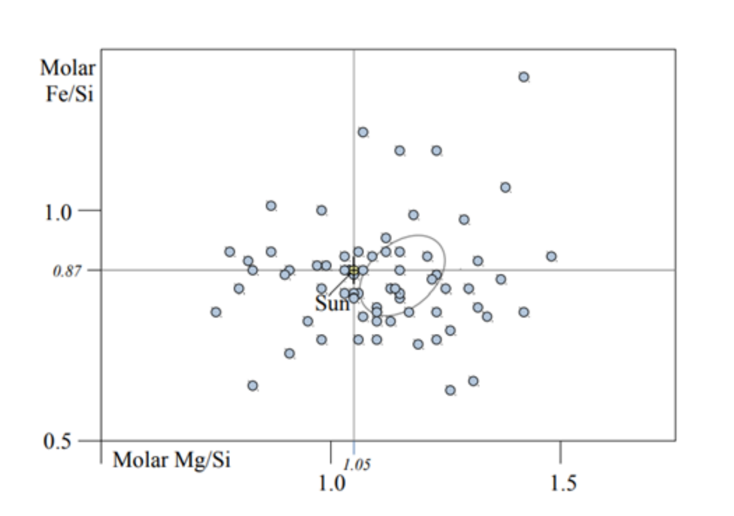


(a)



(b)

Figure 1. The Mg/Si ratios are shown as a function of the Fe/Si abundances for G-type stars (a) and F-type stars (b) in the Solar neighborhood. The corresponding data of the Sun are plotted in yellow for comparison. .

The interpretation of the observed abundances of Fe, Mg and Si and the calculated Mg/Si and Fe/Si planetary ratios provide useful information from the expected compositional diversity of the planetary systems and the plausible interior planet compositions in the Solar neighborhood.

The investigation of the abundances of key planet – building elements in exoplanetary systems play an essential role in better understanding their chemical compositions and evolutions. It is therefore very important to consider a narrow range of the related parameters to investigate the characteristic stellar chemical properties for the abundance analyses. For supporting the concept in this study, we first collect stellar, orbital and planetary parameters of exoplanetary systems based on the data that was selected from the NASA Exoplanet Archive [35] and the exoplanet.eu databases and the literature, respectively. Searching the most suitable exoplanetary systems for supporting our concept the characteristic parameters of the systems have been considered on the bases of the following criteria: gaseous planets with masses between 1–5 M Jupiter orbiting in multiplanetary systems around G–and F–type stars; the perihelion and the orbital inclinations of planets are within 0.5–10 AU and 0.2–20 grad, respectively.

Presence of the gaseous giant planets in the planetary systems has influence on abundances of chemical elements in the host star. It is also necessary to consider that rocky planets of exoplanetary systems with G-type host star but more massive than the Sun may have the specific peculiarities in Mg/Si and Fe/Si ratios. Most of chondrules in carbonaceous chondrites contain many kinds of minerals. They are dominated by olivine, pyroxenes and feldspars, but chondrules may also include

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metal alloys, sulfides in their mineral assemblages. Amongst the metallic phases kamacite (iron-nickel alloy), troilite (FeS) and pentlandite $(Fe, Ni)_9S_8$ can relatively be frequent in chondrules [45]. The bulk elemental compositions carbonaceous chondrites (CI, CV) are largely similar to the Solar and the average Solar System abundances. In order to comparison of the average Solar system abundances and the stellar abundances of the examined elements, the variability of the Mg, Si and Fe abundances of chondritic meteorites are also considered.

3. Results

4.1. Stellar, orbital and planetary parameters of several exoplanetary systems

We have found that a small fraction of the known planetary systems around F-and G-stars can be suitable for our examinations. The set of the relevant parameters collected from databases and the literature includes the parameters of three planet–hosts and four planets and are available in Table 2.

Table 2. Stellar, planetary and system parameters for the selected multiplanet – systems. References: A. NASA Exoplanet Archive [35], B. The Extrasolar Planets Encyclopaedia [52], 1. Wright et al. [49]; 2. Stassun et al. [48]; 3. Deitrich et al. [43]; 4. Stassun et al. [47]; 5. Simpson et al. [46]; 6. Borgniet et al. [42]; 7. Laskar and Correia [36]; 8. Desort et al. [44].

Planet name	ups And c	HD 92788 b	HD 60532 b	HD 60532 c
Number of planets	3[A]	2[A]	2[A]	2[A]
Orbital period (days)	241.33[1]	325.81[4]	201.9[6]	600.1[6]
Orbit Semi-Major Axis /au)	0.832[1]	0.95[4]	0.77[6]	1.60[6]
Planet mass (M_J)	1.92[1]	3.71[4]	1.06[6]	2.51[6]
Eccentricity	0.224[1]	0.33[4]	0.26[6]	0.33[6]
Ra (star)	1h36m47.60s[2]	10h42m48.51s[2]	07h34m03.14s[2]	07h34m03.14s[2]
Dec (star)	+42d24m13.73s[2]	-02d11m04.98s[2]	-22d17m45.12s[2]	-22d17m45.12s[2]
Distance (pc)	13.40[2]	34.6538[2]	25.9716[2]	25.9716[2]
Ecliptic latitude (deg)	28.979[2]	9.57491[2]	-43.27986[2]	120.46676[2]
Ecliptic longitude (deg)	38.54864[2]	163.0288[2]	-43.27986[2]	120.46676[2]
Spectral type (star)	F8V[B]	G5[B]	F6IV-V[B]	F6IV-V[B]
Orbital inclination	11.347[3]	8.0[5]	20[7]	20[7]
Stellar luminosity (log Solar)	0.5254[1]			

Among the three host stars, the F–type star HD 60532 is known to host two super – Jupiter with masses Mb= 1.06 MJup and Mc=2.51 MJup. This system with two planetary companions has been confirmed in a 3:1 mean-motion resonance [36]. The semi - major axes of the planets (0.77, 1.60 au), the minimum masses (1.06, 2.51 MJup), the eccentricities (0.26, 0.33) and the orbital inclinations of the two planets (20 deg) make the HD 60532 multiplanetary – system the most suitable system to study chemical abundances for supporting our conception. The profound examination of HD 60532 system could provide useful information from the Mg, Fe and Si abundances in a characteristic planetary system, and therefore potentially from the heavy element content in planetary cores and the bulk mineralogy of the mantles of hypothetical terrestrial – like planetary objects. We have thought that it would be useful to observe spectroscopically HD 60532 in IR range of wavelengths ~ 1 - 8 μm.

3.2. The observed stellar Mg, Fe and Si abundances of G and F-type stars in the Solar neighborhood.

We have found that the relative stellar abundances of Mg, Fe and Si in the nearby G – stars are similar to the solar abundances of these elements. At the same time, we have also shown that the Sun has a slightly different Mg/Si abundances relative to most analyzed stars. The abundance statistic implies that the solar abundance pattern of key rock–forming elements cannot likely be too frequent among the relevant abundance patterns of middle–aged thin disk Sun – like stars. It indicates for us

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that the Sun is not a typical main–sequence G–star for the Mg/Si abundance, while it may moderately be common for the Fe/Si abundance among the similar type stars.

If the bulk Mg/Si ratio of the BSP is lower than 1, the upper mantle is depleted in olivine and it is dominated by pyroxenes. The lower mantle of Mg – depleted planets are dominated by $Mg(Fe)SiO_3$. The Mg/Si ratio is between 1 and 2 in planets, which are similar to Earth, resulting in planetary mantles composed of both olivine and pyroxenes. The lower mantle in rocky planets is rich in $Mg(Fe)SiO_3$ and Mg(Fe)O, too. For bulk Mg/Si of the BSP higher than 2, rocky planets have olivine upper mantles and Mg(Fe)O – rich lower mantles.

We explore that the core mass fraction could exhibit a wide distribution in the exoplanetary interiors. In the most cases, the mantle mineralogy is compositionally similar to that of the Solar system terrestrial planets. The silicate mantle of a major fraction of the rocky planets builds up from bridgmanite/periclase lower mantle and pyroxene/forsterite upper mantle with a varying amount of these dominant mineral phases.

The results show that the averaged Solar System Fe abundance is higher than the most examined stellar Fe abundances. In conclusion, the mantles of Solar system terrestrial planets, depending on the planetary formation and differentiation, may be highly enriched in Fe than the most rocky exoplanets around the near G- and F- stars. The Fe content is ~ 10 mol % for the bulk composition of the Earth's mantle [22]. The Fe content in the mantle could affect in a great extent the crystal structure and thermodynamic properties of some mantle materials. The most abundant silicate phases in the Earth' lower mantle (pv and ppv) are not consist of pure $MgSiO_3$, but contains Fe and Al as major substituents for Mg and Si (Caracas, 2010) [37]. FeO is an important endmember of (Mg, Fe)O (ferropericlase, fp) in the Earth's lower mantle [38]. The Fe content influences the stability and thermodynamic properties of ferropericlase, hence, the variations of Fe content in the lower mantle minerals could change the geochemical and geodynamical processes in the deep interior of low-mass rocky planets and rocky super–Earths.

In addition, the Fe substitution affect the thermodynamic properties of pv, ppv and fp having a significant role in the geodynamic and thermochemical processes at the base of the mantle, in the so–called D" layer. This layer is thought to be a special thermal and thermochemical boundary layer, thus it may have a great importance for the mantle dynamics of Earth. Consequently, the higher Fe content of the relevant mantle–building minerals, playing a non–negligible role in the dynamical evolution of the Earth's mantle, could contribute to the mineralogical diversity, evolutionary history and life–hosting potential of the Earth. The potential rocky planets of a small fraction of the studied stars may have BSP compositions with Mg, Si and Fe abundances that approaches to that of the BSE. The Mg/Si and Fe/Si values have been plotted for the full 136–G - star sample and for 72 – F - star sample are shown in Figures 1 a and b, respectively.

The relative abundances of examined chemical elements of many G-type stars in the Solar Galactitc Neighborhood approximate to the average abundances in the Solar System. The calculated Mg/Si molar ratio varies in the sample between 0.76–1.50, the Fe/Si molar ratio varies ranging from 0.54–1.12, which are shown in Figure 1a. We find that a significant number of nearby stars have Mg, Fe and Si abundances are inside the range of 1.08–1.25 for Mg/Si and 0.80–0.95 for Fe/Si values. Five stars are found to have Fe/Si values greater than 1 and 17 Fe/Si values smaller than 0.75. The Mg/Si molar ratios of F-stars have been calculated in the sample between 0.75–1.48, the Fe/Si molar ratio varies ranging from 0.61–1.29, which are shown in Figure 1b. The molar Mg/Si and Fe/Si values of F-stars do not exhibit concentrated distributions. We found that roughly a 25 percent of the nearby F – stars have Mg/Si values similar to that of the Sun, while the 30 percent of the Fe/Si values belong to the range of 0.80–090.

The distributions show that rocky planets with slightly higher Mg–abundances than the Sun can be much more common in this sector of the Galaxy than Mg–depleted terrestrial planets. The results implies that the number of rocky planets with bulk Mg/Si higher than 1 is one order of magnitude larger than that of the Mg–depleted planets with Mg/Si values lower than 1. It has also been highlighted that more than half of the rocky planets around G-stars in the Solar neighborhood may have medium–sized metallic core. As known, the Mg/Si ratio gradually increases in the interstellar

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medium toward the galactic center. At the same time, the Mg/Si ratio in the interstellar medium decreases toward the rims of the galactic disk. The obtained distribution implies that the major fraction of the exo-terrestrial planets around nearby stars are Mg–enriched in their bulk compositions relative to that of Earth and they have an intermediate-size of their metallic cores. A similar range of planetary compositions are being predicted to exist in the galactic thin disk at the Solar galactocentric distances.

The Fe/Si ratios of many stars are similar to the corresponding element abundances of the Solar photosphere and CI chondrites, while the Mg/Si ratios of the most stars are higher than the average Solar Mg/Si value. We conclude that in case of this major fraction the analyzed G–type stars, the variation of Mg/Si ratio is positively correlated with the variation of Fe/Si ratio. Several stars amongst them have been found to have higher Mg/Si and Fe/Si ratios than the Sun. If they host planets, the observed elemental abundances may refer to that the planet forming materials within these systems will be Mg- and Fe–enriched compared to that of the planet–building blocks in Solar system. Consequently, a significant fraction of the high–Mg/Si – Fe/Si terrestrial exoplanets are likely to have relatively large core mass fraction. They will contain large amounts of Mg– rich phases in their upper mantles (olivine) and lower mantles (magnesiowustite). Most of the magnesium–rich rocky planets around G–stars may have mantle mineralogy being enriched in Fe–rich mineral phases. More rocky planets in high Fe/Si planetary systems are assumed to have core–dominated interior with the large relatively large - sized metallic core, which may have been overlaid by a relatively thin silicate mantle.

Some rocky exoplanets may be olivine-depleted in their upper mantle and magnesiowüstite-depleted in their lower mantle compared to Earth. Our results indicate that the Mg–poor mantle mineralogies may relatively be rare in the thin disc at the galactocentric distance of the Sun. 20 stars in the sample have lower Mg/Si ratio than the Solar value. This indicates that their potential rocky planets need to have mantles, which are more depleted in magnesium than terrestrial planets in the Solar System. Accordingly, the Mg–poor planetary upper mantles will contain larger amounts of pyroxenes and different kinds of garnets than Earth depending on their chemical differentiation and the bulk planet Mg/Si, Fe/Si, Ca/Si and Na/Si, respectively.

The distribution of Fe/Si ratio values in the analyzed pattern show that the iron – to silicon ratio in the most solar–metallicity stars are relatively homogeneous to within - 10 and 10 %. It may imply that if they have rocky planets with masses ranging from ~ 1 Earth mass or larger, a significant fraction of them may have medium – sized metallic cores. Putirka and Su [39] suggest that some rocky exoplanets are similar to Earth with respect to the crustal mineralogy, but the most of them are exotic in composition and mineralogy in the Solar neighborhood. By analyzing the obtained abundance distribution, we thought that Earth is unique in bulk mineralogy in the rocky planet population of our galactic neighborhood.

4.3 The effect of the variation of the observed Mg, Si and Fe abundances on the bulk mineralogy of rocky planets.

The Mg/Si and Fe/Si are the most important elemental ratios for determining planetary compositions and structures of low- C/O (C/O < 0.8) rocky planets. As shown in Figure 1a, a major fraction of the G – stars, centered at Mg/Si range of 1.08–1.25 have higher Mg/Si ratios than Solar, while their Fe/Si values resemble to the solar photospheric Fe/Si value. It means that many terrestrial exoplanets, consisting of Mg-rich silicates and having similar Fe abundances in bulk to that of inner Solar System planets, may be different in bulk silicate composition from Earth. The obtained distributions of Mg/Si and Fe/Si ratios indicate that the most of G–type stars may host terrestrial planets that are not compositionally identical to Earth. Characterized by approximate Mg/Si and Fe/Si ratios, Mg, Fe and Si abundances of two G–stars are only similar to that of the Sun. In the sample of F–stars, 2 stars only have Mg/Si and Fe/Si abundances, which are very similar to the Solar values. The calculated distribution of the elemental ratios implies that the bulk mineralogical compositions identical to Earth are likely to be rare.

The skiagite $Fe_3^{2+}Fe_2^{3+}(SiO_4)_3$ can also be an important end–member of the garnets in the Earth's upper mantle and transition zone [40]. Obviously, the amount of the skiagite component in mantle garnets depends on the bulk Mg/Si, Fe/Si, Al/Si and Ca/Si ratio. The characteristic elemental composition changes along the $Fe_3Al_2(SiO_4)_3$ – $Fe_3Fe_2(SiO_4)_3$ (almandineskiagite) solid solution and in the Ca–bearing garnets along the $Ca_3Fe_2(SiO_4)_3$–$Fe_3Fe_2(SiO_4)_3$ (andradite-skiagite). Knowing the distribution of stellar Mg/Si and Fe/Si values for both G– and F–type stars, we suggest that the skiagite–majorite garnets can relatively be common in the upper mantles of a significant population of terrestrial planets in the solar neighborhood.

The mineral composition of pyroxenes may also varies depending on the Mg/Si and the Fe/Si ratio. Accordingly, the variation of the Fe/Si ratio is an essential factor for the olivine, the pyroxene and the garnet geochemistry of the rocky exoplanetary mantles. The variation of Mg, Fe and Si abundances in the stars and the distribution of the examined stellar Mg/Si and Fe /Si ratios indicates that the potential rocky planets are thought to have a slightly different major element chemistry in their mantles resulting in a mineralogical diversity of the terrestrial planet population in the Solar neighborhood.

The abundances of major elements O, Fe, Mg and Si can provide important information on the formation conditions of the mineral constituents of chondrites and on the formation processes of the parent bodies. The relative ratios of these major elements in forming planetary systems effect on the composition of the mineral assemblages of chondritic materials. The variations of elemental abundances result in relatively large differences in the bulk chemical and mineral composition of chondrites and in the building materials of rocky planetary bodies.

The distribution of stellar Mg/Si abundances show that the bulk mineralogical composition of the planetary bodies (large terrestrial planets, differentiated asteroids) in most of the potential planetary systems are thought to relatively be Mg–rich ones.

4. Discussion

In the last few years, several studies show that the C/O ratio in the most planet host stars is below 0.8 resulting in that the silicon content of terrestrial planet–building materials can be present in silicates [6,7]. In the possible planets of these stars, the Mg/Si ratio controls the silicate mineralogy. Since there is a direct relation between the host star and the planet abundances for Mg/Si ratio, we can infer the major characteristics of bulk planetary compositions. Most of the G–stars (82 %) have Mg/Si higher than the Solar value. 25 % of the F – stars have Mg/Si values similar to that of the Sun. For Fe/Si ratio of G – type stars, 84 % of the examined stars have iron– to- silicon ratio ranging from 0.75 – 1. The 30 % of the F – stars have Fe/Si values ranging from 0.80 – 0.90.

It is likely that the results and conclusion concerning the statistically examined distribution of Mg/Si and Fe/Si abundances in the solar neighborhood can be extrapolated to the thin disk population of more distant exoplanet host stars in the Solar galactocentric distances. Terrestrial exoplanets with Mg–rich bulk chemical compositions relative to Earth can also be expected in the more distant thin disc stellar populations. According to the obtained abundance distribution of the elements Mg, Si and Fe, we suggest that the most rocky planets in the Galactic thin disk can be different in the mantle mineral composition from Earth, while our planet may be common for the bulk planetary Fe/Si values and many terrestrial planets may have medium - sized metallic core.

The varying abundances of major rock–forming elements O, Si, Mg, Fe, Al, and Ca can yield a wide range of compositions for the bulk silicate planets (BSP). A small fraction of the examined G– and F-stars have Mg/Si abundances higher than Solar but they have Fe/Si abundances lower than the Solar averaged value. As opposed it, another small fraction of G– and F–stars can be characterized by Mg/Si abundances lower than that of the Sun, while their calculated Fe/Si ratios are higher than the Solar. The obtained distributions of the examined element abundances show that the number of high–Mg/Si stars are higher than that of those stars, which are characterized by lower Mg/Si values than the Sun.

Note that, the bulk chemistry and the detailed mineralogical composition of an Earth–mass rocky planet orbiting a Sun–like star in another planetary system and have formed at one astronomical unit may strongly differ from the bulk mineral composition of Earth. At the same time,

 doi:10.20944/preprints202406.0332.v1

the obtained Mg/Si abundances imply on that the significant fraction of the rocky planets have different bulk composition to the Solar system terrestrial planets.

5. Conclusions

The rocky planets characterized by olivine – dominated upper mantles and $MgSiO_3$–perovskite (pv) (and ppv)-dominated lower mantles with higher MgO amount may be the most abundant mineralogical types of rocky planets at similar galactocentric distances than that of the Solar System. The observed Fe/Si abundances could imply on that the most of these rocky planets may have medium–sized metallic cores or smaller core mass fractions than that of Earth. In summary, we thought that the Solar System is not typical amongst the neighboring planetary systems owing to the relatively low Solar Mg/Si abundance related to the medium abundance of Solar Fe/Si ratio. It is likely that the planetary accretion and differentiation, the events of the early history and the mineral composition also contributed to the special evolutionary history of Earth, which had been led to the formation of a habitable planet. In the future, many models can try to explain that the key planet – building element abundances plays an essential role in the chemical evolution and the possibly unique mineralogy, which contribute primarily to the life–hosting potential and habitability of Earth.

Author Contributions: Conceptualization, P.F. and A.G.; methodology, P.F.; validation, P.F..; data curation, P.F..; writing—original draft preparation, P.F., A.G. and I.S.; project administration, A.G. and Gy. K..; All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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