Highlights of Spanish Astrophysics VI, Proceedings of the IX Scientific Meeting of the Spanish Astronomical Society held on September 13 - 17, 2010, in Madrid, Spain. M. R. Zapatero Osorio et al. (eds.)

Detailed chemical abundances of solar analogs with and without planets: no terrestial planet connection

J. I. González Hernández[1,2], G. Israelian[1], N. C. Santos[3,4], S. Sousa[3], E. Delgado-Mena[1], V. Neves[3], and S. Udry[5]

[1] Instituto de Astrofísica de Canarias, C/ Via Láctea s/n, 38200 La Laguna, Spain
[2] Dpto. de Astrofísica y Ciencias de la Atmósfera, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, E-28040 Madrid, Spain
[3] Centro de Astrofísica, Universidade do Porto, Rua das Estrelas, 4150-762 Porto, Portugal
[4] Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Portugal
[5] Observatoire Astronomique de l'Université de Genève, 51 Ch. des Maillettes, -Sauverny-Ch1290, Versoix, Switzerland

Abstract

We present the detailed chemical abundance patterns of 95 solar analogs, 24 hosting planets and 71 without detected planets, using very high-quality HARPS and UVES spectra. We explore the possibility that the presence of terrestial planets could affect the volatile-to-refratory abundance ratios. We do not see any clear difference between the stars with and without planets, either in solar twins or in the whole sample of solar analogs. We also select a sub-sample of 28 solar analogs, 14 with and 14 without planets, in the metallicity range $0.14 < [Fe/H] < 0.36$ and find the same abundance pattern for both star with and without planets. In particular, two of the planetary systems, which contain each of them a Super-Earth like planet, show abundance patterns not consistent with the presence of terrestial planets. We demonstrate that the Galactic chemical evolution effects are probably responsible for any possible difference in mean abundances of refratory and volatile elements in these solar analogs with respect to the solar values.

1 Introduction

The discovery of first exoplanet orbiting a solar-type star by [4] initiated a new and very attractive field in which the number of studies is continuously increasing. So far, more than 400 exoplanets orbiting solar-type stars has been detected and/or confirmed by the radial velocity technique which have provided a substantial sample of high-quality spectroscopic data. In particular, the HARPS GTO planet search program contains so far about 450 stars in the metal-rich domain (see e.g., [6].

[9, 1] firstly studied the abundance patterns and, specially, correlations between the abundance ratio [X/H] as a function of the condensation temperature, T_{C}. They found some indication but no significant difference between stars with and without planets. More recently, [5] have analized a sample of 11 solar twins. By performing a fully line-by-line differential analysis, they obtained a clear trend [X/Fe] versus T_{C}, and stated that the most likely explanation to this abundance pattern is related to the presence of terrestial planets in the solar planetary system. Later on, [7, 8] claimed to have confirmed this result although using lower quality data.

Here we present an accurate chemical abundance study using very high-quality spectroscopic data of a relatively large sample of 95 solar analogs with and without planets, and we examine the element abundance ratios [X/Fe] reported in [7].

2 Observations, stellar parameters and chemical abundances

Spectroscopic observations of the 95 solar analogs with and without planets were carried out with the HARPS/3.6 m, UVES/VLT and UES/WHT spectrographs, covering the spectral range $\lambda\lambda$4500–6800 Å at resolving power $\lambda/\delta\lambda \sim$110,000, 85,000 and 33,000, respectively.

Most of the stars were observed using HARPS and only ten of the whole sample of 95 solar analogs were observed using UVES and two of these using UES. These very high-quality data have on average a S/N ratio of roughly 850.

The stellar parameters and metallicities of the whole sample of stars were computed using the method described in [12], based on the equivalent widths (EWs) of 263 FeI and 36 FeII lines, measured with the code ARES [11] and evaluating the excitation and ionization equilibria. The chemical abundance derived for each spectral line was computed using the 2002 version of the LTE code MOOG [10], and a grid of Kurucz ATLAS9 plane-parallel model atmospheres [3].

We determine the mean abundance of each element relative to its solar abundance by computing the line-by-line mean difference. Our fully differential analysis is, at least, internally consistent. We use the HARPS spectrum of Ganymede, a Jupiter's satellite, as solar reference, which has a S/N $\sim$ 400.

3 Discussions and conclusions

3.1 Solar twins

We examined the whole sample of HARPS targets trying to search for solar twins defined in the same way as in [5] and we found 2 planet host and 5 "single" stars. In Fig. 1 we display the mean abundance difference, $\Delta[\mathrm{X/Fe}]_{\mathrm{SUN-STARS}}$, versus the condensation temperature, T_{C}, using the Ganymede spectrum as solar reference. We may refer to the Fig. 4 in [2] as a

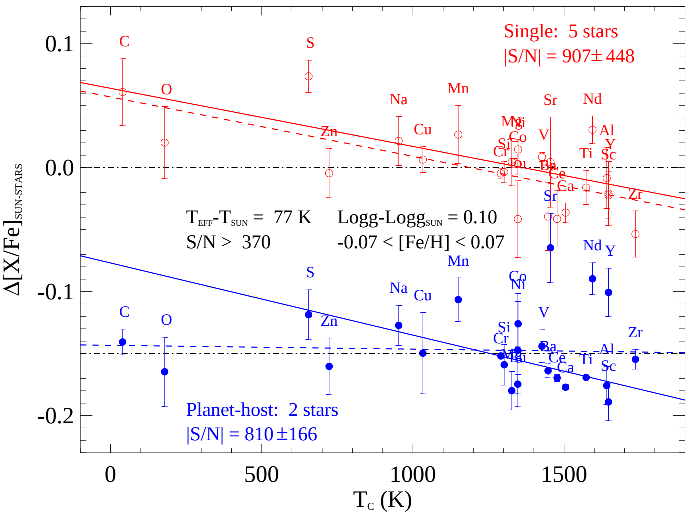

Figure 1: Mean abundance differences, Δ[X/Fe]$_{\mathrm{SUN-STARS}}$, between the Sun, and 2 planet hosts (filled circles) and 5 "single" stars (open circles). Error bars are the standard deviation from the mean divided by the square root of the number of stars. Linear fits to the data points weighted with the error bars are also displayed for planet hosts (blue solid line) and "single" stars (red solid line). Dashed lines are the linear fits using equal weights for all data points. An arbitrary shift of -0.15 dex has been applied to the abundances of the planet-host stars, for the sake of clarity.

different version of this figure. Although the error bars are relatively large to search for any clear trend, it seems that the mean abundance ratios of refractories are on average smaller than those of volatiles. We also depict linear fits to the data points weighted by their error bars. These fits show the decreasing trend of the mean abundance ratios with condensation temperature already reported in [5] but the trend is not so clear. We note here that the S/N is greater than 500 for all stars in this figure, except one "single" star with a S/N $\sim$ 370.

Due to the low significance of the small number of solar twins in this sample, in Fig. 1 we also show linear fits with equal weights for all data points. The slopes of these fits only change significantly in the case of the abundance ratios of the two stars hosting planets, probably due to the small error bars in the abundance ratios of elements like Ca and Ti. The small number of stars, especially for planet hosts, and the high scatter of the data points around the linear fits prevent us from making any strong statement on implications of these differences. In Figs. 5 and 6 of [2] we demonstrate that the results presented here and those in [5] are consistent within our error bars.

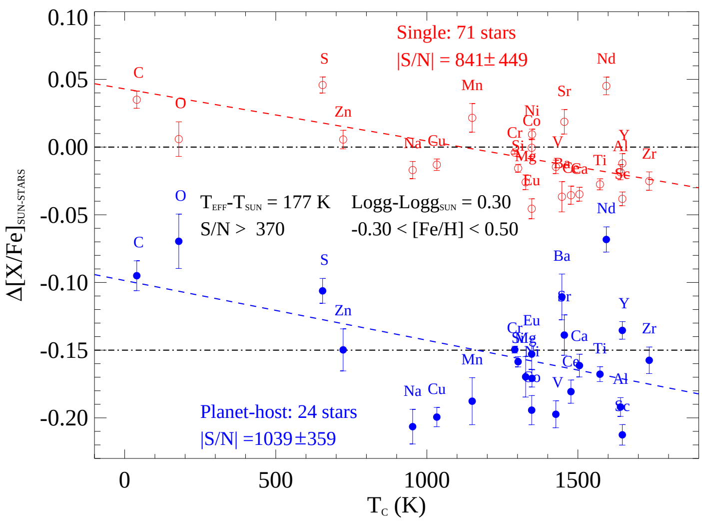

Figure 2: Same as Fig. 1 but for the 24 planet-host stars and 71 "single" stars of the whole sample of solar analogs. Only linear fits weighted with the error bars are shown.

3.2 Solar analogs

The mean abundance $\Delta[\mathrm{X/Fe}]_{\mathrm{SUN-STARS}}$ versus T_{C} of the whole sample of solar analogs, containing 24 planet hosts and 71 stars without known planets, are displayed in Fig. 2. Both stars with and without planets show the decreasing trend towards increasing values of T_{C}, even if the data points are not placed at the same positions. However, the dispersion of the data points around the linear fits is very high and probably related to Galactic chemical evolution effects, as already stated in [2].

3.3 Metal-rich solar analogs

To evaluate the abundance trends with the same number of planet hosts and "single" stars, we studied a super-solar metallicity sample of solar analogs. The position of some elements in Fig. 3 is certainly affected by chemical evolution effects due to the high metal content of the sample, specially, Mn and O. This may explain the higher scatter of the points in this plot with respect to the linear fits. However, what is relevant from this plot is that both samples of stars with and without planets show almost exactly the same abundance pattern. In addition, the linear fits have almost exactly the same slope which agrees with the previous statement.

In Fig. 4, we depict the abundance ratios of the metal-rich sample of solar analogs but after correcting each element abundance ratio for the corresponding Galactic chemical evolution trend, assumed to be that defined as a linear fit to the "single" stars' abundances

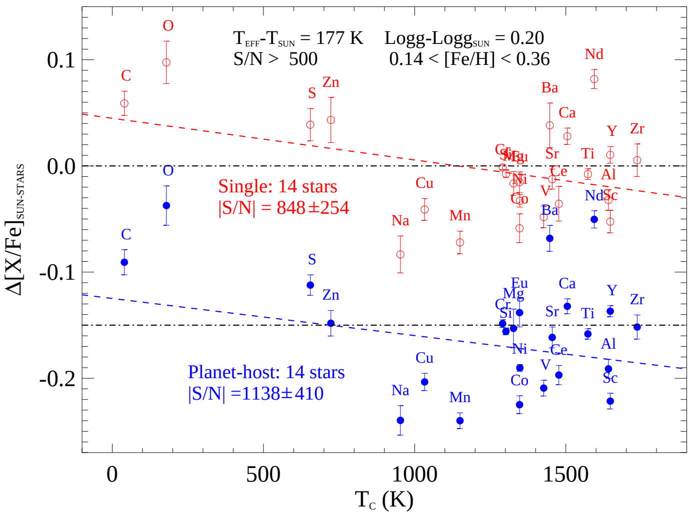

Figure 3: Same as Fig. 2 but for the metal-rich sample of solar analogs.

(see Fig. 3 in [2]).

We have determined the slopes of all solar analogs of our sample with and without known planets (see Fig. 11 in [2]). Although the number of planet hosts is smaller than "single" stars, the peak of the distribution of the slopes of these two samples is centered around the same position. This indicates that stars with already detected planets behave in similar way, with respect to the chemical abundances, as stars without known planets. In addition, according to the line of reasoning in [8], this result also implies that most of the stars with and without planets in our sample would not have terrestial planets. However, in two of them, it has been already detected super-Earth like planets with masses in the range $\sim$ 7–11 Earth masses.

We may conclude that there is no reason to expect that the stars hosting relatively massive planets, with positive slopes, should also contain terrestial planets while the other stars with a already detected super-Earth like planets, with negative slopes, should not, and/or that the amount of refractory metals in the planet hosts depends only on the amount of terrestial planets. In addition, it seems plausible that many of our targets hosts terrestrial planets. This statement agrees with the growing population of low mass planets found in the HARPS sample of exoplanets (see e.g. [13]).

Acknowledgments

J.I.G.H. acknowledges financial support from the Spanish Ministry project MICINN AYA2008-00695 and also from the Spanish Ministry of Science and Innovation (MICINN) under the 2009 Juan de la

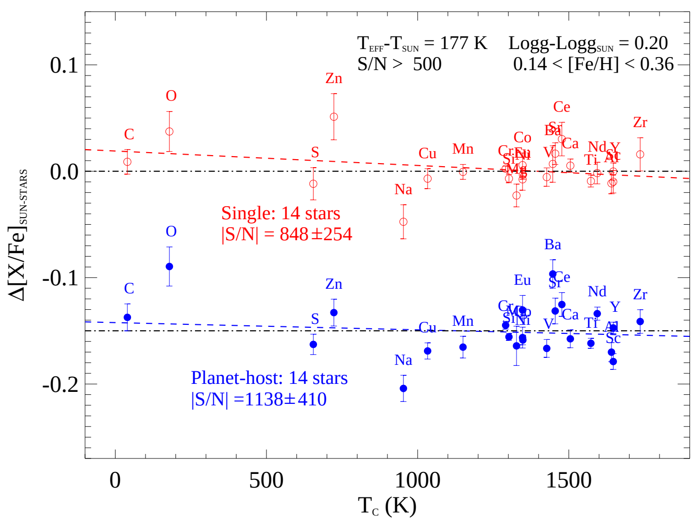

Figure 4: Same as Fig. 3 but after correcting each element abundance ratio of each star using a linear fit to the Galactic chemical trend of the corresponding element at the metallicity of each star.

Cierva Programme. N.C.S., S.S. and V.N. would like to thank the support by the European Research Council/European Community under the FP7 through a Starting Grant, as well from Fundação para a Ciência e a Tecnologia (FCT), Portugal, through a Ciência 2007 contract funded by FCT/MCTES (Portugal) and POPH/FSE (EC), and in the form of grant reference PTDC/CTE-AST/098528/2008 from FCT/MCTES. E.D.M, J.I.G.H. and G.I. would like to thank financial support from the Spanish Ministry project MICINN AYA2008-04874. S.S. acknowledges the support of the FCT grant: SFRH/BPD/47611/2008.

References

[1] Ecuvillon, A., Israelian, G., Santos, N. C., Mayor, M., & Gilli, G. 2006, A&A, 449, 809

[2] González Hernández, J. I., Israelian, G., Santos, N. C., Sousa, S., Delgado-Mena, E., Neves, V., & Udry, S. 2010, ApJ, 720, 1592

[3] Kurucz, R. L. 1993, ATLAS9 Stellar Atmospheres Programs and 2 km s^{-1} Grid, CD-ROM No. 13, Smithsonian Astrophysical Observatory, Cambridge

[4] Mayor, M., & Queloz, D. 1995, Nature, 378, 355

[5] Meléndez, J., Asplund, M., Gustafsson, B., & Yong, D. 2009, ApJ, 704, L66

[6] Neves, V., Santos, N. C., Sousa, S. G., Correia, A. C. M., & Israelian, G. 2009, A&A, 497, 563

[7] Ramírez, I., Meléndez, J., & Asplund, M. 2009, A&A, 508, L17

[8] Ramírez, I., Asplund, M., Baumann, P., Meléndez, J., & Bensby, T. 2010, A&A, 521, A33

[9] Smith, V. V., Cunha, K., & Lazzaro, D. 2001, AJ, 121, 3207

[10] Sneden, C. 1973, PhD Dissertation, Univ. of Texas, Austin

[11] Sousa, S. G., Santos, N. C., Israelian, G., Mayor, M., & Monteiro, M. J. P. F. G. 2007, A&A, 469, 783

[12] Sousa, S. G., et al. 2008, A&A, 487, 373

[13] Udry, S., & Santos, N. C. 2007, ARA&A, 45, 397