Highlights on Spanish Astrophysics IX, Proceedings of the XII Scientific Meeting of the Spanish Astronomical Society held on July 18 – 22, 2016, in Bilbao, Spain. S. Arribas, A. Alonso-Herrero, F. Figueras, C. Hernández-Monteagudo, A. Sánchez-Lavega, S. Pérez-Hoyos (eds.)

C/O vs Mg/Si ratios in solar-type stars: The HARPS sample.

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Abstract

The determination of the chemical composition of extrasolar planets has been the subject of numerous studies in the last years. While the composition of the atmosphere of planets can be observed through, e.g., the absorption of the star light, the composition of the solids remains difficult to estimate. As both planetesimals and planets are formed in the same environment, their composition is expected to be the same as their host star. Elemental ratios are important as they govern the distribution and formation of chemical species in the protoplanetary disc: the C/O ratio controls the amount of carbides and silicates that can be formed while Mg/Si gives information about the silicate mineralogy. Silicates are an important ingredient in the formation of rocky planets, as they are the most abundant component of the mantle and crust of these planets. We present a uniform study of C/O and Mg/Si element abundance ratios for 101 stars with detected planets and 430 stars without detected planets obtained using high resolution spectra from the HARPS sample. We will discuss the implications of these ratios on the nature of planets that could have been formed in those planetary systems.

1 Introduction

The determination of the chemical composition of extrasolar planets has been the subject of numerous studies in the last years. One of the keystone has been the fact that planet hosts stars are considered metal-rich when compared with single stars [19, 20, 9, 10, 6]

As both planetesimals and planets are formed within the same environment, their composition is expected to be the same as their host star. This assumption might be true for refractory species, but not for the volatile ones [13, 28]. Although this fact does not affect the Mg/Si ratio for rocky planets, it can affect the C/O ratio [29]. Variations of C/O ratios can also be found between planetary atmospheres and their hosts star [14, 11, 17] and between planets in the same planetary system. This is due to different parameters (temperature, pressure, etc.) and processes during the planet formation stage, including possible migrations from its birthplace [18, 2, 14, 30, 29] Testing and improving planetary formation models is the key in future studies of habitability, as these ratios are key elements to define the structure of the planet. In this work we present a complete study of C/O and Mg/Si ratios in solar-type stars and their implications on possible terrestrial planetary formation.

2 Sample description

High-resolution spectra analysed in this work were obtained with the HARPS spectrograph installed in La Silla (La Silla Observatory, ESO, Chile) during the HARPS GTO program (see [15, 12, 21] for more information). The spectra have been already used previously in the analysis of stellar parameters as well as derivation of precise chemical abundances (e.g.[24, 25, 1, 31, 3, 27]).

The sample consist of 531 FGK solar-type stars with effective temperatures between 5250K and 7212K, metallicities from −1.10 to 0.55 dex and surface gravities from 3.81 to 4.82 dex. 101 out of 531 are planet hosts [1] while the other 430 are single stars or comparison stars (stars without any known planetary companion)

3 Stellar parameters and chemical abundances

The stellar parameters used in this study were taken from [23, 24, 25] and [31] using the same spectra as we did for this study. All the stellar parameters were derived by measuring equivalent widths of FeI and FeII lines using the ARES and ARES2 code [22, 26].

Chemical abundances of carbon were taken from [27]. Oxygen abundances from [3] and magnesium and silicon from [1]

4 Elemental ratios

Elemental ratios were calculated using the following equation:

$$A/B = N_A/N_B = 10^{log\epsilon(A)}/10^{log\epsilon(B)} \quad (1)$$

where $\log\epsilon(A)$ and $\log\epsilon(B)$ are absolute abundances. Errors where estimated by evaluating an increase or decrease in the $log\epsilon(A) - log\epsilon(B)$ abundance ratio, due to the relative error (For more details, see [8]).

[1]Data from www.exoplanet.eu

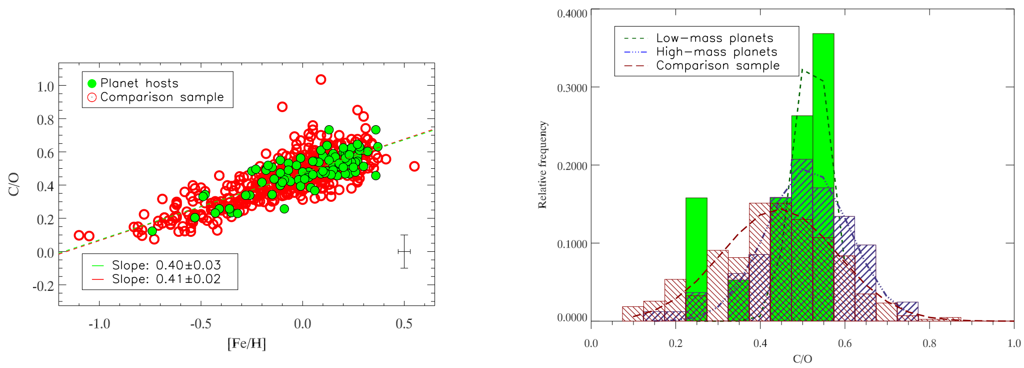

Figure 1: C/O versus [Fe/H]. Red open circles refer to single stars while green dots refer to planet host stars.

4.1 C/O

The carbon-to-oxygen ratio (C/O) in planet-host stars might provide key information about the protoplanetary disk where the planet was formed. This assumption is true for refractory species, as their high condensation temperature places their condensation line closer to the star [13, 28], as opposed to volatile elements. This dependence on the distance for volatile elements will affect the C/O ratios expected in the exoplanetary atmospheres, as volatiles are heavily affected by different distances (or different ice line position) during the early lifetime of the nebula while planets accrete [18, 2].

Fig. 1 shows the C/O ratios derived in this paper as a function of [Fe/H], for both samples, stars with and without planets. We obtain a linear fit for both samples, with very little differences between them. We can see a dependence of C/O with the metallicity, due to massive stars.

If we take a closer look to the C/O distribution for these samples in Fig. 1 we can see that they almost exhibit the same behaviour, with an small offset of 0.1 dex. In our sample, $\sim$ 98% of stars with planets have C/O values lower than 0.8. The other $\sim$ 2% have C/O values below 0.8.

4.2 Mg/Si

Magnesium and silicon elemental ratio, Mg/Si, control the exact composition of silicates that can be found in the planetary companion, as this ratio, along with Fe/Si, does not depend so strongly on the distance to the star as the C/O ratio does [30, 29]. Silicates are key compounds in rocky planets, as they are the main component of the mantle and crust [16]. The distribution of silicates is ruled by the Mg/Si elemental ratio of the host star. Depending on the value of this elemental ratio, several compounds can be formed:

In Fig. 2 left panel we show Mg/Si ratios as a function of T_{eff}. We find a relation

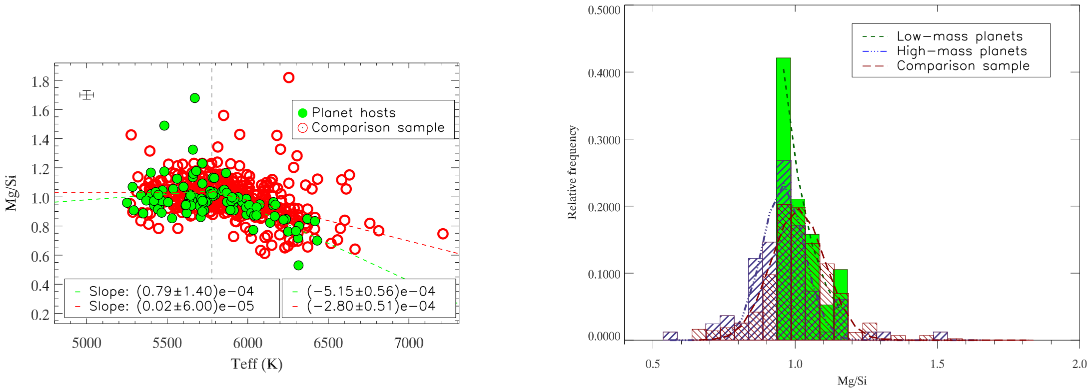

Figure 2: Mg/Si ratios as a function of T_{eff} (left panel). Green dots stand for planet host stars while red open circle refer to single stars.

between Mg/Si ratios and T_{eff}, as while trend slopes rise for effective temperatures lower than the Sun, at $T_{eff} \sim 5777K$, this behaviour changes and the slopes of these trends decrease.

5 C/O vs Mg/Si ratios: Implications on planet formation

We studied C/O ratios as a function of Mg/Si ratios as a way to study the possible scenario for the formation of planets.

The amount of carbides and silicates formed in planets is controlled by the C/O ratio (see, for example, [4])

- if C/O < 0.8: Si will form solid SiO_4^{4-} and SiO_2, forming mostly Mg silicates. This exact composition will be determined by the Mg/Si value
- if C/O > 0.8: Si will be solid as SiC. Also, graphite and TiC will be formed.

Silicates distribution is ruled by the Mg/Si ratio of the planet hosts star, as proposed by [8]. Attending the Mg/Si ratio, the principal components can be:

- if Mg/Si < 1: Mg forms orthopyroxene ($MgSiO_3$) and the remaining Si forms other minerals like feldspars ($CaAl_2Si_2O_8$, $NaAlSiO_8$) or olivine(Mg_2SiO_4)
- if $1 <$ Mg/Si < 2: Mg is distributed equally between pyroxene and olivine.
- if Mg/Si > 2: Si forms olivine and the rest of the Mg forms other oxides like MgO.

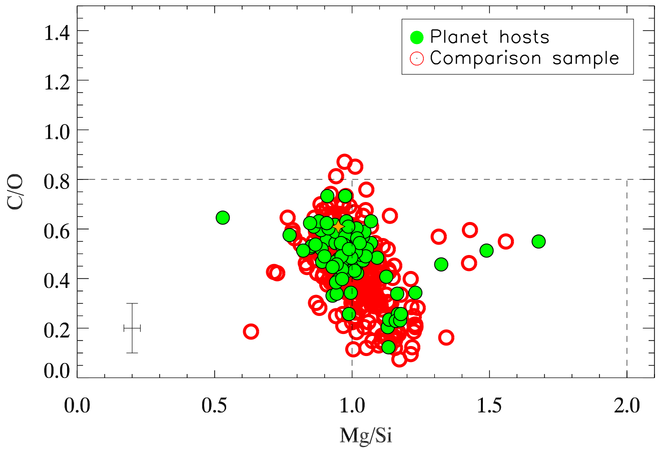

Figure 3: Top panel: C/O vs. Mg/Si for stars with 5200K ¡ T_{eff} ¡ 6100K. Red circle refer to single stars while green dots refer to stars harbouring planets.

In Fig. 3 we can see how stars with and without planets distribute in a C/O against Mg/Si plot. As it can be seen, stars with planets are concentrated at C/O values of 0.55 and Mg/Si of $\sim$ 1.0. 32% stars within our planetary sample have a Mg/Si value between 1.0 and 2.0, which means that Mg is equally distributed between pyroxene and olivine. We also find 68% of planet hosts with Mg/Si values below 1.0, so Mg will only be found in orthopyroxene form while Si will form several forms like feldspars or olivine. No stars with Mg/Si values greater than 2.0 were found.

Regarding C/O, 100% of stars with planets have C/O values lower than 0.8, meaning that Si will appear solid as SiO_4^{4-} and SiO_2. The exact composition will be ruled by the Mg/Si ratio.

Acknowledgments

JIGH acknowledges financial support from the Spanish Ministry of Economy and Competitiveness (MINECO) under the 2013 Ramón y Cajal program MINECO RYC-2013-14875, and the Spanish ministry project MINECO AYA2014-56359-P.

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