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Galactic panel
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Chemical analysis of early-type stars with planets

Abstract

Metallicity plays a fundamental role in stellar and planetary formation. Until now, most studies focused on late-type stars, while early- type stars are poorly studied. In this work, we propose to analyze a possible chemical signature of planet formation in a sample of early- type stars with planets. This will allow us to test stellar and planetary formation in the high-mass regime ($M > 1.3$ Mo), which is almost unexplored. Importantly, our sample would be the largest and most significant group homogeneously studied to date, including 85% of the presently known early-type stars with planets. This will enable us to address important questions such as planet formation scenarios (core accretion vs gravitational instability) and the possible link between planet formation and lambda Bootis stars. Considering that the analysis requires few observations, we believe that they are excellent targets for FEROS.

Observing Blocks

Instrument/Telescope	Req. time	Min. time	1^{st} Option	2^{nd} Option
FEROS/MPG 2.2-m	2 nights	1 nights	April Any	April Any
FEROS/MPG 2.2-m	1 nights	1 nights	September Any	September Any

CoIs

Name	Institution	e-mail	Observer?
Carlos Saffe	OnCL	saffe.carlos@gmail.com	True
Matias Flores	OnCL	mattiasgft@gmail.com	True
Rodolfo Angeloni	OCL	rodolfo.angeloni@noirlab.edu	True

Status of the project

- Past nights: 2
- Future nights: 2

- Long term: False
- Large program: False
- Thesis: False

List of Targets

ID	RA	DEC	Mag
MASCARA-4	09:50:19.0	-66:06:50.0	V=8.19
HD97048	11:08:03.0	-77:39:17.1	V=9.01
HR4372	11:17:12.1	-38:00:51.8	V=6.24
HD104125	11:59:23.8	-57:10:04.7	V=6.76
HR4692	12:20:28.3	-65:50:33.5	V=6.19
HATS-58A	12:27:09.1	-48:58:42.2	V=11.55
HR4796A	12:36:01.1	-39:52:10.0	V=5.77
HD112383	12:57:26.3	-67:57:38.4	V=6.77
HR5008	13:17:13.9	-43:58:46.0	V=5.80
WASP-172	13:17:44.1	-47:14:15.3	V=10.99
HR5121	13:37:23.5	-46:25:40.2	V=5.89
HD130697	14:50:58.7	-42:49:20.8	V=6.82
WASP-178	15:09:05.1	-42:42:18.1	V=9.95
HD137919	15:30:21.3	-41:55:08.3	V=6.33
HD142851	15:57:59.4	-31:43:43.9	V=7.02
piAra	17:38:05.5	-54:30:01.6	V=5.24
HD193571	20:22:27.5	-42:02:58.4	V=5.59
HD221853	23:35:36.2	+08:22:57.4	V=7.34
HD1160	00:15:57.3	+04:15:04.1	V=7.13
HD2685	00:29:18.9	-76:18:14.6	V=9.59
lam1Phe	00:31:24.9	-48:48:12.7	V=4.77
HD3375	00:36:00.8	-59:43:01.9	V=6.91
48Cet	01:29:36.1	-21:37:45.5	V=5.1
HR1189	03:48:35.5	-37:37:19.2	V=5.25

SCIENTIFIC AIM AND RATIONALE

To date, more than ~4800 planets are known orbiting stars of different spectral types and luminosity classes[1]. Important trends were detected by studying the chemical composition of these objects. For instance, the frequency of stars having giant planets is a rising function of the metallicity, which is called the planet-metallicity correlation (e.g. Santos et al. 2004, Fischer & Valenti 2005, Johnson et al. 2010, Sousa et al. 2011). However, several independent studies showed that low-mass planets below 30-40 $M_{\oplus}$, do not prefer metal-rich stars (e.g. Udry et al. 2006, Sousa et al. 2011, 2018). Also, studies based on transiting planets with spectroscopically derived metallicities indicate that small-sized rocky planets (smaller than about 1.7 $R_{\oplus}$) show no preference towards high metallicities (Buchhave et al. 2014, Narang et al. 2018), while other works are more cautious in this respect (Zhu et al. 2016). These works show that the chemical composition plays a fundamental role in stellar and planetary formation.

Most of the works previously mentioned focused on late-type FGK and M dwarf stars, while early-type stars are comparatively poorly studied. In the past few years, a slowly growing number of planets orbiting early-type stars were found, detected mainly by transits (e.g., from the KELT Collaboration, Pepper et al. 2007) and also from direct imaging (such as the GPIES survey, Nielsen et al. 2019). Very recently, our group performed the first homogeneous chemical analysis of early-type stars with planets (Saffe et al. 2020, 2021). Notably, we detected the first chemically peculiar Am star orbited by a planet (KELT-17) and the first λ Boötis star[2] orbited by a brown dwarf (ζ Del), both shown in Figs. 1 and 2. We also found 4 λ Boötis stars in the sample, two of which present giant planets and circumstellar disks. Importantly, we also showed that at least some early-type stars could form planets through the core accretion process and not only gravitational instability.

The remarkable findings of our initial works strongly encourage us to continue studying early-type stars. Then, we propose to observe a new group of 14 early-type stars with planets and 10 without planets detected (see Table 1), which would duplicate the number of stars with planets currently analyzed (n=13, Saffe et al. 2021). This would be the largest and most significant group homogeneously studied to date, including ~85% of the presently known early-type stars with planets. The global sample includes some remarkable objects (such as HR 8799, β Pictoris, Fomalhaut, KELT-9), some important prototype and standard stars for comparison (such as λ Boötis and Vega), and a number of stars for which no abundance study was previously performed in the literature. The general goal of this proposal is to detect a possible signature of planet formation. More specific goals correspond to search a common chemical pattern, to study the likely relation between λ Boötis stars and giant planets (e.g. Kama et al. 2015, Jura 2015, Saffe et al. 2021), and importantly, to study the consequences on the planet formation process (core accretion vs. gravitational instability, see Saffe et al. 2021). These goals will be addresed[3] by comparing different chemical patterns (see Sect. 4.1 to 4.3, Saffe et al. 2021) and contrasting with the expected from planet formation models (see Sect. 4.4, Saffe et al. 2021).

Early-type stars with planets form a very important group, helping to test stellar and planetary formation in the high-mass regime ($M > 1.3\ M_{\odot}$). Several questions remain to be answered for this exciting group of stars, such as those related to the goals of this work. Then, early-type stars with and without planets are ideal to study through FEROS high-resolution and high S/N spectra. Considering that the analysis requires only a few observations that will allow us to obtain, in a short time, publishable important results about early-type stars with planets, we believe that they are excellent targets for FEROS.

[1] See, for example, the Extrasolar Planets Enciclopaedia, http://exoplanet.eu/

[2] These stars present solar abundances of C, N, O and S, while most metals show subsolar values (~1-2 dex).

[3] We explain how to reach our goals and questions, following a previous CNTAC feedback.

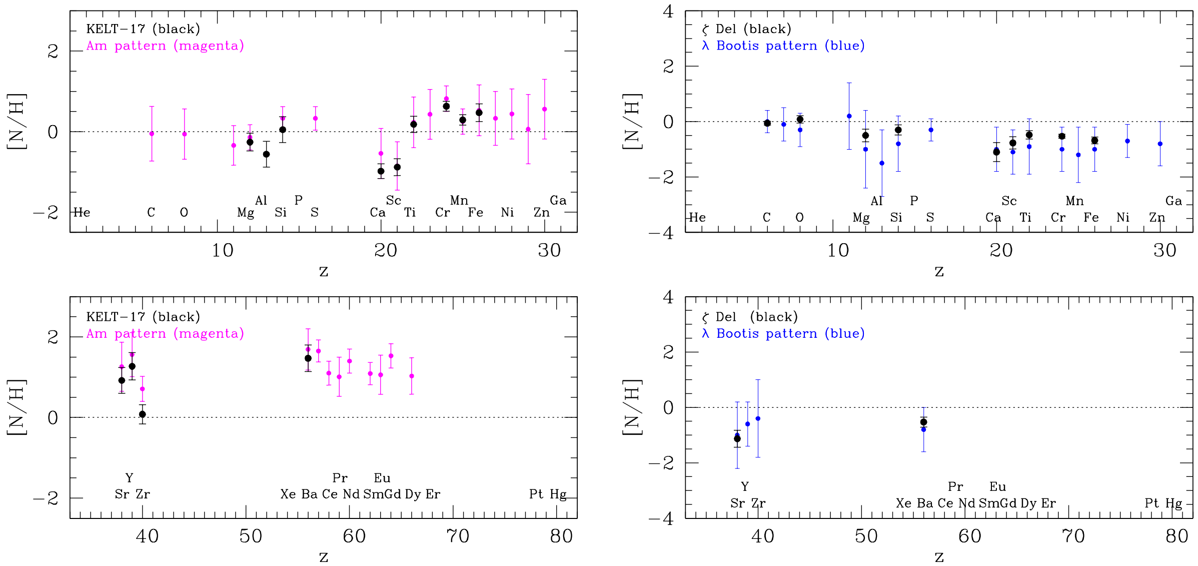

Figure 1: Chemical abundances [N/H] versus atomic number z, for the exoplanet host stars KELT-17 (left) and ζ Del (right). The chemical patterns are compared to those of chemically peculiar Am stars (magenta) and λ Boötis stars (blue). For clarity, the panels are divided for elements with z<32 and z>32. The plots show that KELT-17 and ζ Del agree with the chemical pattern of Am and λ Boötis stars. Figures taken from Saffe et al. (2021).

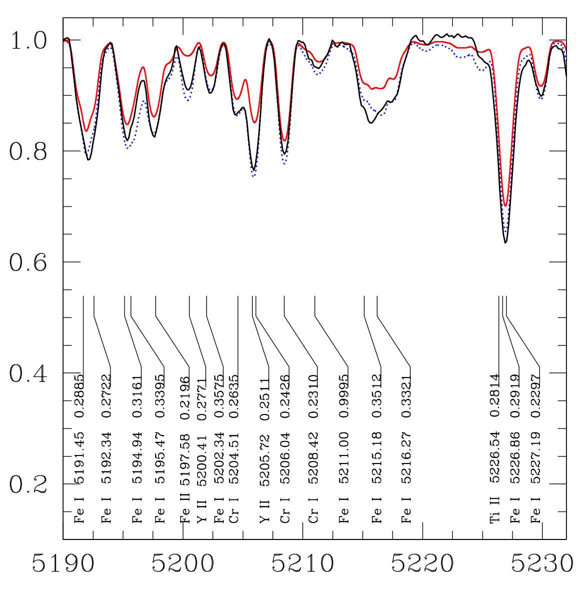

Figure 2: Observed (black) and synthetic (red and blue) spectra for the star KELT-17. Red and blue colors correspond to solar and derived abundances. Figure taken from Saffe et al. (2020).

Table 1: Sample of early-type stars to observe with FEROS.

N^o	Star	Vmag	SpType	AR (J2000)	DEC (J2000)	ExpTime (sec)
1	HD 1160	7.13	A0V	00 15 57.3	+04 15 04.1	(3x) 130
2	HD 2685	9.59	F2III/IV	00 29 18.9	-76 18 14.6	(3x) 1700
3	λ^1 Phe	4.77	A1Va	00 31 24.9	-48 48 12.7	(3x) 15
4	HD 3375	6.91	F2V	00 36 00.8	-59 43 01.9	(3x) 140
5	48 Cet	5.10	A0V	01 29 36.1	-21 37 45.5	(3x) 20
6	HR 1189	5.25	A1Va	03 48 35.5	-37 37 19.2	(3x) 24
7	MASCARA-4	8.19	A3V	09 50 19.0	-66 06 50.0	(3x) 360
8	HD 97048	9.01	A0Vep AeBe	11 08 03.0	-77 39 17.1	(3x) 750
9	HR 4372	6.24	A1V	11 17 12.1	-38 00 51.8	(3x) 59
10	HD 104125	6.76	A2V	11 59 23.8	-57 10 04.7	(3x) 95
11	HR 4692	6.19	B9V	12 20 28.3	-65 50 33.5	(3x) 55
12	HATS-58A	11.55	F2	12 27 09.1	-48 58 42.2	(3x) 10000
13	HR 4796 A	5.77	A0V	12 36 01.1	-39 52 10.0	(3x) 38
14	HD 112383	6.77	A2IV/V	12 57 26.3	-67 57 38.4	(3x) 96
15	HR 5008	5.80	A2mA4-A9/F0	13 17 13.9	-43 58 46.0	(3x) 39
16	WASP-172	10.99	F1V	13 17 44.1	-47 14 15.3	(3x) 6100
17	HR 5121	5.89	B8V	13 37 23.5	-46 25 40.2	(3x) 42
18	HD 130697	6.82	A2V	14 50 58.7	-42 49 20.8	(3x) 100
19	WASP-178	9.95	A1IV-V	15 09 05.1	-42 42 18.1	(3x) 1800
20	HD 137919	6.33	B9.5V	15 30 21.3	-41 55 08.3	(3x) 63
21	HD 142851	7.02	A0V	15 57 59.4	-31 43 43.9	(3x) 120
22	π Ara	5.24	A5IV/V	17 38 05.5	-54 30 01.6	(3x) 30
23	HD 193571	5.59	A0V	20 22 27.5	-42 02 58.4	(3x) 32
24	HD 221853	7.34	F0	23 35 36.2	+08 22 57.4	(3x) 210

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CURRENT STATUS OF THE PROJECT

Following the aims of this work, we performed the first homogeneous chemical analysis of early-type stars with planets (Saffe et al. 2020, 2021). Overall, the sample studied comprise mainly A-type and few F-type stars, including 13 stars with planets, 3 stars likely orbited by brown dwarfs and 21 objects without planets nor brown dwarfs detected. We downloaded archive spectra for the case of HARPS, HARPS-N, HIRES, SOPHIE, ELODIE and REOSC spectrographs, in order to obtain the largest possible sample of stars.

The stellar parameters (temperature $T_{\rm eff}$ and gravity $\log g$) were first estimated by using derredenned Strömgren uvbyβ mean photometry for most stars in our sample. Then, these values were refined iteratively by enforcing excitation and ionization balances of the iron lines. Projected rotational velocities $v \sin i$ were first estimated by fitting the observed profile of the line Mg II 4481.23 Å and then refined by fitting most Fe I and Fe II lines in the spectra. Then, the stellar abundances were derived iteratively by fitting observed spectra (see Fig. 2) using ATLAS12 model atmospheres (Kurucz 1993) together with the SYNTHE code (see Saffe et al. 2020, 2021).

Then, the main results of this study are as follows. We identified the first chemically peculiar Am star orbited by a planet (KELT-17, Saffe et al. 2020) and the first λ Boötis star orbited by a brown dwarf (ζ Del, Saffe et al. 2021). These interesting pairs could help to test stellar and planetary formation scenarios. Overall, we have found four λ Boötis stars, two of which present planets and circumstellar disks (HR 8799 and HD 169142) and one without planets detected (HD 110058). We found no unique chemical pattern for the group of early-type stars bearing giant planets. However, our results support a scenario in which giant planets orbiting pre-main-sequence stars possibly block the dust of the disk and result in a λ Boötis-like pattern. On the other hand, we do not find a λ Boötis pattern in different hot-Jupiter planet host stars, which does not support the idea of possible accretion from the winds of hot-Jupiters. Finally, we suggest that the formation of planets around early-type stars such as HR 8799 and HD 169142, is also possible through the core accretion process and not only gravitational instability.

These remarkable initial findings strongly encourage us to continue investigating early-type stars, in order to improve the statistical significance of the results. In this respect, we also take advantage of collect spectra from archive[4]. In order to perform a meaningful comparison with the proposed new observations, we carefully selected high-quality spectra from high-resolution spectrographs (HARPS, HARPS-N, HIRES, etc.) with the highest possible S/N. If many spectra are available, they are combined in order to reach even a higher S/N. This strategy was succesfully applied in our previous works (Saffe et al. 2020, 2021). Archive spectra include both, stars with planets and stars without detected planets (the control sample). The current FEROS proposal also includes stars from both groups, increasing in this way the statistical significance of the results.

We consider that this work is important for the Chilean community, providing a collaborative research in a relevant and almost unexplored field. In this respect, it is worth stressing that the tasks are well distributed among team members (RA, MJ, CS and MF). RA is in charge of the Phase II of this project, having solid experience as a FEROS Support Scientist. CS will estimate abundances using spectral synthesis, while MJ will make the HR diagrams and the spectral energy distributions (SED) of the individual targets. Finally, MF is in charge of making and comparing the chemical patterns. All members also collaborate in the writing of the work.

[4]This comment follows from a previous CNTAC suggestion.

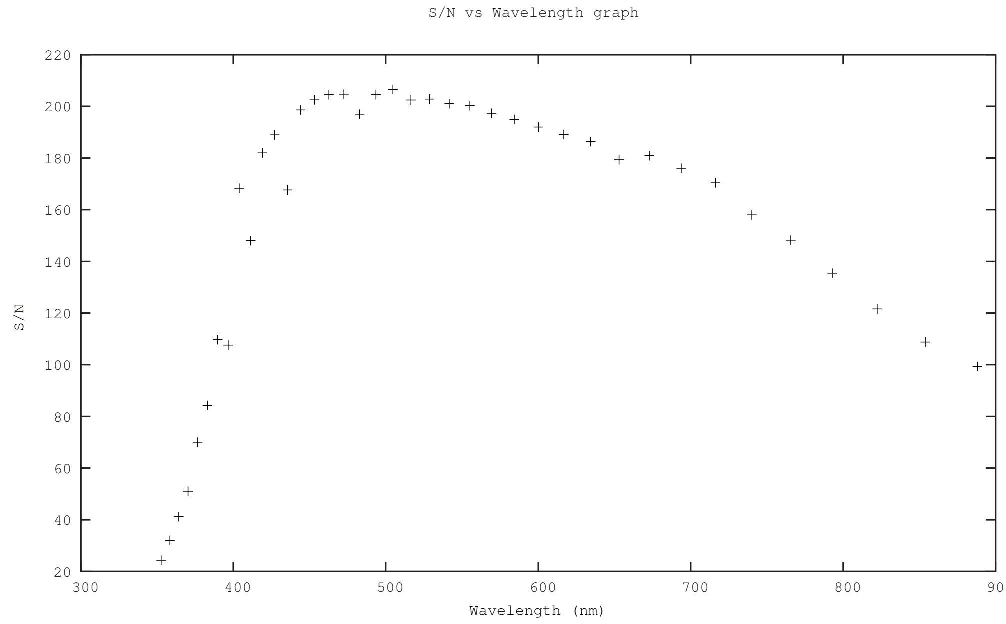

Figure 3: S/N vs wavelength estimated with the FEROS ETC for an average early-type star in our sample (WASP-178 with V = 9.95, airmass = 1.50, image quality IQ 70% and t_{exp} = 1800 sec).

TECHNICAL DESCRIPTION

In order to obtain both precise stellar parameters and chemical abundances for the sample of stars, we require the fiber-fed FEROS spectrograph (on MPG2.2m telescope) which provides a high resolving power (R∼48000) when illuminated via 2.0 arcsec aperture on the sky in the unbinned mode. The spectral coverage between 350-920 nm is particularly appropriate to derive atmospheric parameters and to analyze several chemical species by using many absorption features (e.g. Saffe et al. 2021).

The V magnitudes of the targets range between 4.77 − 11.55 with an average of 8.09, being then ideal for FEROS. We require a minimum S/N ∼ 350 to derive precise stellar parameters and abundances, obtaining a spectra of similar quality to our previous works. We estimated exposure times using the FEROS Exposure Time Calculator Version P109[5], in order to reach S/N ∼ 200 in a single exposure (see Fig. 3). Then, by taking ∼3 spectra per object to avoid excessively large exposures and cosmic rays, we expect a final S/N ∼ $\sqrt{3}$ x 200 ∼ 346, which is appropriate for our study. We note that this high S/N should be reached near ∼500 nm, where most useful lines are present. The stars with and without planets requested in this proposal will increase the statistical significance of the results, being the largest group of early-type stars studied to date.

We estimate that 2 nights in April and 1 night in September are enough to observe the complete sample (t_{total} = 3 nights). A minimum time of 1 night in April and 1 night in September (t_{min} = 2 nights) allow us to start this study by taking the brightest stars of the sample. The coordinates, Vmags and estimated exposure times are shown in Table 1. In particular, Rodolfo Angeloni will be in charge of the Phase II of this project, who have a solid experience as Support Scientist of FEROS. Spectra will be reduced using the FEROS DRS software[6] and also using publicly available CERES routines[7]. The data will be analyzed by using spectral synthesis similar to our previous works (Saffe et al. 2020, 2021).

[5]https://www.eso.org/observing/etc/bin/gen/form?INS.NAME=FEROS+INS.MODE=spectro
[6]https://www.eso.org/sci/facilities/lasilla/instruments/feros/tools/DRS.html
[7]https://github.com/rabrahm/ceres