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Abundance Pattern Analysis of Planet-hosting and Debris-disk Stars

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Abstract. About 16 % of the main-sequence solar-like stars are surrounded by dusty debris disks (DD). These disks are the detritus of small bodies collisions and their presence is a very strong signpost of planet formation. One of the most interesting characteristics of stars hosting a giant planet is a direct relationship between metallicity and probability of planet formation, which was found to increase with stellar metallicity Gonzalez (1997). Instead, the small planets would form around host stars (HS) with a wide range of metallicities (Buchhave et al. 2012). On the other hand the presence of debris disks is uncorrelated with metallicity (Chavero et al. 2006, Greaves et al. 2006, Maldonado et al. 2012).

1. Introduction

Evidence of the formation of the terrestrial planets around the stars is the presence the DD Raymond et al. (2011). According to modern concepts, these discs are a result of the small bodies (e.g., planetesimals, comets, asteroids, planets) destruction in the planetary system Aumann et al. (1984) as a result of their collisions. Debris disks have masses $0.5M_{\odot} - 2.0M_{\odot}$ and ages $t = 10^7 - 10^9$ years.

Debris disks consist mainly of the dust particles which are detected from the IR excesses in the spectrum of the parent star Golimowski at al. (2006). Even if the total mass of the dust particles in the debris disks is smaller than the mass of the Earth, they have a large total surface and effectively reemit the stellar emission in the infrared. In some cases the dust rings are seen near the stars with disks.

Nearly 16% of solar-type stars in the solar vicinity possess the infrared excesses associated with the presence of dusty debris disks Maldonado et al. (2012). Some of the stars with DD also possess by planets or planet systems. So we may conclude that stars with debris disks are suitable objects to study the details of the planetary systems formation. Studies of such stars can also help to explore the process of the planetesimals destruction.

The present work is devoted to the analysis of the spectral observations of stars with debris disks and/or planets on the basis of the program proposed by de la Reza et al. (2006). In the article, we analyze the observations of 14 stars of this type of the spectral classes from F9 to K0 with the fundamental parameters which are similar to those of the Sun. For comparison we added in the list the double star HD 20766, which was previously considered as the star with a debris disk, but so far the evidence for the presence of such a disk is not found Maldonado et al. (2012).

For these stars, we have obtained the high-resolution spectra with a high signal-to-noise ratio. In section 2 we describe the observations of stars and reduction of their spectra. The third section is devoted to deriving the fundamental parameters of the stars. In section 4 we describe how we determine the elements abundances in the atmospheres. Analysis of the relative abundances of the volatile and refractory elements in the atmospheres of the program stars is also presented in this section. The positions of program stars in the Hertzsprung-Russell (H-R) diagram are pointed out. Some conclusions are presented in the last section.

2. Observations and data processing

Spectroscopic observations were carried out at the 2.2-m ESO telescope in Chile in 2008. All observations were made using the spectrograph FEROS having spectral resolution of $R = 48\,000$. Echelle spectra of program stars were obtained in the wavelengths interval of 3700 − 9200 Å with a high signal-to-noise ratio $S/N > 100$.

Reduction of the spectra was carried out in a standard manner using the IRAF[1] packages. The continuum level was also determined with IRAF using the points where the continuum is only slightly distorted by the contribution of absorption lines.

The radial velocities $V_{\rm rad}$ for all program stars were determined using the unblended spectral lines. The results are given in Table 1 (upper part). In the same table we indicate if the system is a star with the debris disc (DD) or with the detected exoplanet (P). Five stars are the hybrid systems (DD+P) (Ertel et al. 2012).

3. Stellar Parameters

Atmospheric parameters and chemical abundances were determined in the LTE model atmospheres (Kurucz 1993) using the current version of the spectral analysis code MOOG Sneden (1973). The oscillator strengths and other atomic parameters for the Fe I and Fe II lines were taken from the paper by Lambert et al. (1996). The atmospheric parameters were determined by forcing the abundances derived from the individual Fe I lines to show no dependence on equivalent width and excitation potential. To measure the equivalent widths W_λ of the lines in the stellar spectra we selected unblended lines with $W_\lambda \leq 150$ mÅ. The W_λ values were measured using IRAF packets and ARES[2] code.

Determination of the atmosphere parameters was made iteratively based on the analysis of the absorption lines of iron. Parameters were fitted in such a way that there were no dependences of the iron abundances obtained from the individual lines of the Fe I on the equivalent widths and the excitation potentials. Details of the method were described in our previous paper Rojas et al. (2013).

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[1]http://iraf.noao.edu/

[2]http://www.astro.up.pt/ sousasag/ares/

Table 1. Parameters of the program stars

Star	m_v	V_{rad} (km/s)	Sp. type	T_{eff} (K)	lg g (km/s^2)	ξ (km/s)	[Fe/H] (dex)	
HD 1581	4.20	+9.7	F9.5V	5915	4.39	1.11	-0.25	DD
HD 10700	3.50	-16.43	G8.5V	5350	4.53	0.70	-0.56	DD
HD 17925	6.00	+17.72	K1V	5040	4.30	1.21	-0.10	DD
HD 20766	5.54	+12.66	G4V	5650	4.39	0.69	-0.25	-
HD 22049	3.73	+16.20	K2Vk	4900	4.20	0.95	-0.30	DD+P
HD 22484	4.30	+28.17	F8V	5900	3.90	1.40	-0.23	DD
HD 222582	7.69	+11.99	G5	5757	4.20	0.54	-0.02	P
HD 202917	8.67	-2.28	G7V	5574	4.50	1.99	-0.11	DD+P
HD 205536	7.07	+34.73	G9V	5301	4.09	0.67	-0.12	DD
HD 210681	8.08	+38.07	K0III	5084	3.23	1.34	+0.08	DD
HD 25457	5.38	+17.96	F6V	6580	4.78	2.00	+0.10	DD
HD 30495	5.50	+21.70	G1.5V	5766	4.28	0.70	+0.04	DD+P
HD 39091	5.67	+10.99	G0V	6000	4.14	1.29	+0.02	DD+P
HD 39833	7.66	+25.02	G0III	5777	4.09	0.90	+0.15	DD
HD 53143	6.80	+23.05	G9V	5387	4.36	1.04	+0.08	DD+P
	π (μs)	r (pc)	B.C.	M_v	M_{bol}	L ($L_\odot$)	M ($M_\odot$)	R ($R_\odot$)
HD 1581	116.46±0.16	8.59±0.01	-0.08	4.53	4.45	1.31	1.06	1.04
HD 10700 5	273.96±0.17	3.65±0.00	-0.18	5.69	5.51	0.49	0.83	0.78
HD 17925	96.00±0.40	10.42±0.04	-0.25	5.91	5.66	0.43	0.72	0.82
HD 20766	83.28±0.20	12.01±0.03	-0.12	5.14	5.02	0.77	0.98	0.88
HD 22049	310.00±0.16	3.23±0.00	-0.30	6.19	5.89	0.35	0.71	0.78
HD 22484	71.62±0.54	13.96±0.10	-0.08	3.58	3.49	3.16	1.22	1.63
HD 222582	23.95±0.74	41.75±1.25	-0.09	4.59	4.49	1.26	0.90	1.05
HD 202917	23.27±0.98	42.97±1.74	-0.13	5.50	5.38	0.56	0.94	0.77
HD 205536	45.41±0.52	22.02±0.25	-0.18	5.36	5.17	0.67	0.92	0.93
HD 210681	15.93±0.56	62.77±2.13	-0.23	4.09	3.86	2.26	1.03	1.86
HD 25457	53.10±0.32	18.83±0.11	-0.01	4.01	3.99	1.99	1.25	1.04
HD 30495	73.32±0.36	13.64±0.07	-0.09	4.83	4.74	1.00	1.00	0.96
HD 39091	54.60±0.21	18.32±0.07	-0.06	4.36	4.29	1.51	1.15	1.09
HD 39833	24.26±0.91	41.22±1.49	-0.09	4.58	4.50	1.25	1.06	1.07
HD 53143	54.57±0.34	18.33±0.11	-0.16	5.48	5.33	0.58	0.94	0.84

Analysis of the data showed that errors in the values of the effective temperature (T_{eff}) do not exceed 120 K, whereas the errors in the values of the surface gravity ($\log g$) and the microturbulent velocity (ξ) do not exceed 0.2 km s^{-2} and 0.2 km s^{-1} respectively. Our values of the stellar parameters agree at the level of one or two standard deviations with those given by Santos et al. (2001).

4. Abundance determinations

We derive abundances 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 the equivalent widths of the corresponding lines. Atomic Data for the lines used in the analysis of the chemical composition of program stars are taken from the papers by Preston & Sneden (2001) and many others (see Rojas et al. (2013) for the full list).

The relative abundances [X/H] for all above mentioned elements are derived. This value is determined in the standard way, such as $[X/H] = \log \varepsilon(X)_* - \log \varepsilon(X)_\odot$, where the indices $*$ and $\odot$ indicate the stellar and solar abundances. Here, ($\log \varepsilon(X) =$

log(N(X)/N(H)) + 12) and N(X) is the total number of atoms of element X in the stellar photosphere. Derived metallicities [Fe/H] for all 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 $T_{\rm c}$. This dependence can shed light on the details of the planetary systems formation. In particular, studying the aforementioned dependence can help to find out whether the self-enrichment of the atmospheres of the planet-hosting stars by heavy elements is effective as it was proposed by Smith et al. (2001) and Gonzalez et al. (2006).

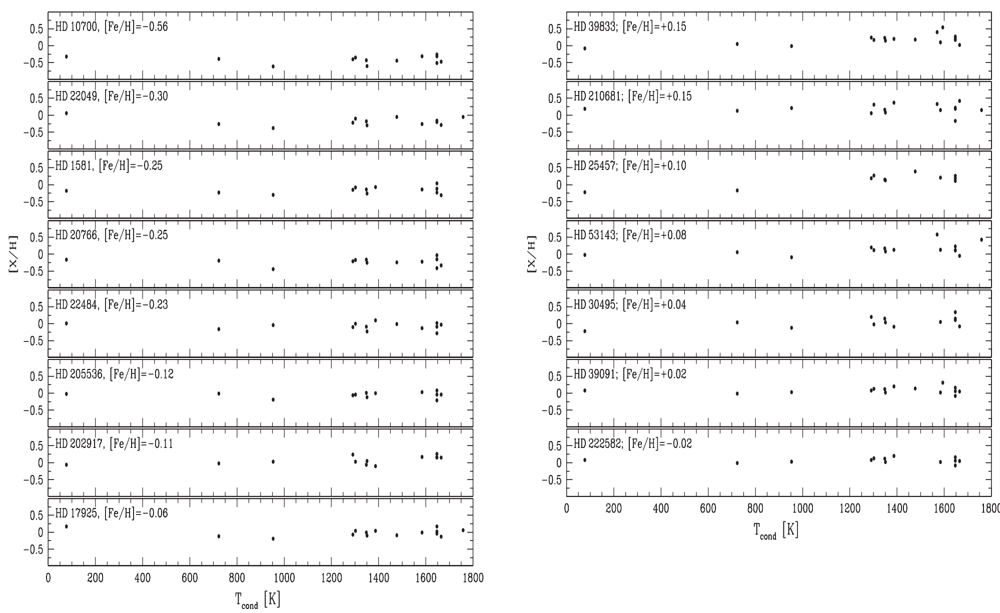

Figure 1. Left panel: Element abundances vs. high $T_{\rm c}$ for stars with [Fe/H]< 0. Right panel: The same as in the top panel, but for the objects with [Fe/H]< 0.

We determined the relative abundance of both refractory (high $T_{\rm c}$) and volatile (low $T_{\rm c}$) elements for all program stars. The values of the condensation temperatures were taken from Lodders et al. (2003). The aforementioned dependence for stars with subsolar metallicity ([Fe/H]< 0) is shown in Fig. 1 (left panel). In the right panel we plot the same dependence for stars with enhanced metallicity [Fe/H]> 0.

We can see that the dependence of the relative abundances [X/H] on $T_{\rm c}$ for stars with debris disks (DD), stars with planets (P) and the hybrid (DD+P) systems practically do not differ. It should also be noted that the relative abundances of all studied elements in stars with DD is similar to that for star HD 20766 without debris disc.

In the same time, the abundances of the refractory elements and the ratio [ref/vol] of the abundances of refractory and volatile elements for stars with [Fe/H] > 0 slightly exceed those for stars with subsolar metallicity [Fe/H] < 0, as it seen in Fig. 1. We plan to increase the size of our sample of the low-mass stars in a feature to investigate the reality the observed effect. In the case of its reality, this effect can be connected with the enhanced probability of the formation of the earth-like planets for stars with metallicity [Fe/H]> 0.

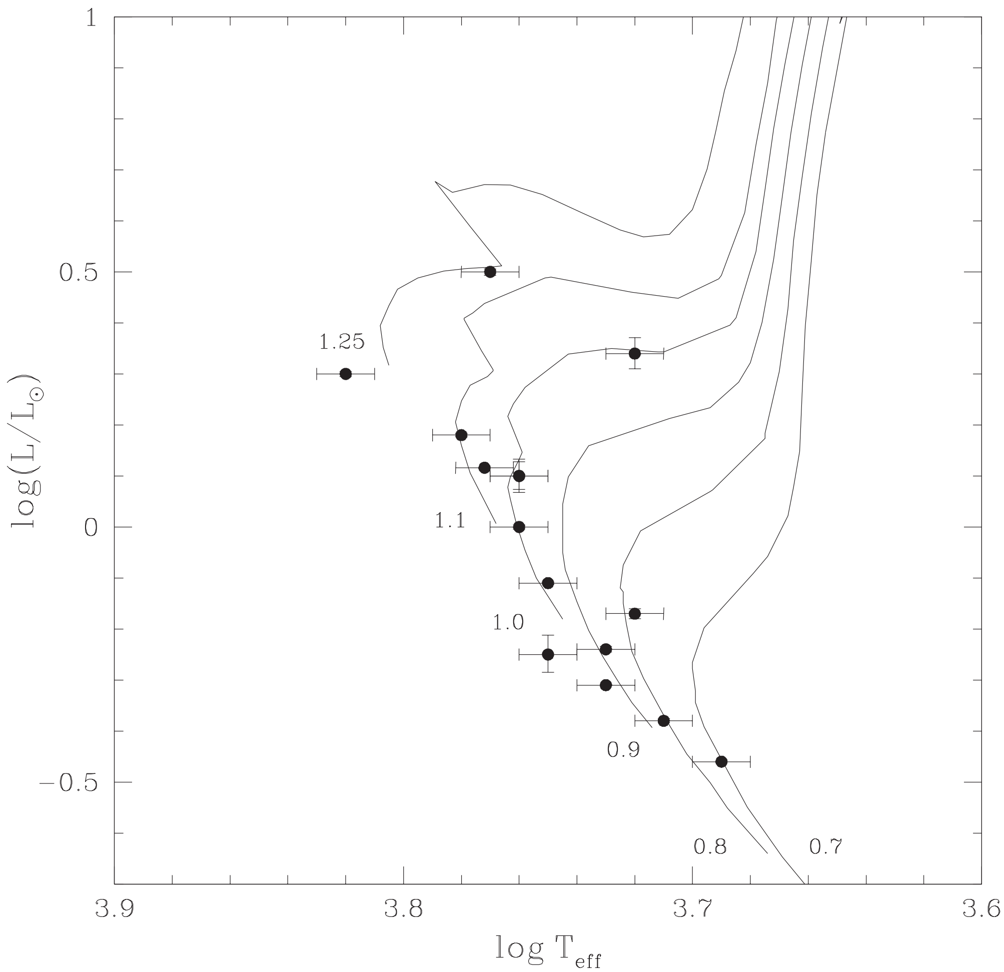

Figure 2. Positions of program stars at H-R diagram

To analyze the evolutionary status of the program stars we define their positions in the H-R diagram. Luminosities and radii of the stars were calculated using the standard formulas (e.g. Rojas et al. 2013) and the distances to the stars from SIMBAD[3] data base with van Leeuwen (2007) corrections. Bolometric corrections to the absolute magnitudes were determined by interpolation of the BC values as functions of $T_{\rm eff}$ and metallicity given by Alonso et al. (1999).

The determined parameters of the program stars are given in Table 1. Positions of the program stars in the H-R diagram are shown in Fig. 2. Evolutionary tracks of stars with masses in the range from 0.7 to 1.25 $M_{\odot}$ are taken from the paper by Girardi at al. (2000). The stellar masses were estimated from their positions in the H-R diagram. As it can be seen, all stars which were studied by us are located at the evolutionary tracks of relatively low-mass stars.

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[3]http://simbad.u-strasbg.fr/simbad/

5. Conclusion

We determined physical parameters and chemical abundances of 15 stars with debris disk (DD), planets (P) and hybrid systems (DD+P). We analyzed the relative abundance distribution of refractory, intermediate, and volatile elements ([ref/vol]) as a function of their condensation temperature T_c.

Some conclusions can be drawn:

- All stars with DD analyzed in this work have the masses $M \leq 1.25 M_{\odot}$.
- Stars with [Fe/H]<0 show the flat distribution of the relative abundances, whereas refractory elements in host stars with [Fe/H]>0 are slightly overabundant.
- The value [ref/vol] (the ratio of the refractory and volatile element abundances) is larger for stars with higher metallicity.

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