# Abundance analysis of planet-hosting and debris-disk stars

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**Abstract**     We present an analysis of element abundances in planet-hosting and debris-disk stars based on high-resolution spectra obtained with the FEROS echelle spectrograph and the 2.2-m ESO telescope at La Silla. Atmospheric parameters and abundance patterns for the stars are determined. A comparison of the abundances is made between planet-hosting stars, debris-disk stars, and field stars

## 1.   Introduction

The presence of debris disks (DDs) around stars seems to be evidence of terrestrial planet formation [11]. These discs appear as a result of small body collisions in planetary or protoplanetary systems [1]. Stars with DDs have masses in the range 0.5–2.0 $M_\odot$, and their ages vary from $t = 10^7$ to $\sim 10^9$ years. Debris disks consist mainly of dust particles, and those in turn are responsible for the infrared (IR) excesses in the spectra of the parent stars [4].

About 16% of solar-type stars in the solar vicinity possess IR excesses that are associated with the presence of a dusty DD [9]. For some stars, both DDs and planets (or planet systems) have been detected. Stars with DDs seem to be appropriate objects for studying the details of the formation of planetary systems.

For our study we selected 14 stars with spectral types from F9 to K0, and which were known to be associated with DDs and/or planets. For comparison, we included the double star HD 20766, which does not have a DD [9].

## 2.   Observations and stellar parameters

Spectra of the program stars were observed in 2008 with the FEROS echelle spectrograph mounted on the 2.2-m ESO telescope, with a resolving power of 48 000. Each covered the full spectral range $\lambda$ 3700–9200 Å, with a high S/N ratio > 100.

Atmospheric parameters and chemical abundances were determined via LTE model atmospheres [6] and the current version of the spectral analysis

code MOOG [15]. The oscillator strengths and other atomic parameters of the Fe I and Fe II lines were taken from [7]. The atmospheric parameters were determined by forcing the abundances derived from individual Fe I lines to show no dependence on equivalent width and excitation potential. The equivalent widths were measured with IRAF[1] and ARES[2]. Details of the method have been described in [12, 13].

We divided the program stars having DDs and/or planetary systems into two groups. The first included objects with metallicities [Fe/H]> 0, the second contained stars with [Fe/H]< 0. The program stars are listed in Table 1. The Table also indicates whether the system contains a DD or a detected exoplanet (P). Two of the stars are hybrid systems and contain both (DD+P) [3].

Table 1. Parameters of the program stars.

| Star | Type | [Fe/H] | $L$ $(L_\odot)$ | $R$ $(R_\odot)$ | $M$ $(M_\odot)$ | $t$ $(10^9$ year) |
|---|---|---|---|---|---|---|
| HD 1581 | DD | -0.25 | 1.31±0.01 | 1.05±0.03 | 1.04±0.02 | 7.68±2.19 |
| HD 10700 | DD | -0.56 | 0.49±0.01 | 0.78±0.01 | 0.83±0.11 | 9.12±2.40 |
| HD 17925 | DD | -0.06 | 0.42±0.01 | 0.79±0.01 | 0.82±0.06 | 5.74±4.17 |
| HD 20766 | – | -0.27 | 0.76±0.01 | 0.93±0.10 | 0.95±0.08 | 5.47±3.77 |
| HD 22049 | DD+P | -0.17 | 0.33±0.01 | 0.71±0.01 | 0.79±0.14 | 4.75±4.08 |
| HD 22484 | DD | -0.10 | 3.09±0.05 | 1.56±0.05 | 1.18±0.11 | 5.85±0.77 |
| HD 222582 | P | -0.05 | 1.25±0.08 | 1.08±0.07 | 1.04±0.12 | 7.28±2.63 |
| HD 202917 | DD | -0.08 | 0.55±0.05 | 0.87±0.19 | 0.93±0.09 | 1.56±1.61 |
| HD 205536 | DD | -0.10 | 0.66±0.02 | 0.95±0.05 | 0.86±0.08 | 8.09±3.43 |
| HD 210681 | DD | +0.15 | 2.19±0.15 | 1.77±0.11 | 0.99±0.11 | 10.08±0.85 |
| HD 25457 | DD | +0.09 | 1.99±0.03 | 1.09±0.08 | 1.23±0.05 | 0.23±0.11 |
| HD 30495 | DD | -0.04 | 1.00±0.01 | 0.98±0.04 | 1.08±0.17 | 3.45±2.73 |
| HD 39091 | DD+P | +0.05 | 1.51±0.02 | 1.10±0.03 | 1.10±0.05 | 2.65±1.84 |
| HD 39833 | DD | +0.09 | 1.24±1.24 | 1.06±0.07 | 0.99±0.10 | 4.08±2.69 |
| HD 53143 | DD | +0.08 | 0.58±0.58 | 0.92±0.11 | 0.91±0.01 | 4.03±3.53 |

## 3. Abundances: volatile and refractory elements

We derived abundances from lines of Na I, Si I, Ca I, Sc I, Ti I, Cr I, Ni I, Y I, Zr II, Ba II, La II, and Ce II using our measured equivalent widths, and atomic data from [10] and other authors ([12] provides a full listing).

The relative abundances [X/H] for the elements mentioned above were derived in the standard way: $[X/H] = \log\varepsilon(X)_* - \log\varepsilon(X)_\odot$, where the indices $*$ and $\odot$ indicate stellar and solar abundances, respectively; $\log\varepsilon(X) =$

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[1]http://iraf.noao.edu/
[2]http://www.astro.up.pt/ sousasag/ares/

$\log(N(X)/N(H)) + 12$, and $N(X)$ is the total number of atoms of element X in the stellar photosphere. The metallicities [Fe/H] which we derived for the program stars are given in Table 1.

It is very important to study the dependence of the relative abundances of the elements [X/H] on the condensation temperature, $T_c$, since it can shed light on details of any planetary system formation [2]. In particular, analyses of that dependence can help us to discover whether the self-enrichment of the atmospheres of the planet-hosting and DDs stars by heavy elements, as proposed in [14] and [5], is effective.
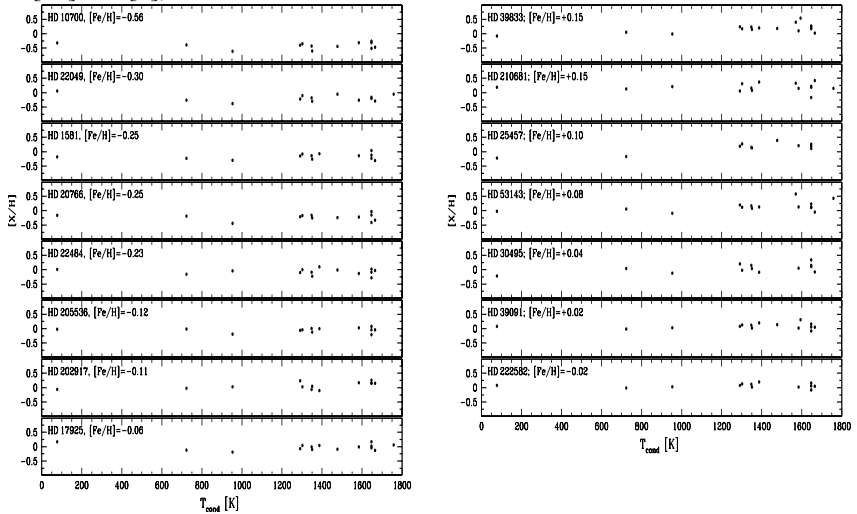


Figure 1. *Left panel*: Element abundances vs. high $T_c$ for stars with [Fe/H] < 0. *Right panel*: As for the left panel, but for the group with [Fe/H] > 0.

For each of the program stars we determined the relative abundances both of refractory (high $T_c$) and volatile (low $T_c$) elements Values of the respective condensation temperatures were taken from [8]. The dependence of abundances on condensation temperatures for stars with [Fe/H] < 0 is shown in the left panel of Fig. 1; the right panel shows the similar case for stars with [Fe/H] > 0.

The abundances of the refractory elements, and the ratio of abundances of refractory to volatile elements for stars with [Fe/H] > 0, slightly exceed those for stars with [Fe/H] < 0, as seen in Fig. 1. This effect may be associated with an enhanced probability of earth-like planet formation for stars with [Fe/H] > 0.

The dependence of the relative abundances [X/H] on the condensation

temperature can be given by the linear relation:

$$[X/H] = [X/H]_0 + \langle d[X/H]/dT_c \rangle \, T_c \tag{1}$$

where the coefficient $\langle d[X/H]/dT_c \rangle$ is the abundance gradient averaged over the entire condensation temperature range, as a function of $T_c$.

The dependence of the average gradient $\langle d[X/H]/dT_c \rangle$ on the metallicity can be found from

$$\left\langle \frac{d[X/H]}{dT_c} \right\rangle = \alpha + \beta[Fe/H], \tag{2}$$

with $\alpha = 0.06 \pm 0.02$ and $\beta = 0.27 \pm 0.08$. One can therefore conclude that the dependence (2) is valid at the level of more than three standard deviations.

Figure 2 shows the gradients we obtained versus [Fe/H]. For the stars with [Fe/H]< 0 the errors in the mean gradient $\langle d[X/H]/dT_c \rangle$ are comparable to the gradient itself, or even exceed it, whereas for stars with [Fe/H]> 0 the errors do not exceed $1/3$ to $1/2$ of the value of the gradient. That means that the relative abundances of the refractory elements compared with the solar ones exceed those of the volatile elements in stars with metallicity [Fe/H]> 0, at a level of 2 to 3 standard deviations. The most negative gradient, for HD 10700, which is the most metal-deficient star in our sample, may somehow be associated with Galactic chemical evolution.
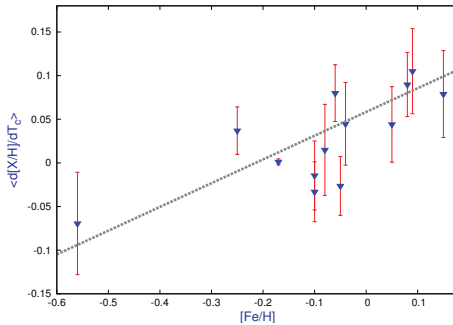


Figure 2. The dependence of the gradient $\langle d[X/H]/dT_c \rangle$ (in dex/kK) on metallicity. The *vertical* lines show the errors in the gradient. The *dotted* line shows the dependence (2).

Equation (2) can be explained if the accretion rate of the elements depends on $T_c$ for stars with [Fe/H]> 0. In principle, such dependence could be utilized for testing different models of chemical evolution and mixing for stars with planets and DDs.

## 4.   Conclusions

We have determined the physical parameters and chemical abundances of 15 stars that have either a debris disk (DD) or planets (P), and for some hybrid systems (DD+P). We analysed the relative abundance distribution of refractory, intermediate, and volatile elements as a function of their condensation temperatures. We can draw the following conclusions:

- All stars with a DD analyzed in this work have masses $M \leq 1.25 M_\odot$.

- Stars with [Fe/H]$< 0$ show a flat distribution of relative abundances, whereas refractory elements in host stars with [Fe/H]$> 0$ are slightly overabundant.

- The ratio of the refractory to volatile element abundances is larger for stars with higher metallicity.

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