

Spectroscopic and photometric investigation of some potentially chemically peculiar δ Scuti stars

Filiz KAHRAMAN ALIÇAVUŞ, ^{1,2,*} Fahri ALIÇAVUŞ, ^{1,2} Burcu ÖZKARDEŞ,^{2,3} and Eda ÇELİK ⁴

¹Faculty of Science, Physics Department, Çanakkale Onsekiz Mart University, TR-17100, Çanakkale, Türkiye

²Astrophysics Research Center and Ulupinar Observatory, Çanakkale Onsekiz Mart University, TR-17100, Çanakkale, Türkiye

³Faculty of Science, Çanakkale Onsekiz Mart University, Space Sciences and Technologies Department, TR-17100, Çanakkale, Türkiye

⁴School of Graduate Studies, Physics Department, Çanakkale Onsekiz Mart University, TR-17100, Çanakkale, Türkiye

*E-mail: filizkahraman01@gmail.com

Abstract

Investigating chemically peculiar pulsating stars is crucial for understanding the pulsation driving mechanism in detail. To reveal the true peculiarity properties of stars, detailed spectroscopic analysis is essential. Therefore, in this study, we focused on δ Scuti stars previously identified as chemically peculiar but which needed comprehensive updated spectroscopic analysis to uncover their chemical abundance structure. We selected 10 targets which have publicly available high-resolution spectroscopic and photometric data. Performing spectral analyses, we determined the spectral classification, atmospheric parameters, and detailed chemical abundance distributions of the selected stars. The pulsation properties were also analyzed using TESS data, and pulsation modes for the highest amplitude pulsation frequencies were derived. We estimated the masses and ages of the targets using the evolutionary tracks and isochrones. As a result of our study, we show that only three targets exhibit chemical peculiarity: AU Scl and FG Eri as metallic A (Am) stars, and HZ Vel as a λ Bootis. However, others were found to be chemically normal stars. This study shows us the importance of chemical abundance analysis in the classification of chemical peculiar stars.

Keywords: stars: chemically peculiar — stars: fundamental parameters — stars: oscillations — stars: variables: delta Scuti

1 Introduction

Stars that exhibit chemical abundance patterns different from the solar abundance are known as chemically peculiar stars. There are various types of chemically peculiar stars, ranging from spectral types B to F, and they can primarily be classified on the basis of their magnetic field properties. According to Preston (1974), chemically peculiar stars can be categorized into four main classes: metallic A (Am), Ap, HgMn, and helium-weak stars. Additionally, there are other subclasses of chemically peculiar stars, such as λ Bootis stars (Faraggiana & Gerbaldi 1998) and helium-strong objects (Pedersen & Thomsen 1977). The Am, Ap, and λ Bootis stars share a similar temperature type, approximately between A and F (Paunzen 2024), but they exhibit distinct chemical compositions. Am stars show an overabundance of iron-peak elements while having weak Ca and Sc lines (Conti 1970). The chemical peculiarities in Am stars are thought to be mainly caused by diffusion of elements and the loss of the outer convection zone due to helium settling (Théado et al. 2005; Aurière et al. 2010). Ap stars exhibit an overabundance of certain elements such as Eu, Sr, and Cr and they are known by their strong magnetic fields (Gray & Corbally 2009; Alecian 2015). The chemical peculiarity in these systems is caused by the magnetic diffusion processes which tend to raise certain chemical elements to accumulate near the magnetic poles (Aleician 2015). In contrast of Am and Ap stars, λ Bootis stars display a metal-deficient atmospheric structure (Faraggiana & Gerbaldi 1998). In the case of λ Bootis stars, their peculiar chemical patterns are thought to result from the accretion of material from the interstellar medium (Kamp & Paunzen 2002).

Some chemically peculiar stars were found to display oscillations (Smalley et al. 2011; Murphy & Paunzen 2017). One such class is the δ Scuti variables, which are A–F type stars pulsating in the frequency range of $\sim 5\text{--}80\text{ d}^{-1}$ with pressure and mixed modes (Breger 2000; Aerts et al. 2010; Chang et al. 2013). These variables lie within their own instability strip, overlapping with the instability domain of γ Doradus stars. γ Doradus stars, typically F-type, oscillate at lower frequencies (below 5 d^{-1}) in gravity modes (Kaye et al. 1999). Within the overlapping region of the instability strips of these pulsating stars, hybrid pulsators, which simultaneously exhibit the pulsation characteristics of both types of variables, are located (Handler & Shobbrook 2002; Uytterhoeven et al. 2011).

Pulsations in Am stars were initially unexpected due to atomic diffusion and gravitational element settling (Kurtz 1976; Turcotte et al. 2000). However, it is now well established that many δ Scuti and γ Doradus stars exhibit chemical peculiarities (Smalley et al. 2017; Niemczura et al. 2017; Antoci et al. 2019). Investigating these peculiar pulsating stars is crucial to understanding how chemical anomalies influence oscillations. Smalley et al. (2017) studied a large sample of δ Scuti Am stars using low-resolution LAMOST spectra and ground-based photometric data from the WASP (the Wide Angle Search for Planets). They found that δ Scuti Am stars are predominantly located near the cool edge of the δ Scuti instability strip. The effect of metallicity on pulsation was also investigated in this study; however, no significant correlation between oscillation properties and metallicity was found. Moreover, δ Scuti-type pulsations in Am stars could not be fully explained by the conventional κ mechanism alone. In

Received: 2025 March 26; Accepted: 2025 August 5

© The Author(s) 2025. Published by Oxford University Press on behalf of the Astronomical Society of Japan. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Table 1. Information about the targets.*

HD number	Star name	RA [°]	Dec [°]	V [mag]	Spectral type	Reference
1097	AU Scl	3.78	−29.01	9.05	A3/5mF0-F5	Houk (1982)
11956	FG Eri	28.95	−55.07	6.71	kF0hA5mF0V	Paunzen et al. (2001)
23194	V1187 Tau	56.00	24.56	8.07	A4-A7m	Renson and Manfroid (2009)
75654	HZ Vel	132.47	−39.14	6.37	hF0mA5V	Paunzen (2001)
95321	V527 Car	164.84	−58.12	9.10	A3mA7-A9	Houk and Cowley (1975)
104513	DP UMa	180.53	43.05	5.21	F0Vam	Rodríguez et al. (2000)
107513	KU Com	185.36	24.99	7.38	kA7hF0mF0IV	Ghazaryan, Alecian, and Hakobyan (2018)
125081	MX Vir	214.42	−21.83	7.35	kF2hF5mF5II	Renson and Manfroid (2009)
					F3 Sr Cr Eu	
143232	IO Lup	240.19	−39.09	6.66	A5mA5-F2	Rodríguez et al. (2000)
213204	UV PsA	337.55	−30.44	8.39	F1m	Smalley et al. (2011)

*The spectral types given in this table were taken from literature studies as cited in the last column.

Table 2. Observational information.*

Star name	TESS sector	Spectrograph	S/N
AU Scl	29	HARPS	120
FG Eri	2, 3, 29, 30, 69	HARPS	190
V1187 Tau	42, 43, 44, 70, 71	HARPS	170
HZ Vel	8, 9, 35, 62	HARPS	160
V527 Car	37	HARPS	140
DP UMa	22, 49, 76	SOPHIE	490
KU Com	22, 49	ELODIE	210
MX Vir	1	HARPS	170
IO Lup	65	HARPS	160
UV PsA	1, 28	HARPS	150

*The S/N (signal-to-noise) value for DP UMa is given considering the combined spectrum as explained in section 2.

the study by Antoci et al. (2014), the pulsations in these stars were explained for the first time by turbulent pressure, a result later supported by Smalley et al. (2017). More recently, Murphy et al. (2020b) and Dürfeldt-Pedros et al. (2024) provided further evidence that pulsations in chemically peculiar stars are more common than previously believed. Murphy et al. (2020b) demonstrated that δ Scuti type pulsations can exist with rapid oscillations in magnetic Ap stars, even under significant helium depletion and moderate magnetic field strengths. Additionally, Dürfeldt-Pedros et al. (2024) analyzed a large sample of metallic A and F stars using the Transiting Exoplanet Survey Satellite (TESS) and Gaia data and found that a substantial fraction of them exhibit pressure mode pulsations. Their results show that many of these pulsating chemically peculiar stars are located near the main sequence and cluster toward the red edge of the classical instability strip.

Even if some stars are classified as δ Scuti Am in the literature (Rodríguez et al. 2000), many of their classifications rely on photometric analysis and/or spectral analysis without detailed chemical abundance studies and this may cause misclassifications. These results could negatively affect the investigation into pulsating chemically peculiar stars. Therefore, to control peculiarity classification, we selected some target stars for in-depth analysis to accurately determine their atmospheric parameters and chemical compositions.

We determined the targets based on several criteria. They were selected from the catalog of δ Scuti stars (Chang et al. 2013) through a review of the literature. First, we focused on δ Scuti stars that are identified as chemically peculiar based on their spectral types, and for which there is a need of detailed spectroscopic study for determinations chemical abundances of individual elements available in the literature.

Additionally, we only considered stars with available public spectroscopic data. Following this process, a set of potential targets was identified, and from this group, only those with TESS data were selected to investigate pulsation properties in detail with the same source of data for all targets. Information about the targets is provided in table 1 and literature information of the selected targets is given in the Appendix. The paper is organized as follows. In section 2, details about photometric and spectroscopic data are given. The spectral analysis to determine the spectral classification, atmospheric parameters, and also the chemical abundances of individual elements is presented in section 3. The photometric investigation is introduced in section 4. Discussion and conclusions are given in the last section, section 5.

2 Photometric and spectroscopic data

The TESS photometric data for the targets were used in the analysis. TESS provides at least approximately 27 days of data for each target, depending on the objects's position in the sky (Ricker et al. 2015). These photometric data are available in the Mikulski Archive for Space Telescopes (MAST),¹ with varying fluxes and exposure lengths depending on the specific TESS observations. The exposure times of the TESS data are 120 s, 200 s, 600 s, and 1800 s. Since our targets are δ Scuti type pulsators with pulsation frequencies ranging around from 5 to 80 d^{−1} (Rodríguez et al. 2000; Chang et al. 2013), and considering the Nyquist frequency of the TESS data, we chose to use the 120 s TESS data for our analysis. We selected the pre-search aperture photometry (PDSCAP) data for the analysis (Ricker et al. 2015). The available TESS sector data for our targets are listed in table 2. Since TESS pixels are relatively large (21"), there is a possibility of contamination from nearby sources. To minimize this, we examined the TESS pixel-level data and ensured that the extracted flux predominantly originates from our target. Figure 1 shows an example of a pixel file for one of our targets (V1187 Tau), where the flux is clearly concentrated within the selected aperture and no significant contamination from nearby sources is evident.

Spectroscopic data for the selected targets were retrieved from public spectral databases. High-resolution spectra for the targets were found in the European Southern Observatory (ESO) Science Archive Facility (SAF, Romaniello et al. 2023),² ELODIE,³ and SOPHIE⁴ archives. The ESO SAF in-

¹ (<https://mast.stsci.edu/>).

² (<http://archive.eso.org/cms.html>).

³ (<http://atlas.obs-hp.fr/elodie/>).

⁴ (<http://atlas.obs-hp.fr/sophie/>).

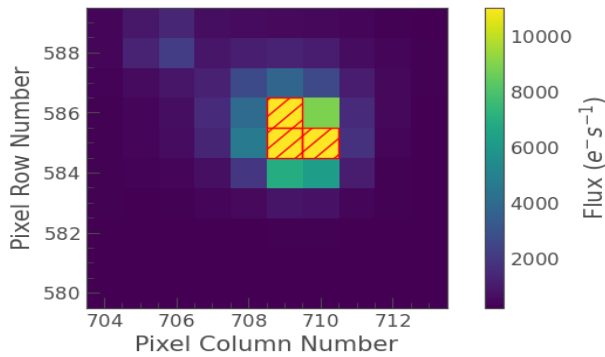


Fig. 1. TESS target pixel file image for V1187 Tau. The color scale represents the flux intensity recorded in each pixel. The over-plotted hatched region indicates the photometric aperture used to extract the light curve, centered on the main flux-contributing source.

cludes spectra taken with spectrographs attached to ESO telescopes at the La Silla Paranal Observatory. One of the ESO spectrographs is the High Accuracy Radial Velocity Planet Searcher (HARPS), an échelle spectrograph with a resolving power of 80000, which provides spectra within a wavelength range of 378–691 nm (Mayor et al. 2003). The ELODIE and SOPHIE échelle spectrographs were mounted on telescopes at the Observatoire de Haute-Provence (OHP). These have resolutions of 42000 and 75000, respectively, and offer spectra in the wavelength ranges 385–680 nm for ELODIE and 387–694 nm for SOPHIE (Moultaka et al. 2004; Perruchot et al. 2008).

Except for DP UMa, all targets have only a single spectrum. When DP UMa was selected for this study, six spectra taken in 2020 were available in the SOPHIE archive. Therefore, we used these six spectra in our analysis for this target. After collecting the spectra of the targets they were normalized using the SUPNET program (Rózański et al. 2022). After normalization, the spectra of each target were examined for possible effects of a binary component (if present). In addition, a cross-correlation technique was applied using the IRAF FXCOR package (Tody 1986),⁵ but no evidence of a secondary component was found in the spectra. The normalized spectra of DP UMa were combined to obtain a combined spectrum with higher signal-to-noise ratio. The details about the spectroscopic data and the signal-to-noise (S/N) ratio of the spectra are given in table 2.

3 Spectral analysis

The spectroscopic data of the targets were used to estimate their atmospheric parameters such as effective temperature (T_{eff}), surface gravity ($\log g$), chemical composition, and projected rotational velocity ($v \sin i$). With this information, we can understand the chemical nature of the targets and reclassify them based on their chemical compositions.

Before determining the atmospheric parameters and the chemical composition, we performed spectral classification for the targets. The spectral classification provides preliminary and crucial information about the stars' chemical properties and atmospheric parameters (Gray & Corbally 2009; Niemczura et al. 2014). The spectral classification was used to estimate the temperature type (e.g., A0, A2) and lumi-

nosity class (e.g., V, IV) of the targets by comparing the observed spectra with standard stars, as outlined in Gray and Corbally (2009). During this process, we specifically compared the hydrogen, metal, and Ca II K lines (if available) to ensure accurate classification, particularly for chemically peculiar stars. This method is detailed in Kahraman Aliçavuş et al. (2016). The estimated spectral classifications are listed in table 3.

As observed from the spectral classifications, some stars exhibit different temperature types depending on whether hydrogen (h), metal (m), or Ca II K (k) lines are considered. If there is a significant subclass difference between the temperature types derived from metal and Ca II K lines, and if the metal lines suggest a cooler temperature type, the star is classified as a metallic-line (Am) star. Conversely, if the temperature type derived from the metal lines indicates a hotter type, the star is categorized as a metal-weak star. According to the spectral classification presented in table 3, AU Scl and FG Eri appear to be exhibiting Am type spectral classification, while HZ Vel seems a metal-weak star. Even though spectral classification provides an idea about the T_{eff} values and chemical structure of stars, it should be noted that this method is subjective and involves higher uncertainties compared to spectral analysis. Therefore, for a reliable classification of peculiarities, determining the chemical abundance pattern of the stars is the most accurate approach.

3.1 Determination of the atmospheric parameters

Before determining the spectroscopic atmospheric parameters, to have an initial value for the T_{eff} and $\log g$, we first estimated the T_{eff} and $\log g$ parameters using photometric colors. Since these colors are influenced by interstellar reddening, $E(B - V)$, we calculated these values using the dust map from Green et al. (2019). After determining the $E(B - V)$ values for each target, we gathered the photometric colors from the Tycho-2 catalog (Høg et al. 2000), 2MASS catalog (Cutri et al. 2003) and the Stroemgren–Crawford $uvby\beta$ photometry catalog (Pauzen 2015). We estimated the photometric T_{eff} values from each of the collected photometric colors using the studies of Sekiguchi and Fukugita (2000), Masana, Jordi, and Ribas (2006), and Moon and Dworetzky (1985). The $\log g$ values were also computed from the $uvby\beta$ photometry based on Moon and Dworetzky's (1985) study. The estimated photometric atmospheric parameters and $E(B - V)$ values for each target are listed in table 3.

These photometric atmospheric parameters were then used as input for the spectroscopic analysis. In all spectroscopic analyses, we utilized the ATLAS9 model atmospheres (Kurucz 1993) along with the SYNTHE code (Kurucz & Avrett 1981) to generate synthetic spectra. Initially, hydrogen Balmer lines were used to estimate T_{eff} . If the star was hotter than 8000 K, the $\log g$ parameters were then determined, as the effect of $\log g$ is negligible for stars cooler than 8000 K (Niemczura et al. 2014). For these cooler stars we fixed the $\log g$ value as 4.0. In the Balmer lines analysis, the best-fitting theoretical Balmer lines were determined using the method of Catanzaro, Leone, and Dall (2004). In addition to atmospheric parameter determination with the Balmer line analysis, we also utilized the Saha–Boltzmann expression. According to this expression, the abundances of an element derived from different ionizations or excitations of the element must be the same. We utilized this idea and took into account the most

⁵ (<https://iraf.readthedocs.io>).

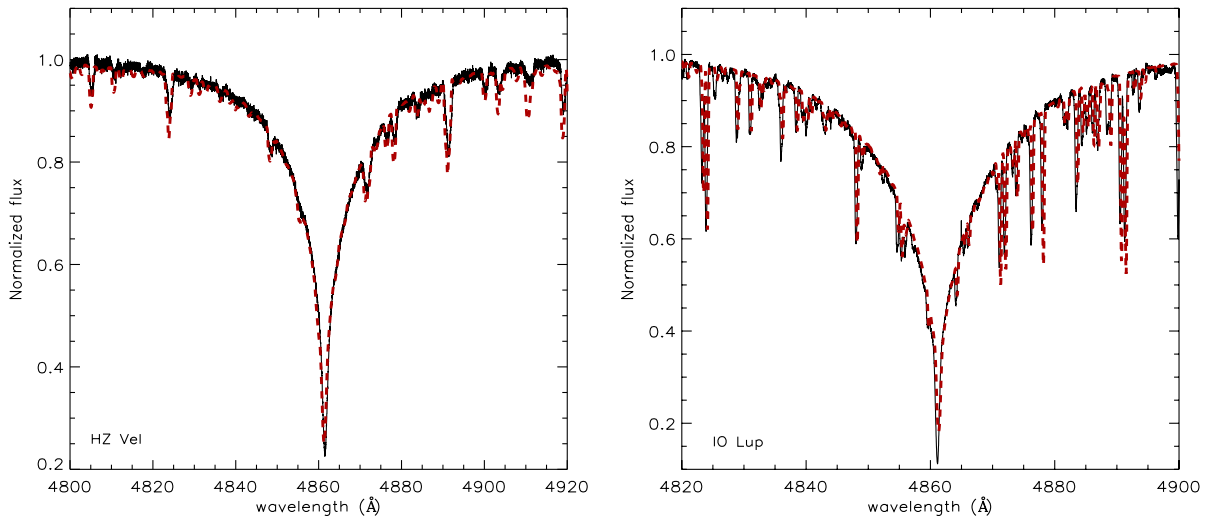
Table 3. Updated spectral classification, $E(B - V)$ values, and atmospheric parameters derived from photometric indices.*

Star name	Spectral class	$E(B - V)$ [mag]	T_{eff}^{UBV} [K]	T_{eff}^{VK} [K]	$T_{\text{eff}}^{uvby\beta}$ [K]	$\log g^{uvby\beta}$ [cgs]
AU Scl	kA4hA3mF3 IV/V	0.054	6770 ± 178	7410 ± 80	7200 ± 120	4.85 ± 0.20
FG Eri	kA7hA7mF0 V	0.010	8090 ± 152	7700 ± 120	8050 ± 100	3.48 ± 0.11
V1187 Tau	A5/6 V	0.031	7890 ± 145	7910 ± 120	8370 ± 100	4.37 ± 0.15
HZ Vel	hF0mA5 V	0.000	7540 ± 160	7190 ± 100	8700 ± 150	3.70 ± 0.15
V527 Car	A3/4 IV	0.043	8110 ± 290	7500 ± 130		
DP UMa	F0 IV	0.000	6800 ± 155	7500 ± 150	7400 ± 120	4.10 ± 0.12
KU Com	F0 V	0.000	7380 ± 120	7230 ± 100	7270 ± 120	4.01 ± 0.10
MX Vir	kF3hF5mF5 IV-III	0.012	6575 ± 100	6440 ± 80	6850 ± 80	3.70 ± 0.10
IO Lup	F0 IV	0.005	7595 ± 130	7580 ± 100	7760 ± 100	3.75 ± 0.13
UV PsA	F2/IV	0.060	7160 ± 170	7310 ± 135	7000 ± 90	3.77 ± 0.12

*The standard error for $E(B - V)$ is 0.002 mag.**Table 4.** Atmospheric parameters obtained from hydrogen Balmer and iron (Fe) lines' analysis.*

Star name	$T_{\text{eff}}^{\text{Balmer}}$ [K]	$T_{\text{eff}}^{\text{Fe}}$ [K]	$\log g^{\text{Fe}}$ [cgs]	ξ [km s ⁻¹]	$v \sin i$ [km s ⁻¹]	$\log \epsilon$ (Fe)
AU Scl	7000 ± 200	7300 ± 150	4.4 ± 0.2	2.6 ± 0.2	67 ± 4	8.01 ± 0.17
FG Eri	7700 ± 200	7800 ± 200	4.3 ± 0.1	1.8 ± 0.2	110 ± 5	7.67 ± 0.16
V1187 Tau	8000 ± 150	8100 ± 100	4.0 ± 0.1	2.3 ± 0.2	37 ± 2	7.30 ± 0.15
HZ Vel	7400 ± 150	7800 ± 100	4.0 ± 0.1	3.1 ± 0.2	45 ± 2	6.95 ± 0.12
V527 Car	7300 ± 200	7700 ± 150	4.1 ± 0.1	2.8 ± 0.1	78 ± 3	7.28 ± 0.15
DP UMa	7000 ± 200	7100 ± 100	4.2 ± 0.1	3.2 ± 0.2	72 ± 2	7.31 ± 0.15
KU Com	7100 ± 200	7100 ± 150	4.0 ± 0.1	3.0 ± 0.1	64 ± 3	7.29 ± 0.14
MX Vir	7200 ± 100	7000 ± 100	4.1 ± 0.1	3.2 ± 0.2	15 ± 1	7.43 ± 0.12
IO Lup	7500 ± 200	7500 ± 100	4.0 ± 0.1	2.5 ± 0.1	18 ± 2	6.12 ± 0.38
UV PsA	7100 ± 150	7000 ± 100	4.1 ± 0.1	2.3 ± 0.2	74 ± 3	7.51 ± 0.16

*The Fe/H value.

**Fig. 2.** Theoretical spectral fits (red dashed lines) of the observed H β lines (black solid lines) for two of our targets.

abundant lines of iron (Fe) due to the multitude of possible transitions between energy levels in our stars' T_{eff} range. During this analysis, the spectrum synthesis method was applied and also the $v \sin i$ values were estimated simultaneously. Details about the analysis can be found in the study of Kahraman Aliçavuş et al. (2016). The results of the spectroscopic analysis are listed in table 4, and the best-fitting theoretical spec-

tra to the Balmer lines are shown in figure 2 for two of our targets.

3.2 Analysis of chemical abundances

After determining the atmospheric parameters for each target, we performed a chemical abundance analysis using these parameters, which were derived from the analysis of Fe lines, as

fixed inputs. Before the chemical abundance analysis, the lines in the spectra of the targets were identified using the Kurucz line list.⁶ Once the lines in each target's spectrum were defined, the spectrum synthesis method was employed to determine the chemical compositions. In this method, the abundance ratios of the elements responsible for the lines are adjusted until the theoretical spectrum closely matches the observed spectral lines. The ATLAS9 model atmospheres and SYNTHE code were used in this analysis as well.

As a result of the chemical abundance analysis, we determined the absolute chemical abundance [$\log \epsilon(\text{Element})$] of elements for each target. The list of absolute chemical abundances is provided in table 7 in the Appendix and the [Fe/H] values for each target is listed in table 4. Furthermore, the distribution of chemical abundances of the targets is shown in figure 3. The uncertainties in the derived absolute chemical abundances were estimated by considering the errors in the input atmospheric parameters as explained in the study of Kahraman Aliçavuş et al. (2016). For this, we systematically changed the atmospheric parameters to evaluate the impact on the derived elemental abundances, in particular in the absolute Fe abundance [$\log \epsilon(\text{Fe})$]. A variation of $\pm 100\text{K}$ in T_{eff} creates a change of approximately 0.07 dex in $\log \epsilon(\text{Fe})$. In comparison, a ± 0.1 dex shift in $\log g$ and $\pm 0.1 \text{ km s}^{-1}$ in ξ result in changes of around about 0.01 and 0.02 dex, respectively. We also assessed the influence of $\nu \sin i$ on abundance determinations. Our results indicate that $\nu \sin i$ introduces uncertainties ranging from ~ 0.05 to 0.15 dex. These error sources were combined in quadrature and given as uncertainties in absolute abundances (see table 7).

4 Photometric analysis

4.1 Pulsation analysis

The 120s photometric TESS data of the targets were collected and they were converted into magnitude before investigating the oscillations. To convert the fluxes into magnitudes, the equation given by Kahraman Aliçavuş et al. (2022) was used.

The oscillation properties of the targets were examined using the PERIOD04 software (Lenz & Breger 2005), which applies a discrete Fourier transform and successive prewhitening. Given that the targets were previously identified as δ Scuti variables (see the Appendix), the frequency search was conducted in the range of $0\text{--}100 \text{ d}^{-1}$ with a significance threshold set at 4.5σ (Baran & Koen 2021). All available TESS sectors for each star were analyzed simultaneously.

The significant oscillation frequencies (f) and their corresponding amplitudes are provided in table 8 in the Appendix, while the amplitude spectra of all targets are displayed in figure 4. According to the extracted frequencies and their amplitudes, all stars display variability consistent with δ Scuti-type pulsations. However, several stars exhibit additional low-frequency variability. Among them, AU Scl, MX Vir, IO Lup, UV PsA, and V1187 Tau were confirmed as δ Scuti variables. Although a few low-frequency peaks were detected in V1187 Tau, they are likely due to small flux level shifts between sectors. Conversely, stars such as FG Eri, HZ Vel, V527 Car, DP UMa, and KU Com show both low- and high-frequency pulsations, suggesting hybrid behavior between δ Scuti and

γ Doradus types. The pulsation classifications are listed in table 5.

In addition, we computed the pulsation constant (Q) for the dominant frequency of each target using the classical equation of Breger (1990), together with the stellar parameters (e.g., T_{eff} , $\log g$, M_{bol}) derived in the previous sections. The derived Q values are also presented in table 5. These values provide useful constraints on the nature of the dominant oscillations (e.g., low-overtone radial or non-radial modes), although definitive mode identification (i.e., determination of radial order n , spherical degree l , and azimuthal order m) is not attempted in this study due to the lack of spectroscopic mode diagnostics or rotational splitting analysis. Therefore, we refrain from assigning specific mode identifications and instead provide only general pulsational classifications based on the observed frequency regime and Q values.

5 Estimating fundamental stellar parameters

We estimated fundamental stellar parameters and the ages of the stars using evolutionary tracks and isochrones. Prior to these estimations, we also calculated other key parameters, such as luminosity (L), absolute magnitude (M_V), and bolometric magnitude (M_{bol}), using Gaia DR3 distances (Gaia Collaboration et al. 2023) and bolometric corrections (Flower 1996) based on the derived T_{eff} and $E(B - V)$ values. For these calculations, we followed the method described in Poro et al. (2021). The uncertainties of the calculated parameters were estimated by propagating the errors of the input parameters. These parameters and their uncertainties are listed in table 6. It should be noted that, beyond these uncertainties, the possible presence of unresolved binary components may introduce additional errors in the estimated parameters of L , M_V , and M_{bol} .

For the estimation of mass (M) and age, we used evolutionary tracks and isochrones from MESA and Stellar Tracks (MIST) (Dotter 2016; Choi et al. 2016). Details about the adopted physics used to generate the MIST evolutionary tracks and isochrones can be found in table 1 of Choi et al. (2016). The evolutionary tracks adopted in this work assume an initial rotational velocity of $\nu/\nu_{\text{crit}} = 0.4$, implying that the stars initially rotate at 40% of their critical breakup speed. This parametrization allows for moderate rotational mixing, which can influence surface abundances and stellar lifetimes, particularly in intermediate- and high-mass stars. For each target, multiple evolutionary tracks and isochrones were generated, taking into account the calculated [Fe/H] values. The tracks and isochrones were computed with steps of $0.01 M_{\odot}$ in M and the same steps in age. Using these, we estimated the M and age values by matching the observed T_{eff} and L values on the $\log T_{\text{eff}}\text{--}\log L$ diagram. Two of our targets, V1187 Tau and KU Com, are members of clusters Melotte 22 and 111, respectively. For M value estimation of these systems we adopted the cluster ages from Dias et al. (2021) and fixed them during the examinations. The estimated masses and ages are listed in table 6. The locations of the targets on the $\log T_{\text{eff}}\text{--}\log L$ diagram, within the δ Scuti instability strip and along the isochrones, are shown in figure 5. The uncertainties in the estimated mass and age values were derived by considering the propagated errors in the stellar parameters T_{eff} , $\log L$, and [Fe/H], which directly affect the stars' positions on the Hertzsprung–Russell (H-R) diagram and thus

⁶ (<http://kurucz.harvard.edu/linelists.html>).

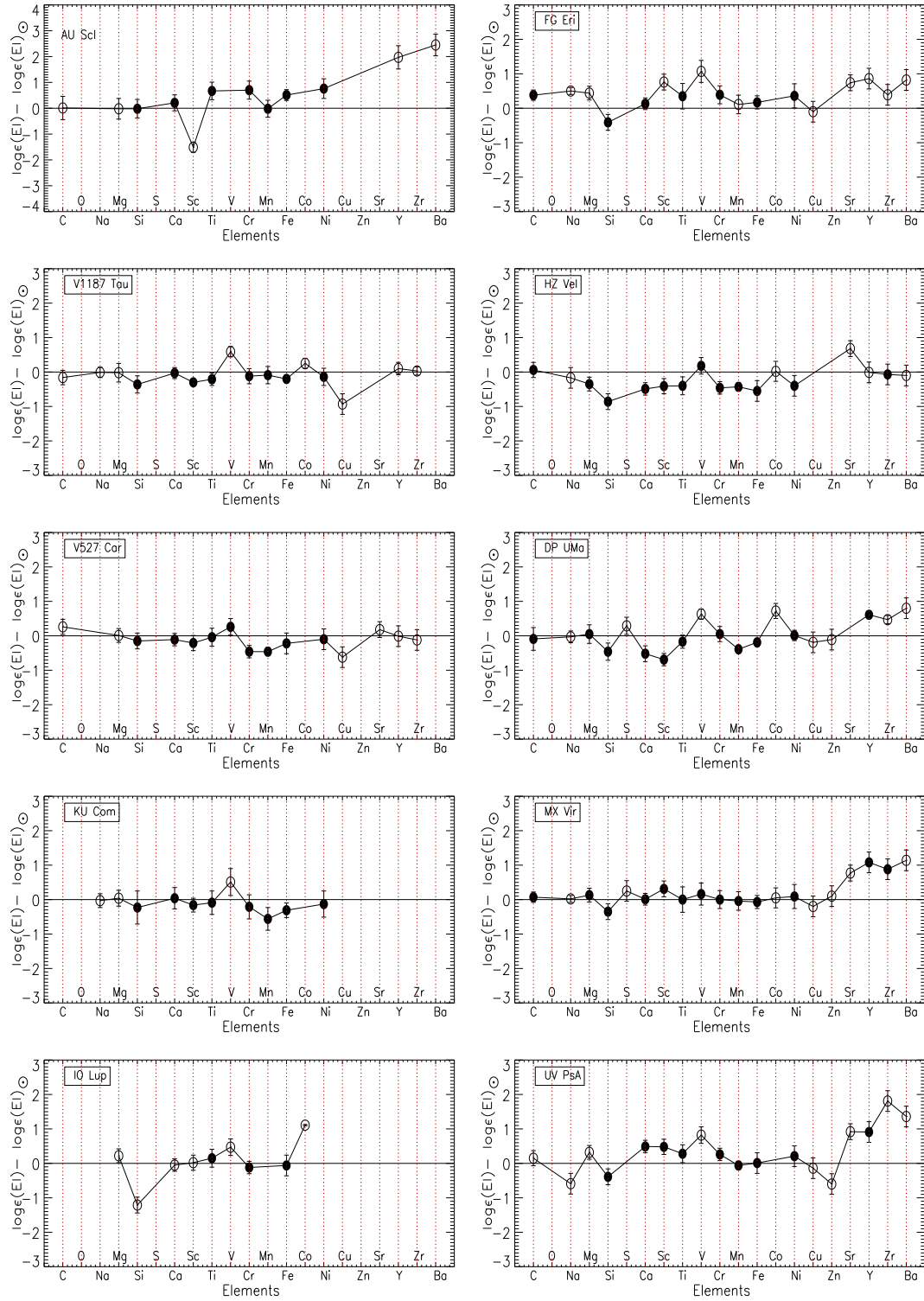


Fig. 3. Chemical abundance distribution compared to solar abundances (Asplund et al. 2009). The filled and open symbols represent the number of lines used to estimate the chemical abundances of individual elements. Filled symbols indicate abundances determined from five or more lines, while open symbols correspond to abundances derived from fewer than five lines.

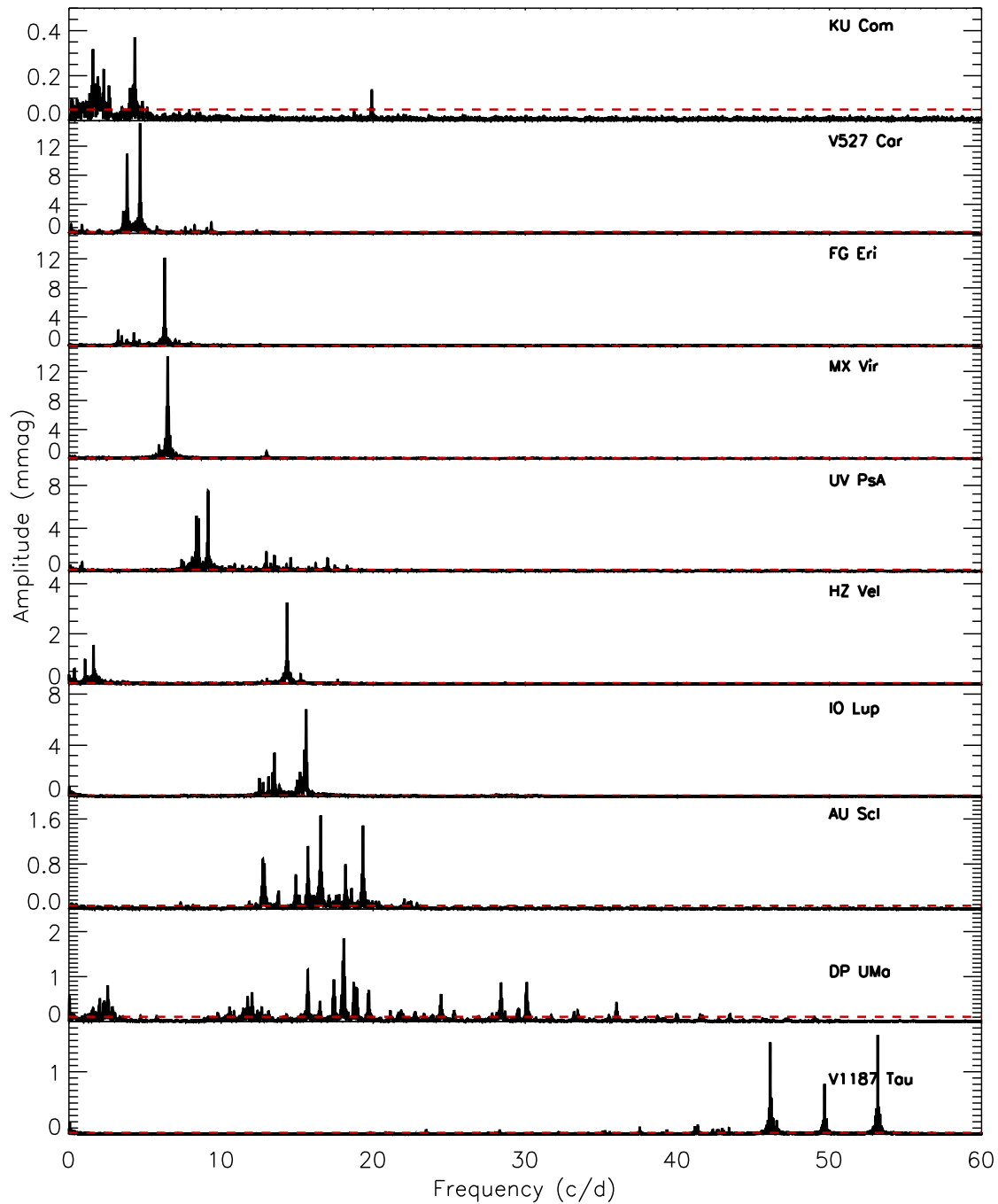


Fig. 4. Amplitude spectra of the targets. Dashed vertical lines represent the 4.5σ level.

Table 5. List of the highest amplitude δ Scuti frequencies and their pulsation constant (Q) values.

Star name	Pulsation class	High. amp. frequency [d^{-1}]	Q [d]
AU Scl	δ Scuti	16.5501	0.033 (6)
FG Eri	Hybrid	6.2921	0.060 (11)
V1187 Tau	δ Scuti	53.1771	0.009 (2)
HZ Vel	Hybrid	14.3398	0.031 (6)
V527 Car	Hybrid	9.3603	0.033 (3)
DP UMa	Hybrid	18.0751	0.032 (6)
KU Com	Hybrid	19.9108	0.023 (4)
MX Vir	δ Scuti	6.4950	0.057 (10)
IO Lup	δ Scuti	15.5946	0.020 (4)
UV PsA	δ Scuti	9.1511	0.043 (8)

the resulting evolutionary track fitting. In addition to these statistical sources of uncertainty, we also included systematic lower limits following the findings of Tayar et al. (2022), who demonstrated that even under optimal conditions, isochrone-based determinations are subject to minimum uncertainties of $\sim 5\%$ in mass and $\sim 20\%$ in age. These systematic floors were incorporated into the final uncertainties to provide more realistic error bars.

In addition to fundamental stellar parameters' estimation we also controlled the position of these pulsating components on the δ Scuti instability strip, as can be seen in figure 5. All stars in our sample were found to lie inside or close to the red edge of the δ Scuti instability strip, within the uncertainties.

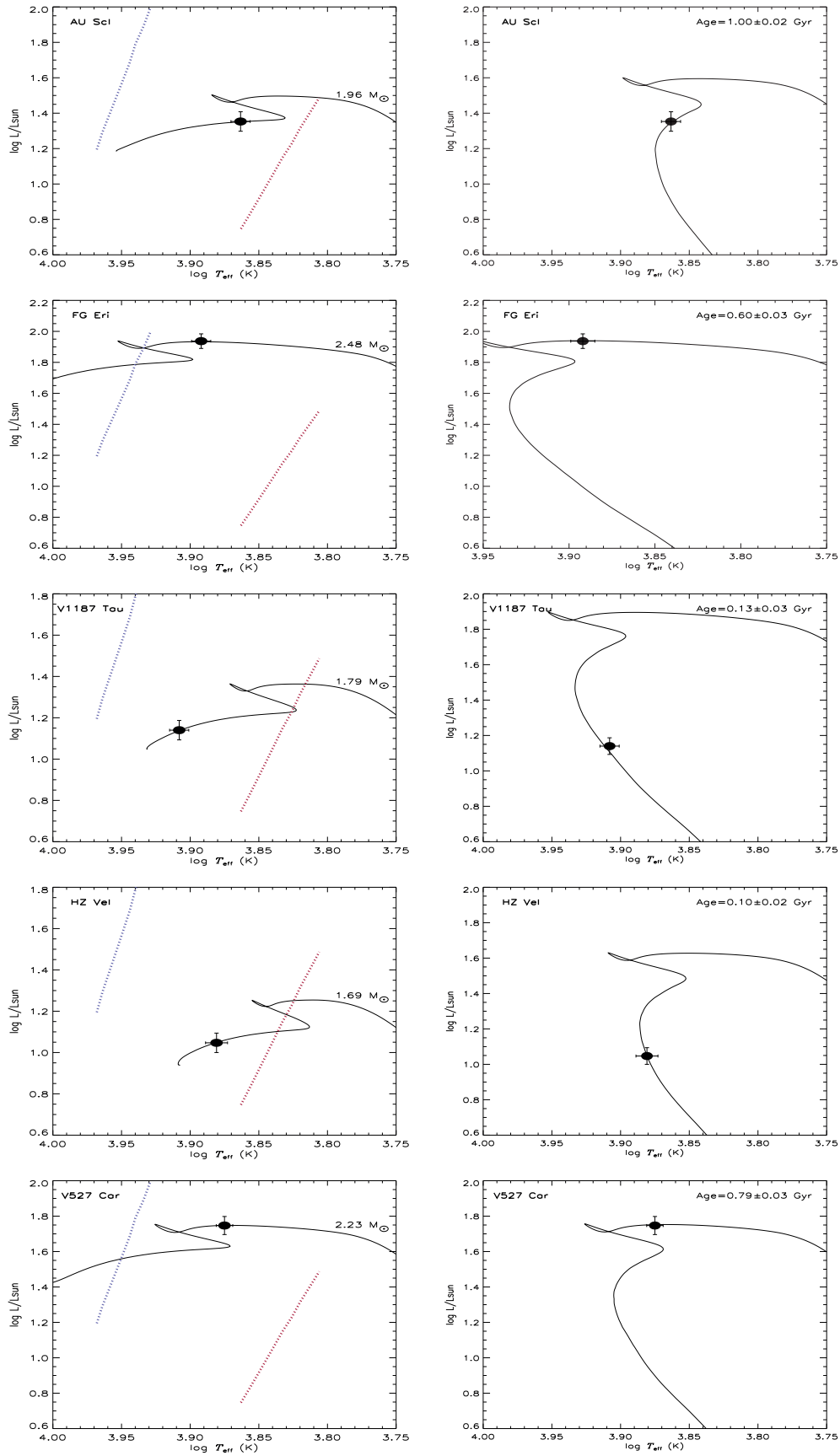


Fig. 5. Evolutionary tracks (left-hand panels) and isochrones (right-hand panels) for targets. The evolutionary tracks and isochrones were generated considering the Fe/H of each targets. The dotted lines represent the cool (upper) and hot (lower) observational borders of the δ Scuti instability strip (Murphy et al. 2019).

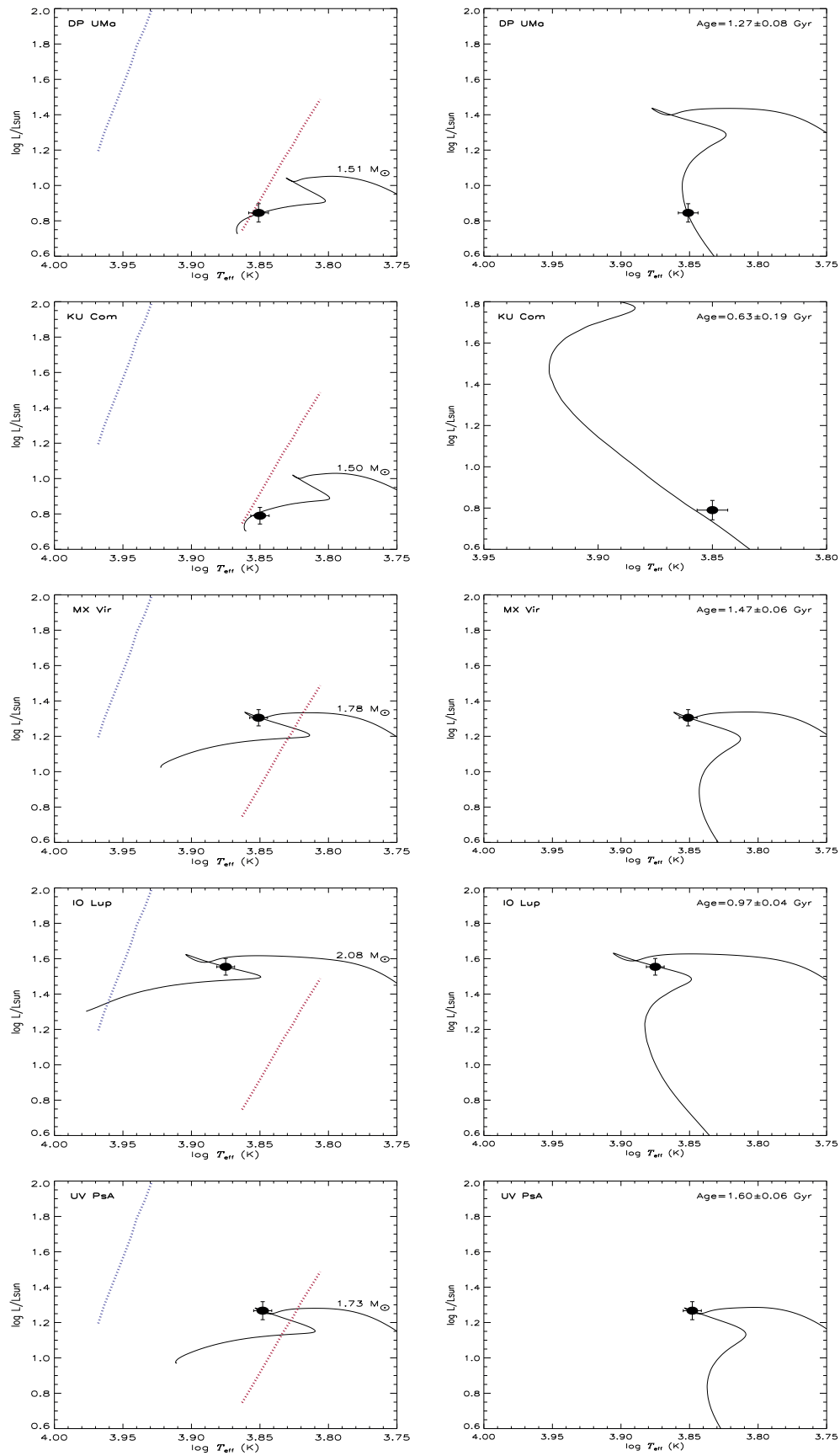


Fig. 5. (Continued)

6 Discussion and conclusion

In this study, we examined 10 targets identified in the literature as δ Scuti variables and chemically peculiar stars (see the Appendix 1). Although some of the selected stars have been previously studied, a detailed chemical abundance analysis has not been conducted for all of them. Therefore, we first revised their spectral classifications, determined their atmospheric parameters and $\nu \sin i$ values, and derived the abundances of individual elements. Using this information, we analyzed the chemical peculiarity properties of these targets.

We first carried out spectral classification for all targets and, as a result, found that only three stars—AU Scl, FG Eri, and HZ Vel—are likely chemically peculiar. However, the other stars were found to be chemically normal based on our spectral classification, which contradicts their classifications in the literature (see table 1). Since the spectral classification was performed manually and is inherently subjective, we carried out a detailed chemical abundance analysis to confirm the chemical composition of the stars. In advance to chemical abundance analysis, the atmospheric parameters of the targets were determined. Most of our targets have atmospheric parameter estimates available in the literature. For example, five of them—AU Scl, FG Eri, MX Vir, IO Lup, and UV PsA—were analyzed by Rainer et al. (2016), who investigated high-resolution HARPS spectra of a large sample of stars to determine atmospheric parameters (for details, see the Appendix). We also used HARPS spectra in our spectral analysis. However, the $\log g$ and $[\text{Fe}/\text{H}]$ values obtained by Rainer et al. (2016) and those derived in this study are mostly inconsistent with each other. This discrepancy may result from differences in the methods and models used in both studies, as well as the fact that their analysis involved a significantly larger number of stellar spectra.

For V1187 Tau, the atmospheric parameters based on spectral analysis were reported by Draper et al. (2018) as $T_{\text{eff}} = 8031$ K, $\log g = 4.0$, and $[\text{Fe}/\text{H}] = -0.17$. When compared to our results, they are in agreement within the error bars, except for the $[\text{Fe}/\text{H}]$ value. For DP UMa, Catanzaro and Ripepi (2014) provided the spectral parameters as $T_{\text{eff}} = 7200$ K, $\log g = 3.6$, and $\nu \sin i = 72 \text{ km s}^{-1}$. These values are generally consistent with ours, although the $\log g$ value shows a significant difference (our value is 4.2). For the final target, KU Com, Prugniel, Vauglin, and Koleva (2011) reported $T_{\text{eff}} = 7360$ K, $\log g = 3.99$, and $[\text{Fe}/\text{H}] = -0.05$, all of which agree with our findings within uncertainties while $[\text{Fe}/\text{H}]$ differs from ours ($[\text{Fe}/\text{H}] = -0.21$). The differences between our results and those in the literature could be because of the methods followed, the atmospheric models used, and the line list. For the other objects, V527 Car and HZ Vel, no spectral atmospheric parameter estimates are available in the literature.

After the estimation of atmospheric parameters, the chemical abundances of the targets were derived. As given in the Appendix, most of the targets have been classified as Am stars in the literature, which exhibit an overabundance of iron-peak elements (Gray & Corbally 2009), and some of the targets have also been identified as metal-weak λ Bootis stars, characterized by under-abundances of iron-peak elements (Gray & Corbally 2009). Therefore, considering all chemically peculiar star types along with our chemical abundance results obtained in this study, we reclassified the peculiarities of the stars. Based on our analysis, we identified three chemically peculiar stars among our targets. AU Scl and FG Eri were classi-

fied as Am stars, while HZ Vel exhibited typical λ Bootis-type chemical properties. The remaining objects were classified as normal stars based on their abundance distributions. Among the target stars, only two objects—AU Scl and FG Eri—were identified as metallic A stars based on our spectroscopic analysis. AU Scl is located within the region of the H-R diagram suggested for pulsating Am stars by Smalley et al. (2017) and Dürfeldt-Pedros et al. (2024), whereas FG Eri deviates from this common location expected for metallic A stars. Notably, FG Eri exhibits a relatively high pulsation constant. When considered together with the distinct position of FG Eri on the H-R diagram and its chemical peculiarities, these findings make it an interesting case for further theoretical investigation. FG Eri may represent a transition object or an outlier that could provide constraints on models of pulsation in metallic A stars.

The pulsation structures of the targets were also examined, and their pulsation types were identified. According to the oscillation analysis, most of the stars were classified as δ Scuti variables, consistent with the literature classification (see the Appendix) and some were identified as δ Scuti- γ Doradus hybrids. The pulsation frequencies of eight of our targets (except for V1187 Tau and IO Lup) were examined by Barac et al. (2022) using TESS data. They provided the dominant δ Scuti frequencies for each target and these results are consistent with our findings. For V1187 Tau and IO Lup the dominant frequencies were given as 53.18 d^{-1} (Bedding et al. 2023) and 13.40 d^{-1} (Mellon et al. 2019), respectively, in their latest studies. While the result for V1187 Tau matches with ours, for IO Lup it differs because this study is based on the ground-based photometric observations.

In addition to estimating the pulsation frequencies for each target, we also determined the pulsation modes of the dominant (highest amplitude) frequency using the Q values and the $\log P_{\text{puls}} - M_V$ relationship. Furthermore, we presented the positions of the stars on the H-R diagram and within the δ Scuti instability strip. All targets were found to lie within or near the cool edge of the δ Scuti instability strip. While some of the hybrid stars (HZ Vel, DP UMa, KU Com) are located close to the cool edge as their suggested region, others are situated in the central region of the instability strip.

We estimated fundamental stellar parameters such as M and age for our targets. To achieve this, we first calculated the L for each target and then generated evolutionary tracks and isochrones based on the corresponding $[\text{Fe}/\text{H}]$ values. By identifying the best-fitting evolutionary tracks and isochrones that match the current positions of the stars on the H-R diagram, we determined the M and age values.

We conducted a detailed analysis of 10 possible chemically peculiar stars and found that most of them are, in fact, chemically normal. Such studies highlight the importance of spectroscopic analysis in reliably classifying stars as chemically peculiar. Even a basic spectral classification can provide valuable insights into chemical peculiarities; however, a more robust identification of chemically peculiar stars can be achieved through comprehensive spectroscopic investigations. Moreover, analyzing such stars is crucial for understanding the pulsation structures of δ Scuti stars and their relationship with the chemical abundances of individual elements, especially through spectral diagnostics.

Our findings further support recent results indicating that chemically peculiar A stars can indeed pulsate in the δ Scuti domain, challenging earlier assumptions that atomic

Table 6. Estimated fundamental stellar parameters for the targets.*

Star name	M_V [mag]	M_{bol} [mag]	$\log(L/L_\odot)$	M [$M_\odot$]	Age [Gyr]
AU Scl	1.326 ± 0.032	1.357 ± 0.034	1.353 ± 0.055	1.96 ± 0.10	1.00 ± 0.20
FG Eri	-0.135 ± 0.024	-0.103 ± 0.026	1.937 ± 0.047	2.48 ± 0.12	0.60 ± 0.12
V1187 Tau	1.800 ± 0.022	1.870 ± 0.052	1.148 ± 0.047	1.75 ± 0.09	$0.13 \pm 0.03^*$
HZ Vel	2.087 ± 0.023	2.121 ± 0.025	1.047 ± 0.046	1.69 ± 0.08	0.10 ± 0.02
V527 Car	0.322 ± 0.027	0.384 ± 0.029	1.743 ± 0.051	2.23 ± 0.11	0.79 ± 0.14
DP UMa	2.595 ± 0.029	2.627 ± 0.031	0.845 ± 0.052	1.51 ± 0.08	1.27 ± 0.23
KU Com	2.694 ± 0.024	2.774 ± 0.052	0.786 ± 0.057	1.50 ± 0.07	$0.63 \pm 0.19^*$
MX Vir	1.183 ± 0.014	1.263 ± 0.043	1.391 ± 0.064	1.78 ± 0.09	1.47 ± 0.27
IO Lup	0.820 ± 0.024	0.854 ± 0.026	1.554 ± 0.047	2.08 ± 0.10	0.97 ± 0.19
UV PsA	1.539 ± 0.028	1.572 ± 0.030	1.267 ± 0.051	1.73 ± 0.09	1.60 ± 0.28

*The age values are taken from Dias et al. (2021) and fixed during the examinations.

diffusion and helium settling would suppress such pulsations. The identification of AU Scl and FG Eri as metallic-line A stars with δ Scuti pulsations is consistent with the conclusions of Dürfeldt-Pedros et al. (2024), who found that many pulsating metallic A and F stars cluster near the red edge of the instability strip on the H-R diagram. Our spectroscopic results confirm AU Scl's position in this expected region, while FG Eri appears to deviate, which, along with its relatively large pulsation constant, renders it an interesting outlier that may provide constraints for future theoretical models. Understanding chemically peculiar stars with confirmed pulsational properties may contribute significantly to stellar structure and evolution theories, particularly in the transition region between chemically normal and peculiar A-type stars. Therefore, our work not only reassesses the classifications of several candidates but also adds spectroscopically verified examples to the growing population of pulsating CP stars, strengthening the empirical basis for such theoretical efforts.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

This work was supported by Çanakkale Onsekiz Mart University Research Foundation under project number FBA-2020-3219.

Acknowledgments

This study has been supported by Çanakkale Onsekiz Mart University Research foundation through project FBA-2020-3219. We thank the referee for the review and remarks. The TESS data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST). Funding for the TESS mission is provided by the NASA Explorer Program. This work has made use of data from the European Space Agency (ESA) mission Gaia (<http://www.cosmos.esa.int/gaia>), processed by the Gaia Data Processing and Analysis Consortium (DPAC; <http://www.cosmos.esa.int/web/gaia/dpac/consortium>). Funding for the DPAC has been provided by national institutions, in particular, the institutions participating in the Gaia Multilateral Agreement. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

Appendix 1 Literature information of targets

A.1.1 AU Scl

AU Scl was first reported in the list of early-type stars near the South Galactic pole given by Slettebak and Brundage (1971), and the spectral type of AU Scl was given to be A7p in this list. Graham and Slettebak (1973) discussed the spectroscopically peculiar stars near the South Galactic pole, and they noted that AU Scl could be a Peculiar A star of β CrB type or late-type Am star. Kurtz (1989) discovered δ Scuti variability in AU Scl (= HD 1097) for the first time and concluded that AU Scl is a classical Am star based on the spectral classification of A3/5mF0-F5 given by Houk (1982). Balona et al. (2011) listed the pulsating Am stars not in the Kepler field and gave the T_{eff} and $\log(L/L_\odot)$ of AU Scl to be 7586 K and 0.11, respectively, based on the photometric colors. Smalley et al. (2011) studied 1600 Am stars with SuperWASP data, and they gave the frequency, the amplitude, and the class of the pulsating Am star AU Scl as 15.5491 d^{-1} , 2.01 mmag , and δ Scuti, respectively. Rainer et al. (2016) formed a large database of the physical parameters and variability indicators of the variable and active stars using HARPS spectra, including AU Scl. In this study they estimated the atmospheric parameters of the star to be $T_{\text{eff}} = 6595 \text{ K}$, $\log g = 3.70$, and $\text{Fe/H} = 0.31$. Barac et al. (2022) studied δ Scuti stars and their period–luminosity relation using TESS and Gaia DR3 data. They gave the dominate frequency of AU Scl as 16.55 d^{-1} .

A.1.2 FG Eri

The first study of FG Eri was undertaken by Twarog (1980). Grenier et al. (1999) determined radial velocities of B8-F2 type stars observed by the Hipparcos satellite. They gave the T_{eff} and spectral type of FG Eri as 8500 K and A5V, respectively. Paunzen et al. (2001) presented a spectroscopic survey for λ Boo type stars listing the galactic stars, of which one of the list stars was FG Eri with spectral type kF0hA5mF0V. Royer et al. (2002) determined the rotational velocities of A-type stars using the spectra of 525 B8 to F2-type stars collected at ESO, and they derived the $v \sin i$ of FG Eri as $95 \pm 10 \text{ km s}^{-1}$. Xu et al. (2002) plotted the δ Scuti stars on the H-R diagram to examine the theoretical red edge. They found some stars which have higher luminosity and are located beyond the δ Scuti instability strip, one of which is FG Eri. They excluded these stars from their instability strip investigation. de Bruijne and Eilers (2012) determined the radial velocity errors for the Hipparcos–Gaia HTPM Project and gave the T_{eff} and $v \sin i$ of FG Eri as 7873 K and 107.2 km s^{-1} , respectively.

Rainer et al. (2016) formed a large database of the physical parameters and variability indicators of the variable and active stars using HARPS spectra, including FG Eri; in that study T_{eff} , $\log g$, and Fe/H were determined to be 8986 K, 3.93, and 0.71, respectively. Antoci et al. (2019) determined stellar parameters and variability type of the 2min cadence TESS δ Scuti and γ Doradus pulsators. They defined FG Eri's variability type as developed δ Scuti. Barceló Forteza et al. (2020) analyzed the δ Scuti stars using TESS data to propose the frequency at the maximum power, and classified the star FG Eri to be a δ Scuti/ γ Doradus hybrid. The dominant frequency measured with TESS of FG Eri was given in Barac et al. (2022) as 6.29d^{-1} .

A.1.3 V1187 Tau

V1187 Tau belongs to the open cluster Cl Melotte 22 (=Pleiades). Abt et al. (1965) gave the spectral type of the star as A5 V and noted that the radial velocity of V1187 Tau may vary slowly with time. Conti and Strom (1968) analyzed the chemical abundances of V1187 Tau, and eight stars in the Pleiades, and concluded that measured Sc/Sr ratios of these stars support the hypothesis that stars showing Sc/Sr ratios near unity are those with normal metal abundances. Pearce and Hill (1975) observed a total of 115 stars in the Pleiades at Dominion Astrophysical Observatory spectroscopically to investigate the binary friction and cluster membership, and they obtained a radial velocity value for V1187 Tau. Abt and Levato (1978) presented the spectral classifications and absolute magnitudes of stars in the Pleiades and noted that V1187 Tau was a marginal Am star with ranges of only 0.2–0.3 classes between the Ca II K and metallic-line types. Morse, Mathieu, and Levine (1991) measured the radial velocities of late O-B type and early A type stars, including V1187 Tau. Koen et al. (1999) detected a pulsation with a period of $\sim 30\text{min}$. for V1187 Tau, and concluded that V1187 Tau may be a marginal Am star in a binary system. Fox-Machado et al. (2002) presented the results obtained in the STEPHI X multi-site campaign for two δ Scuti stars (V624 Tauri and HD 23194 = V1187 Tau). They found that V1187 Tau is a multi-periodic, non-radial pulsator exhibiting two oscillation modes. Fox Machado et al. (2006) performed a seismological analysis of six δ Scuti stars, one of which was V1187 Tau, belonging to the Pleiades cluster to identify their frequency modes. They found two pulsation frequencies for V1187 Tau: 46.10 and 49.65 d^{-1} . Prugniel, Vauglin, and Koleva (2011) re-determined the atmospheric parameters of the stars in the medium spectral resolution library MILES containing V1187 Tau. They found the atmospheric parameters to be $T_{\text{eff}} = 8031\text{ K}$, $\log g = 4.00$ and $\text{Fe}/\text{H} = -0.17$. Bedding et al. (2023) studied a total of 89 A–F type members of open cluster Pleiades, and found the highest amplitude frequency to be 53.18 d^{-1} using TESS data.

A.1.4 HZ Vel

In the literature, the first information about HZ Vel was given in a study by Stokes (1972) based on $ubvy$ and H_{β} photometry. Balona (1977) searched the southern β CMA stars and noted that HZ Vel was a new δ Scuti star with pulsation period of 0.087d. Heck et al. (1977) applied a cluster analysis method and redetermined the spectral classification of HZ Vel to be A7-F2 III-V. Mersch and Heck (1980) determined the spectral classification of the star HZ Vel to be

A8 III using their algorithm based on $uvby\beta$ photometry and MK classification. Hauck (1986) included HZ Vel on the list of suspected λ Bootis stars in their search for these types of candidates; they studied the metallics of 132 stars considered as A and F giant stars and expressed that HZ Vel could be assumed to be λ Bootis star regarding its low metallicity value. Rodriguez et al. (1994) presented the updated list of δ Scuti stars, including HZ Vel. Paunzen et al. (1997) determined the distance and absolute magnitude of HZ Vel and the remaining λ Bootis type program stars to derive the evolutionary state of these stars using Hipparcos data. Paunzen et al. (1998) gave a list of pulsating λ Bootis stars, including HZ Vel. Paunzen et al. (1999) derived stellar parameters and abundances of their sample stars with HZ Vel. HZ Vel was included in the study of Faraggiana and Bonifacio (1999) as a λ Boo candidate star. Paunzen et al. (2002) re-observed HZ Vel and found two frequencies, 14.80 and 15.99 d^{-1} , using their observations. Royer et al. (2002) measured the $v \sin i$ of the northern star HZ Vel to be 45 km s^{-1} . Faraggiana et al. (2004) studied the sample of λ Boo stars, which shows composite spectra, given by Gerbaldi, Faraggiana, and Lai (2003), and classified HZ Vel as the suspected double. Murphy and Paunzen (2017) gave the parameters of 172 λ Boo stars and candidates using Gaia DR1/Hipparcos parallaxes, and derived the T_{eff} , $\log(L/L_{\odot})$, and variability type of HZ Vel to be $7270 \pm 85\text{ K}$, 1.06, and δ Scuti, respectively. Barceló Forteza et al. (2020) derived the power spectra of δ Scuti stars with TESS and determined the T_{eff} (7400 K) and variability type (δ Scuti/ γ Doradus hybrid) of HZ Vel. Murphy et al. (2020a) derived the pulsation features of southern λ Boo stars using TESS data, and gave the atmospheric parameters of HZ Vel as $T_{\text{eff}} = 7270 \pm 145\text{ K}$, $\log g = 4.03 \pm 0.05$, and $[\text{Fe}/\text{H}] = 0.00\text{--}0.17 \pm 0.15$ based on the photometric investigations. The dominant frequency of the stars was given as 14.34 d^{-1} in the study of Barac et al. (2022).

A.1.5 V527 Car

V527 Car was recorded for the first time by Houck and Cowley (1975), in which the spectral type of the star was given as A3mA7-A9. Duerbeck (1997) investigated true and possible contact binaries in the Hipparcos catalog and recorded the star V527 Car as pulsating or EW; a visual binary. Paunzen and Maitzen (1998) provided new variable chemically peculiar stars using the extensive Hipparcos Variability Annex, one of which is V527 Car. Koen et al. (1999) found that V527 Car is an evolved Am (Puppis) star with a 5.1h periodicity, and identified the mode of its pulsation as non-radial with $l = 2$ based on the multicolor photometry. The dominant frequency measured for V527 Car was given in the study of Barac et al. (2022) as 4.68 d^{-1} .

A.1.6 DP UMa

The target star DP UMa is one of the peculiar stars with spectral type A5 (Morgan 1932; Slettebak & Stock 1959). Eggen (1976) discussed the photometry and kinematics of Am stars and ultrashort-period cepheids (USPC) in the HR catalog, giving DP UMa's spectral type as A7m. Kurtz (1978) first announced the discovery of pulsation of DP UMa with another Am star, HR 8210. Kurtz (1979) expressed that the frequency of DP UMa changes on a time-scale as short as 1d. Tsvetkov (1982) estimated the radial pulsation modes for δ Scuti stars

Table 7. Result of the analysis of chemical abundances.*

Element	AU Scl	FG Eri	HZ Vel	MX Vir	IO Lup
⁶ C	8.44 ± 0.35 (2)	8.81 ± 0.29 (5)	8.49 ± 0.33 (6)	8.50 ± 0.35 (7)	
¹¹ Na		6.74 ± 0.35 (1)	6.07 ± 0.26 (2)	6.26 ± 0.27 (3)	
¹² Mg	7.58 ± 0.31 (4)	8.04 ± 0.24 (3)	7.25 ± 0.28 (6)	7.73 ± 0.20 (8)	7.82 ± 0.38 (2)
¹⁴ Si	7.49 ± 0.39 (14)	7.10 ± 0.33 (9)	6.65 ± 0.23 (9)	7.16 ± 0.53 (17)	6.30 ± 0.38 (2)
¹⁶ S				7.37 ± 0.35 (2)	
²⁰ Ca	6.55 ± 0.34 (6)	6.47 ± 0.31 (11)	5.93 ± 0.31 (20)	6.35 ± 0.17 (23)	6.29 ± 0.38 (2)
²¹ Sc	1.64 ± 0.32 (2)	3.91 ± 0.28 (4)	2.60 ± 0.29 (6)	3.46 ± 0.23 (8)	3.17 ± 0.36 (3)
²² Ti	5.62 ± 0.30 (8)	5.30 ± 0.31 (23)	4.55 ± 0.22 (33)	4.95 ± 0.37 (83)	5.10 ± 0.30 (24)
²³ V		5.00 ± 0.30 (2)	4.11 ± 0.26 (7)	4.09 ± 0.32 (8)	4.41 ± 0.35 (3)
²⁴ Cr	6.34 ± 0.39 (20)	6.03 ± 0.27 (14)	5.18 ± 0.24 (33)	5.67 ± 0.53 (90)	5.52 ± 0.35 (9)
²⁵ Mn	5.41 ± 0.25 (5)	5.54 ± 0.23 (4)	5.00 ± 0.28 (7)	5.39 ± 0.27 (24)	
²⁶ Fe	8.01 ± 0.17 (60)	7.67 ± 0.16 (49)	6.95 ± 0.12 (104)	7.43 ± 0.12 (369)	7.44 ± 0.14 (56)
²⁷ Co			5.01 ± 0.33 (2)	5.04 ± 0.32 (2)	6.12 ± 0.38 (2)
²⁸ Ni	6.98 ± 0.29 (14)	6.58 ± 0.31 (15)	5.82 ± 0.29 (24)	6.31 ± 0.35 (84)	
²⁹ Cu		4.09 ± 0.35 (2)		3.99 ± 0.35 (2)	
³⁰ Zn				4.66 ± 0.35 (2)	
³⁸ Sr		3.61 ± 0.74 (1)	3.55 ± 0.68 (1)	3.64 ± 0.36 (2)	
³⁹ Y	4.18 ± 0.34 (2)	3.07 ± 0.35 (2)	2.20 ± 0.37 (2)	3.29 ± 0.35 (6)	
⁴⁰ Zr		2.97 ± 0.36 (4)	2.51 ± 0.23 (6)	3.46 ± 0.32 (7)	
⁵⁶ Ba	4.63 ± 0.36 (2)	3.00 ± 0.35 (2)	2.08 ± 0.38 (2)	3.32 ± 0.35 (3)	
Element	KU Com	V527 Car	V1187 Tau	UV PsA	DP UMa
⁶ C		8.69 ± 0.52 (3)	8.27 ± 0.29 (4)	8.58 ± 0.32 (4)	8.34 ± 0.33 (6)
¹¹ Na	6.21 ± 0.52 (2)		6.23 ± 0.35 (3)	5.65 ± 0.28 (1)	6.21 ± 0.27 (3)
¹² Mg	7.64 ± 0.23 (4)	7.59 ± 0.53 (4)	7.58 ± 0.12 (4)	7.92 ± 0.36 (3)	7.65 ± 0.27 (6)
¹⁴ Si	7.28 ± 0.48 (8)	7.36 ± 0.52 (9)	7.15 ± 0.25 (11)	7.12 ± 0.27 (13)	7.05 ± 0.25 (19)
¹⁶ S					7.41 ± 0.30 (3)
²⁰ Ca	6.38 ± 0.50 (15)	6.23 ± 0.50 (10)	6.31 ± 0.26 (14)	6.82 ± 0.26 (13)	5.82 ± 0.27 (18)
²¹ Sc	2.99 ± 0.52 (5)	2.94 ± 0.52 (5)	2.85 ± 0.34 (5)	3.63 ± 0.25 (5)	2.46 ± 0.28 (6)
²² Ti	4.86 ± 0.53 (29)	4.91 ± 0.53 (29)	4.74 ± 0.18 (21)	5.23 ± 0.26 (17)	4.78 ± 0.29 (29)
²³ V	4.44 ± 0.53 (3)	4.54 ± 0.53 (9)	4.52 ± 0.32 (2)	4.75 ± 0.35 (2)	4.56 ± 0.29 (4)
²⁴ Cr	5.43 ± 0.55 (29)	5.58 ± 0.55 (25)	5.52 ± 0.30 (19)	5.90 ± 0.25 (17)	5.69 ± 0.26 (26)
²⁵ Mn	4.87 ± 0.54 (4)	4.97 ± 0.54 (9)	5.34 ± 0.25 (6)	5.37 ± 0.34 (7)	5.04 ± 0.22 (7)
²⁶ Fe	7.29 ± 0.14 (79)	7.28 ± 0.15 (91)	7.30 ± 0.15 (92)	7.51 ± 0.16 (61)	7.31 ± 0.15 (92)
²⁷ Co			5.24 ± 0.33 (1)		5.71 ± 0.35 (1)
²⁸ Ni	6.09 ± 0.27 (21)	6.12 ± 0.57 (18)	6.08 ± 0.31 (16)	6.43 ± 0.30 (25)	6.23 ± 0.25 (30)
²⁹ Cu		3.57 ± 0.53 (1)	3.26 ± 0.34 (1)	4.05 ± 0.35 (2)	4.00 ± 0.25 (2)
³⁰ Zn				3.96 ± 0.15 (1)	4.45 ± 0.25 (1)
³⁸ Sr		3.05 ± 0.53 (1)		3.79 ± 0.26 (1)	
³⁹ Y			2.31 ± 0.18 (4)	3.12 ± 0.62 (5)	2.82 ± 0.19 (5)
⁴⁰ Zr		2.46 ± 0.53 (1)	2.61 ± 0.28 (2)	4.39 ± 0.64 (3)	3.05 ± 0.23 (3)
⁵⁶ Ba				3.54 ± 0.25 (2)	2.98 ± 0.27 (1)

*The numbers given in the parenthesis represent the number of lines used in the analysis.

from Breger's (1979) list and gave the oscillation mode of DP UMa. Wonnacott et al. (1994) reported that the range of temperature classes covered by the spectral type of DP UMa is rather small (K4hA6mA7), implying that the star DP UMa is quite a marginal Am star. Bartkevicius and Lazauskaite (1997) conducted classification of Population II stars in the Vilnius photometric system, and identified the class of DP UMa as optical binary. Bush and Hintz (2008) measured the rotational velocities of 118 δ Scuti variables using DAO spectra and gave $v \sin i = 70 \text{ km s}^{-1}$ for DP UMa. Catanzaro and Ripepi (2014) presented a detailed analysis of eight Am stars, and obtained the T_{eff} , $\log g$ and $v \sin i$ of DP UMa of 7200 K, 3.6, and 72 km s^{-1} . They also reported the binary feature as belonging to the Am class and the presence of pulsation for DP UMa. Draper et al. (2018) derived the stellar parameters ($T_{\text{eff}} = 7514 \text{ K}$, $\log g = 3.5$, $v \sin i = 70 \text{ km s}^{-1}$ for DP UMa) of their program stars using the spectra obtained at the McDonald Observatory. Barac et al. (2022) obtained some properties of 372 δ Scuti stars, and gave the dominant frequency value to be 18.07 d^{-1} for DP UMa.

A.1.7 KU Com

KU Com is a member of open cluster Cl Melotte 111 (Eggen 1950; Bahner & Miczaika 1952; Johnson & Knuckles 1955), and is a δ Scuti type variable star with an A7m spectral type (Slettebak & Stock 1959). Schutt (1991) reported four new probable δ Scuti stars, one of which was KU Com, and concluded that KU Com could be a metallic line star, and thus might be a member of the δ Del group. Rodriguez et al. (1994) presented an extensive list of δ Scuti stars covering the basic properties of KU Com. Hui-Bon-Hoa, Burkhart, and Alecian (1997) gave metal abundances of KU Com and remaining program stars in young galactic clusters. Abt and Willmarth (1999) studied the evolution of binary systems in five open clusters of various ages, and derived the constant velocity for KU Com, which is one of the observed stars in the Coma cluster. Burkhart and Coupry (2000) gave the third in a series of papers about the abundances of the elements Li, Al, Si, S, Fe, Ni, and Eu for A-stars, including KU Com, in open clusters of different ages. Makarov (2003) corrected the Hipparcos parallaxes of Coma Berenices and NGC 6231

Table 8. Pulsation frequencies of the targets.*

	Frequency [d ⁻¹]	Amplitude (mmag) ±0.02	SNR		Frequency [d ⁻¹]	Amplitude (mmag) ±0.02	SNR
— AU Scl —				— FG Eri —			
f_1	16.5501 (1)	1.66	46	f_1	6.2921 (1)	12.08	274
f_2	19.3299 (1)	1.49	42	f_2	3.2367 (2)	2.28	59
f_3	15.7103 (1)	1.11	36	f_3	4.2721 (1)	1.90	44
f_4	12.7477 (2)	0.90	46	f_4	3.4718 (1)	1.28	33
f_5	12.8545 (2)	0.79	42	f_5	3.7962 (1)	0.99	23
f_6	18.1823 (2)	0.75	25	f_6	6.9964 (1)	0.97	21
f_7	14.9199 (3)	0.55	27	f_7	4.6368 (2)	0.73	16
f_8	18.5724 (4)	0.37	12	f_8	5.1924 (2)	0.46	10
f_9	16.5234 (3)	0.41	11	f_9	7.2574 (3)	0.52	12
f_{10}	13.7907 (6)	0.26	16	f_{10}	3.8729 (2)	0.54	12
f_{11}	17.0798 (5)	0.28	8	$f_5 + 2f_4 - 2f_1$	4.4477 (2)	0.46	11
f_{12}	16.3468 (6)	0.25	7	$2f_1 - 2f_{11}$	3.6887 (3)	0.43	10
f_{13}	17.5725 (7)	0.23	7	$f_3 + f_6 - f_2$	8.0318 (2)	0.34	9
$f_{11} + f_9 - f_{13}$	16.0306 (6)	0.23	7	f_{14}	6.2786 (2)	0.39	9
f_{15}	19.2355 (6)	0.23	6	$f_{10} + f_6 - f_5$	7.0732 (2)	0.34	7
f_{16}	17.7655 (6)	0.22	6	f_{16}	7.7698 (2)	0.32	8
f_{17}	15.1478 (7)	0.21	8	$f_{13} + f_3 - f_{16}$	4.5341 (2)	0.31	7
$f_{14} + 2f_1 - 2f_{12}$	16.4371 (9)	0.21	6	$2f_8 - 2f_2$	3.9113 (2)	0.27	6
f_{19}	22.0606 (9)	0.17	5	f_{19}	0.6986 (2)	0.25	6
f_{20}	17.7018 (9)	0.19	5	$3f_2 - f_{11}$	5.2624 (2)	0.24	5
— V1187 Tau —				— HZ Vel —			
f_1	53.1771 (1)	1.61	249	f_1	14.3398 (1)	3.24	291
f_2	46.1046 (2)	1.42	225	f_2	1.6155 (1)	1.51	30
f_3	49.6750 (2)	0.81	138	f_3	1.0665 (1)	1.05	20
f_4	46.1684 (2)	0.33	50	f_4	0.3542 (1)	0.63	15
f_5	46.3098 (2)	0.29	44	f_5	1.5977 (1)	0.51	10
f_6	49.8145 (1)	0.24	41	f_6	15.2400 (2)	0.39	30
f_7	46.5351 (1)	0.22	34	$2f_2 - f_3 - f_4$	1.8104 (2)	0.33	6
f_8	0.0541 (1)	0.22	15	f_8	2.0003 (2)	0.34	7
f_9	53.1192 (1)	0.18	28	f_9	1.5285 (2)	0.30	6
f_{10}	41.3432 (1)	0.14	30	f_{10}	1.6640 (2)	0.29	6
f_{11}	41.1478 (1)	0.12	26	f_{11}	13.0191 (2)	0.23	21
f_{12}	37.5270 (1)	0.12	24	$f_4 + f_5 + 2f_7$	1.9796 (2)	0.24	5
f_{13}	43.4031 (1)	0.12	22				
f_{14}	42.9542 (1)	0.11	21				
f_{15}	0.0384 (1)	0.10	6				
f_{16}	46.1130 (1)	0.12	20				
f_{17}	49.4738 (1)	0.09	16				
f_{18}	0.1342 (1)	0.09	18				
f_{19}	42.3250 (1)	0.08	5				
f_{20}	23.4808 (1)	0.08	14				
f_{21}	0.1173 (1)	0.07	15				
f_{22}	39.3151 (1)	0.08	13				
$f_{10} + 2f_{14} - 2f_{19}$	42.6018 (1)	0.07	15				
f_{24}	0.0691 (1)	0.07	5				
— V527 Car —				— DP UMa —			
f_1	4.6812 (1)	15.05	207	f_1	18.0751 (1)	2.03	49
f_2	3.8243 (1)	11.03	133	f_2	15.7013 (2)	1.15	33
f_3	3.5775 (1)	3.13	41	f_3	17.4207 (1)	0.98	26
f_4	9.3603 (2)	1.44	26	f_4	30.0962 (1)	0.89	24
f_5	0.1402 (2)	1.27	12	f_5	28.4044 (1)	0.88	22
$f_1 - f_2$	0.8569 (2)	1.09	12	f_6	17.9254 (1)	0.90	22
$f_1 + f_3$	8.2587 (3)	1.02	14	f_7	18.7253 (2)	0.82	16
$2f_4 - f_1 - f_7$	5.7809 (4)	1.03	17	f_8	2.5492 (2)	0.82	16
$2f_2$	7.6486 (3)	0.83	11	f_9	18.9370 (3)	0.70	17
f_{10}	9.0642 (6)	0.72	12	f_{10}	19.7218 (2)	0.54	17
f_{11}	0.2073 (5)	0.58	6	f_{11}	12.0358 (2)	0.63	12
f_{12}	2.0099 (6)	0.52	6	$f_{10} +$	24.4695 (3)	0.63	16
				$2f_1 - 2f_2$			
f_{13}	4.3771 (7)	0.47	6	f_{13}	0.0342 (2)	0.39	6
f_{14}	1.1886 (6)	0.50	5	$2f_{13} - f_{10} +$	11.7493 (2)	0.55	10
				$2f_2$			
f_{15}	12.3376 (6)	0.43	7	f_{15}	18.8258 (2)	0.52	12
$f_{10} - f_{11} - f_6$	4.6535 (6)	0.41	6	f_{16}	2.0295 (2)	0.48	7

Table 8. (Continued)

	Frequency [d ⁻¹]	Amplitude (mmag) ±0.02	SNR		Frequency [d ⁻¹]	Amplitude (mmag) ±0.02	SNR
f_{17}	4.8273 (7)	0.39	6	f_{17}	16.5033 (2)	0.43	12
f_{18}	4.1935 (9)	0.36	5	f_{18}	2.3246 (2)	0.41	7
				$f_{15} + f_{18} - f_7$	2.4251 (2)	0.44	8
				f_{20}	36.0029 (2)	0.42	8
				f_{21}	2.8464 (2)	0.38	8
				f_{22}	11.4798 (2)	0.32	6
				f_{23}	1.5890 (2)	0.32	5
				f_{24}	10.5624 (2)	0.32	5
— KU Com —				— MX Vir —			
f_1	4.3339 (1)	0.36	16	f_1	6.4950 (1)	14.15	318
f_2	1.5763 (2)	0.32	10	f_2	6.5949 (1)	1.30	30
f_3	2.2930 (2)	0.23	9	f_3	5.9161 (1)	1.16	26
f_4	1.8980 (2)	0.18	6	f_4	6.3117 (1)	1.51	33
f_5	1.7381 (2)	0.20	7	$2f_1$	12.9900 (1)	0.99	35
f_6	1.9995 (1)	0.20	7	f_6	6.3575 (2)	0.68	14
f_7	2.6353 (1)	0.15	6	f_7	6.2680 (2)	0.63	13
f_8	4.0217 (1)	0.13	6	f_8	5.7661 (2)	0.55	9
f_9	19.9108 (1)	0.14	15	$f_7 + 2f_8 - 2f_3$	5.9681 (2)	0.39	5
f_{10}	2.1425 (1)	0.17	7	f_{10}	5.8245 (2)	0.36	8
f_{11}	2.0861 (1)	0.15	5	$f_5 + f_6 - 2f_4$	6.7240 (2)	0.21	5
f_{12}	4.2173 (1)	0.11	5				
— IO Lup —				— UV PsA —			
f_1	15.5946 (1)	7.14	94	f_1	9.1511 (1)	7.06	53
f_2	15.4881 (1)	3.91	49	f_2	8.3837 (2)	5.06	40
f_3	13.5090 (1)	3.46	37	f_3	8.5227 (1)	4.74	37
$f_2 + f_3 - f_1$	13.4025 (2)	2.04	22	f_4	12.9809 (1)	1.81	21
f_5	15.1976 (2)	1.73	20	f_5	13.5153 (1)	1.43	19
f_6	13.1255 (2)	1.55	16	f_6	14.5789 (1)	1.30	16
f_7	15.2712 (3)	1.57	18	f_7	17.0111 (2)	1.22	14
f_8	12.5291 (4)	1.32	18	f_8	9.0969 (2)	1.20	9
f_9	15.0194 (3)	1.30	15	f_9	7.4104 (3)	1.11	14
$f_2 + f_5 - f_9$	15.6662 (6)	1.33	18	f_{10}	7.8275 (2)	0.88	10
f_{11}	13.8304 (5)	0.98	10	f_{11}	13.2752 (2)	0.81	9
f_{12}	12.7634 (6)	0.94	11	$f_3 + 2f_1 - 2f_4$	0.8631 (3)	0.80	8
f_{13}	15.6236 (7)	0.69	8	f_{13}	16.2202 (2)	0.79	9
f_{14}	14.9304 (6)	0.59	7	f_{14}	7.5458 (2)	0.79	9
f_{15}	13.5845 (6)	0.54	5	f_{15}	8.1020 (2)	0.66	6
				$f_{14} + f_2 - f_{10}$	9.2901 (2)	0.70	5
				$f_1 + f_3 - f_2$	8.8062 (2)	0.62	5

*Formal error estimates are given in the parenthesis in units of the last digits after the comma.

open clusters, giving the recomputed parallax of 12.35(0.94) for KU Com. Monier and Richard (2004) gave the abundances obtained by synthesizing AURELIE spectra for KU Com and other A and F dwarfs in Coma Berenices. Cenarro et al. (2007) presented the set of stellar atmospheric parameters of 985 stars, counting KU Com, found in a new spectral stellar library called MILES. Gebran, Monier, and Richard (2008) derived the chemical composition (abundances relative to hydrogen and to the solar value) of KU Com with spectral type Am/kA7hF0mF0. Milone, Sansom, and Sánchez-Blázquez (2011) obtained [Mg/Fe] measurement for KU Com. Their work is based on understanding stellar atmospheres and stellar populations in galaxies and star clusters using the stars in the MILES spectral library. Prugniel, Vauglin, and Koleva (2011) determined the MILES atmospheric parameters T_{eff} , $\log g$, and Fe/H of KU Com as 7360 K, 3.99, and -0.05 , respectively. Silaj and Landstreet (2014) aimed to obtain accurate ages for the seven nearby open clusters, each of which contains at least one magnetic Ap—one of these stars being KU Com—or Bp star. Oh et al. (2017) cataloged the candidate

co-moving pairs of stars in the Tycho–Gaia Astrometric Solution (TGAS), which is the primary sample of the Gaia Data Release 1. Barac et al. (2022) provided a catalog of 372 bright δ Scuti stars and their period–luminosity relation using TESS and Gaia DR3 data, and determined the dominant frequency to be 19.91 d⁻¹. Olivares et al. (2023) applied their membership algorithm to the nearly 45 million Gaia DR3 sources and found 302 candidate members, one of which is KU Com, in the cluster Coma Berenices.

A.1.8 MX Vir

The first study of MX Vir was aimed at determining its spectral type (Abt et al. 1979). They re-defined the spectral type of stars with unusual photometric indices and found that MX Vir is a star with F5 Vp (Sr, Cr, Eu strong; Ca weak) spectral type. Perry and Christodoulou (1996) computed color excesses and distances for southern A-early F stars, including MX Vir. Paunzen and Maitzen (1998) identified new, variable, chemically peculiar stars using the Hipparcos catalog, in which the spectral type of MX Vir was given as F3.

De Cat et al. (2006) gave the spectroscopic study results of 37 candidate γ Doradus stars, and they determined MX Vir to be a δ Scuti star with a F2 II spectral type. Bruntt, De Cat, and Aerts (2008) studied the southern γ Doradus stars, spectroscopically, and gave the abundance amounts of MX Vir. Casagrande et al. (2011) presented improved astrophysical parameters for the Geneva–Copenhagen Survey (GCS). They gave the T_{eff} Fe/H, and $\log g$ of MX Vir as 6803 ± 136 K, 0.31, and 3.57, respectively. Rainer et al. (2016) presented spectroscopic information on the observed targets using HARPS spectra. In this study, MX Vir's parameters and variability type were given as $T_{\text{eff}} = 7002$ K, $\log g = 3.25$, $[\text{Fe}/\text{H}] = -0.06$ and δ Scuti. The mean T_{eff} and $\log g$ of MX Vir were given in the study by Barceló Forteza et al. (2020) as 7400 K and 3.58, respectively. Barac et al. (2022) determined the dominant frequency to be 6.49 d^{-1} using TESS data. Royer et al. (2024) presented a new spectral library consisting of 3256 spectra containing 2043 stars, including MX Vir.

A.1.9 IO Lup

IO Lup is one of the relatively least studied stars among our target stars. It was recorded in Paunzen and Duffee (1996); they chose it as a comparison star for a survey to detect variability in λ Bootis stars, because of IO Lup's classification as Am star (Houk 1982). Royer et al. (2002) measured $v \sin i$ of A-type stars in the northern and southern hemispheres. They gave the rotational velocity and spectral type of the star as 15 km s^{-1} and A5m A5-F2. Rainer et al. (2016) determined the atmospheric parameters of IO Lup as $T_{\text{eff}} = 7550$ K, $\log g = 3.37$, and $[\text{Fe}/\text{H}] = 0.28$ using the spectra obtained with the ESO echelle spectrograph HARPS. Mellon et al. (2019) searched for periodic variations in the data obtained by Ring instruments located in South Africa and Australia; they included IO Lup in their list and gave a pulsation frequency value of 13.40 d^{-1} for it.

A.1.10 UV PsA

Houk (1982) gave the spectral type of UV PsA as F2 III(m). Koen et al. (1995) presented differential photometry in the VB wavebands for 11 δ Scuti stars together with UV PsA, nine of which were not previously known to be variable stars. Smalley et al. (2011) studied over 1600 Am stars using SuperWASP photometric data with a photometric precision of 1 mmag. They gave the stellar parameters (spectral type = F1m, $\log T_{\text{eff}} = 3.843$, $\log(L/L_{\odot}) = 1.120$), pulsation class (δ Scuti), and identified frequencies of UV PsA. Rainer et al. (2016) derived the atmospheric parameters and variable type of UV PsA using HARPS spectra as $T_{\text{eff}} = 7918$ K, $\log g = 4.00$, $[\text{Fe}/\text{H}] = 0.18$, and δ Scuti. Barac et al. (2022) determined the dominant frequency as 9.15 d^{-1} for UV PsA in their catalog of 372 bright δ Scuti stars and their period–luminosity relation using TESS and Gaia DR3 data.

Appendix 2 Supplementary tables

Table 7 provides the list of absolute chemical abundances derived for the target stars. The numbers in parentheses represent the number of lines used in the estimation of the chemical abundances of the individual elements. Table 8 provides the significant oscillation frequencies and their corresponding amplitudes for all targets. SNR denotes the signal-to-noise ratio.

References

- Abt, H. A., Barnes, R. C., Biggs, E. S., & Osmer, P. S. 1965, *ApJ*, 142, 1604
- Abt, H. A., Brodzik, D., & Schaefer, B. 1979, *PASP*, 91, 176
- Abt, H. A., & Levato, H. 1978, *PASP*, 90, 201
- Abt, H. A., & Willmarth, D. W. 1999, *ApJ*, 521, 682
- Aerts, C., Christensen-Dalsgaard, J., & Kurtz, D. W. 2010, *Asteroseismology* (Dordrecht: Springer)
- Alecian, G. 2015, *MNRAS*, 454, 3143
- Antoci, V., et al. 2014, *ApJ*, 796, 118
- Antoci, V., et al. 2019, *MNRAS*, 490, 4040
- Asplund, M., Grevesse, N., Sauval, A. J., & Scott, P. 2009, *ARA&A*, 47, 481
- Aurière, M., et al. 2010, *A&A*, 523, A40
- Bahner, K., & Miczaika, G. R. 1952, *Z. Astrophys.*, 31, 236
- Balona, L. A. 1977, *MmRAS*, 84, 101
- Balona, L. A., et al. 2011, *MNRAS*, 414, 792
- Barac, N., Bedding, T. R., Murphy, S. J., & Hey, D. R. 2022, *MNRAS*, 516, 2080
- Baran, A. S., & Koen, C. 2021, *Acta Astron.*, 71, 113
- Barceló Forteza, S., Moya, A., Barrado, D., Solano, E., Martín-Ruiz, S., Suárez, J. C., & García Hernández, A. 2020, *A&A*, 638, A59
- Bartkevicius, A., & Lazauskaite, R. 1997, *Baltic Astron.*, 6, 499
- Bedding, T. R., et al. 2023, *ApJ*, 946, L10
- Breger, M. 1979, *PASP*, 91, 5
- Breger, M. 1990, *Delta Scuti Star Newsletter*, 2, 13
- Breger, M. 2000, in *ASP Conf. Ser. 210, Delta Scuti and Related Stars*, ed. M. Breger & M. Montgomery (San Francisco: ASP), 3
- Bruntt, H., De Cat, P., & Aerts, C. 2008, *A&A*, 478, 487
- Burkhart, C., & Coupry, M. F. 2000, *A&A*, 354, 216
- Bush, T. C., & Hintz, E. G. 2008, *AJ*, 136, 1061
- Casagrande, L., Schönrich, R., Asplund, M., Cassisi, S., Ramírez, I., Meléndez, J., Bensby, T., & Feltzing, S. 2011, *A&A*, 530, A138
- Catanzaro, G., Leone, F., & Dall, T. H. 2004, *A&A*, 425, 641
- Catanzaro, G., & Ripepi, V. 2014, *MNRAS*, 441, 1669
- Cenarro, A. J., et al. 2007, *MNRAS*, 374, 664
- Chang, S.-W., Protopapas, P., Kim, D.-W., & Byun, Y.-I. 2013, *AJ*, 145, 132
- Choi, J., Dotter, A., Conroy, C., Cantiello, M., Paxton, B., & Johnson, B. D. 2016, *ApJ*, 823, 102
- Conti, P. S. 1970, *PASP*, 82, 781
- Conti, P. S., & Strom, S. E. 1968, *ApJ*, 152, 483
- Cutri, R. M., et al. 2003, *2MASS All-Sky Catalog of Point Sources*, VizieR Online Data Catalog, II/246
- de Bruijne, J. H. J., & Eilers, A.-C. 2012, *A&A*, 546, A61
- De Cat, P., et al. 2006, *A&A*, 449, 281
- Dias, W. S., Monteiro, H., Moitinho, A., Lépine, J. R. D., Carraro, G., Paunzen, E., Alessi, B., & Vilella, L. 2021, *MNRAS*, 504, 356
- Dotter, A. 2016, *ApJS*, 222, 8
- Draper, Z. H., Matthews, B., Venn, K., Lambert, D., Kennedy, G., & Sitnova, T. 2018, *ApJ*, 857, 93
- Duerbeck, H. W. 1997, *IBVS*, 4513, 1
- Dürfeldt-Pedros, O., Antoci, V., Smalley, B., Murphy, S., Posilek, N., & Niemczura, E. 2024, *A&A*, 690, A104
- Eggen, O. J. 1950, *ApJ*, 111, 414
- Eggen, O. J. 1976, *PASP*, 88, 402
- Faraggiana, R., & Bonifacio, P. 1999, *A&A*, 349, 521
- Faraggiana, R., Bonifacio, P., Caffau, E., Gerbaldi, M., & Nonino, M. 2004, *A&A*, 425, 615
- Faraggiana, R., & Gerbaldi, M. 1998, *Contrib. Astron. Obs. Skalnaté Pleso*, 27, 413
- Flower, P. J. 1996, *ApJ*, 469, 355
- Fox Machado, L., Pérez Hernández, F., Suárez, J. C., Michel, E., & Lebreton, Y. 2006, *MmSAI*, 77, 455
- Fox-Machado, L., et al. 2002, *A&A*, 382, 556
- Gaia Collaboration 2023, *A&A*, 674, A1
- Gebran, M., Monier, R., & Richard, O. 2008, *A&A*, 479, 189
- Gerbaldi, M., Faraggiana, R., & Lai, O. 2003, *A&A*, 412, 447
- Ghazaryan, S., Alecian, G., & Hakobyan, A. A. 2018, *MNRAS*, 480, 2953

- Graham, J. A., & Slettebak, A. 1973, *AJ*, 78, 295
- Gray, R. O., & Corbally, C. 2009, *Stellar Spectral Classification* (Princeton: Princeton University Press)
- Green, G. M., Schlafly, E., Zucker, C., Speagle, J. S., & Finkbeiner, D. 2019, *ApJ*, 887, 93
- Grenier, S., Burnage, R., Faraggiana, R., Gerbaldi, M., Delmas, F., Gómez, A. E., Sabas, V., & Sharif, L. 1999, *A&AS*, 135, 503
- Handler, G., & Shobbrook, R. R. 2002, *MNRAS*, 333, 251
- Hauck, B. 1986, *A&A*, 155, 371
- Heck, A., Albert, A., Delays, D., & Mersch, G. 1977, *A&A*, 61, 563
- Høg, E., et al. 2000, *A&A*, 355, L27
- Houk, N. 1982, *University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars. Vol. 3* (Ann Arbor: University of Michigan)
- Houk, N., & Cowley, A. P. 1975, *University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars. Volume 1* (Ann Arbor: University of Michigan)
- Hui-Bon-Hoa, A., Burkhardt, C., & Alecian, G. 1997, *A&A*, 323, 901
- Johnson, H. L., & Knuckles, C. F. 1955, *ApJ*, 122, 209
- Kahraman Açıcaş, F., et al. 2016, *MNRAS*, 458, 2307
- Kahraman Açıcaş, F., Gümüş, D., Kırmızıtaş, Ö., Ekinci, Ö., Çavuş, S., Kaya, Y. T., & Açıcaş, F. 2022, *Res. Astron. Astrophys.*, 22, 085003
- Kamp, I., & Paunzen, E. 2002, *MNRAS*, 335, L45
- Kaye, A. B., Handler, G., Krisciunas, K., Poretti, E., & Zerbi, F. M. 1999, *PASP*, 111, 840
- Koen, C., Kilkeny, D., van Wyk, F., Roberts, G., & Marang, F. 1995, *MNRAS*, 277, 217
- Koen, C., van Rooyen, R., van Wyk, F., & Marang, F. 1999, *MNRAS*, 309, 1051
- Kurtz, D. W. 1976, *ApJS*, 32, 651
- Kurtz, D. W. 1978, *ApJ*, 221, 869
- Kurtz, D. W. 1979, *MNRAS*, 186, 575
- Kurtz, D. W. 1989, *MNRAS*, 238, 1077
- Kurucz, R. L. 1993, *Kurucz CD-ROM, No. 13, ATLAS9 Stellar Atmosphere Programs and 2 km/s Grid* (Cambridge, MA: Harvard-Smithsonian Center for Astrophysics)
- Kurucz, R. L., & Avrett, E. H. 1981, *SAO Special Rep.*, 391
- Lenz, P., & Breger, M. 2005, *Commun. Asteroseismology*, 146, 53
- Makarov, V. V. 2003, *AJ*, 126, 2408
- Masana, E., Jordi, C., & Ribas, I. 2006, *A&A*, 450, 735
- Mayor, M., et al. 2003, *Messenger*, 114, 20
- Mellon, S. N., et al. 2019, *ApJS*, 244, 15
- Mersch, G., & Heck, A. 1980, *A&A*, 85, 93
- Milone, A. D. C., Sansom, A. E., & Sánchez-Blázquez, P. 2011, *MNRAS*, 414, 1227
- Monier, R., & Richard, O. 2004, in *IAU Symp. 224, The A-Star Puzzle*, ed. J. Zverko et al. (Cambridge: Cambridge University Press), 209
- Moon, T. T., & Dworetzky, M. M. 1985, *MNRAS*, 217, 305
- Morgan, W. W. 1932, *ApJ*, 75, 46
- Morse, J. A., Mathieu, R. D., & Levine, S. E. 1991, *AJ*, 101, 1495
- Moultaka, J., Ilovaisky, S. A., Prugniel, P., & Soubiran, C. 2004, *PASP*, 116, 693
- Murphy, S. J., Hey, D., Van Reeth, T., & Bedding, T. R. 2019, *MNRAS*, 485, 2380
- Murphy, S. J., & Paunzen, E. 2017, *MNRAS*, 466, 546
- Murphy, S. J., Paunzen, E., Bedding, T. R., Walczak, P., & Huber, D. 2020a, *MNRAS*, 495, 1888
- Murphy, S. J., Saio, H., Takada-Hidai, M., Kurtz, D. W., Shibahashi, H., Takata, M., & Hey, D. R. 2020b, *MNRAS*, 498, 4272
- Niemczura, E., et al. 2017, *MNRAS*, 470, 2870
- Niemczura, E., Smalley, B., & Pych, W. 2014, *Determination of Atmospheric Parameters of B-, A-, F- and G-Type Stars* (Cham: Springer)
- Oh, S., Price-Whelan, A. M., Hogg, D. W., Morton, T. D., & Spergel, D. N. 2017, *AJ*, 153, 257
- Olivares, J., Lodieu, N., Béjar, V. J. S., Martín, E. L., Žerjal, M., & Galli, P. A. B. 2023, *A&A*, 675, A28
- Paunzen, E. 2001, *A&A*, 373, 633
- Paunzen, E. 2015, *A&A*, 580, A23
- Paunzen, E. 2024, *IAU Symp. 376, At the Crossroads of Astrophysics and Cosmology: Period-Luminosity Relations in the 2020s*, ed. R. de Grijs et al. (Cambridge: Cambridge University Press), 91
- Paunzen, E., & Duffee, B. 1996, *IBVS*, 4297, 1
- Paunzen, E., & Maitzen, H. M. 1998, *A&AS*, 133, 1
- Paunzen, E., Duffee, B., Heiter, U., Kuschnig, R., & Weiss, W. W. 2001, *A&A*, 373, 625
- Paunzen, E., et al. 1998, *A&A*, 335, 533
- Paunzen, E., et al. 1999, *A&A*, 345, 597
- Paunzen, E., Iliev, I. K., Kamp, I., & Barzova, I. S. 2002, *MNRAS*, 336, 1030
- Paunzen, E., Weiss, W. W., Heiter, U., & North, P. 1997, *A&AS*, 123, 93
- Pearce, J. A., & Hill, G. 1975, *Publ. Dominion Astrophys. Obs. Victoria*, 14, 319
- Pedersen, H., & Thomsen, B. 1977, *A&AS*, 30, 11
- Perruchot, S., et al. 2008, in *Proc. SPIE, 7014, Ground-based and Airborne Instrumentation for Astronomy II*, ed. I. S. McLean & M. M. Casali (Bellingham, WA: SPIE), 70140J
- Perry, C. L., & Christodoulou, D. M. 1996, *PASP*, 108, 772
- Porro, A., et al. 2021, *PASP*, 133, 084201
- Preston, G. W. 1974, *ARA&A*, 12, 257
- Prugniel, P., Vauglin, I., & Koleva, M. 2011, *A&A*, 531, A165
- Rainer, M., et al. 2016, *AJ*, 152, 207
- Renson, P., & Manfroid, J. 2009, *A&A*, 498, 961
- Ricker, G. R., et al. 2015, *J. Astron. Telesc., Instrum. Syst.*, 1, 014003
- Rodríguez, E., López de Coca, P., Rolland, A., Garrido, R., & Costa, V. 1994, *A&AS*, 106, 21
- Rodríguez, E., López-González, M. J., & López de Coca, P. 2000, *A&AS*, 144, 469
- Romaniello, M., et al. 2023, *Messenger*, 191, 29
- Royer, F., Grenier, S., Baylac, M.-O., Gómez, A. E., & Zorec, J. 2002, *A&A*, 393, 897
- Royer, P., et al. 2024, *A&A*, 681, A107
- Rózański, T., Niemczura, E., Lemiesz, J., Posilek, N., & Rózański, P. 2022, *A&A*, 659, A199
- Schutt, R. L. 1991, *AJ*, 101, 2177
- Sekiguchi, M., & Fukugita, M. 2000, *AJ*, 120, 1072
- Silaj, J., & Landstreet, J. D. 2014, *A&A*, 566, A132
- Slettebak, A., & Brundage, R. K. 1971, *AJ*, 76, 338
- Slettebak, A., & Stock, J. 1959, *Astronom. Abhandlungen Hamburger Sternw.*, 5, 105
- Smalley, B., et al. 2011, *A&A*, 535, A3
- Smalley, B., et al. 2017, *MNRAS*, 465, 2662
- Stokes, N. R. 1972, *MNRAS*, 160, 155
- Tayar, J., Claytor, Z. R., Huber, D., & van Saders, J. 2022, *ApJ*, 927, 31
- Théado, S., Vauclair, S., & Cunha, M. S. 2005, *A&A*, 443, 627
- Tody, D. 1986, in *Proc. SPIE, 627, Instrumentation in Astronomy VI*, ed. D. L. Crawford et al. (Bellingham, WA: SPIE), 733
- Tsvetkov, T. G. 1982, *Soviet Ast.*, 26, 666
- Turcotte, S., Richer, J., Michaud, G., & Christensen-Dalsgaard, J. 2000, *A&A*, 360, 603
- Twarog, B. A. 1980, *ApJS*, 44, 1
- Uytterhoeven, K., et al. 2011, *A&A*, 534, A125
- Wonnacott, D., Kellett, B. J., Smalley, B., & Lloyd, C. 1994, *MNRAS*, 267, 1045
- Xu, Y., Li, Z.-P., Deng, L.-C., & Xiong, D.-R. 2002, *Chin. J. Astron. Astrophys.*, 2, 441