Fundamental parameters of eight Am stars: comparing observations with theory*

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ABSTRACT

In this paper we present a detailed analysis of a sample of eight Am stars, four of them are in the Kepler field of view. We derive fundamental parameters for all observed stars, effective temperature, gravity, rotational and radial velocities, and chemical abundances by spectral synthesis method. Further, to place these stars in the Hertzsprung–Russel diagram, we computed their luminosity. Two objects among our sample, namely HD 114839 and HD 179458, do not present the typical characteristic of Am stars, while for the others six we confirm their nature. The behaviour of lithium abundance as a function of the temperature with respect the normal A-type stars has been also investigated, we do not find any difference between metallic and normal A stars. All the pulsating Am stars present in our sample (five out of eight) lie in the δ Sct instability strip, close to the red edge.

Key words: stars: abundances – stars: chemically peculiar – stars: early-type – stars: fundamental parameters.

1 INTRODUCTION

Among main sequence, A-type stars show a large variety of chemical peculiarities. They are driven by several physical processes, such as diffusion and/or magnetic field, just to quote some of them. All these processes have the same factor in common, i.e. the very stable radiative atmosphere which is the principal condition needed for peculiarities to arise.

The metallic or Am stars are those whose Ca II K-line types appear too early for their hydrogen line types, and metallic-line types appear too late, such that the spectral types inferred from the Ca II K- and metal-lines differ by five or more spectral subclasses. The marginal Am stars are those whose difference between Ca II K- and metal-lines is less than five subclasses. The commonly used classification for this class of objects includes three spectral types prefixed with k, h, and m, corresponding to the K-line, hydrogen lines and metallic lines, respectively. The typical abundances pattern shows underabundances of C, N, O, Ca, and Sc and overabundances of the Fe-peak elements, Y, Ba and of the rare earths elements (Adelman et al. 1997; Fossati et al. 2007). The presence of magnetic field has also been investigated but with null result by Fossati et al. (2007). The abundance of lithium in Am stars compared to that observed in normal A-type stars has been discussed in the literature since the work of Burkhart & Coupry (1991). They found that in general Li abundance in Am stars is close to the cosmic value or even lower in some case.

Richer, Michaud & Turcotte (2000) developed models of the structure and evolution of Am stars in order to reproduce the observed chemical pattern of 28 elements. The most important improvement of these models has been the introduction of turbulence as the hydrodynamical process competing with atomic diffusion in such a way that the resulting mixing reduces the large abundance anomalies predicted by previous models, leading to abundances which closely resemble those observed in Am stars.

Another open question in the framework of Am stars concerns the pulsations in these objects. For many years it was thought that Am stars did not pulsate, in accordance with the expectation that diffusion depletes helium from the driving zone. Recently, intensive ground-based (Smalley et al. 2011, SuperWASP survey) and space-based (Balona et al. 2011, Kepler mission) observations have shown that many Am/Fm stars do pulsate. Smalley et al. (2011), for example, found that about 169, 30 and 28 Am stars out of a total of 1600 show δ Sct, γ Dor or Hybrid pulsations (see Grigahcène et al. 2010, for a definition of these classes). These authors found also that the positions in the Hertzsprung–Russel (HR) diagram of Am stars pulsating as δ Sct are confined between the red and blue radial fundamental edges, in agreement with Balona et al. (2011) and Catanzaro & Balona (2012).

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In this study we continue a programme devoted to determining photometric abundance pattern in Am stars by means of high-resolution spectra. Three Am stars have already been analysed by us, namely: HD 178327 (KIC 11445913) and HD 183489 (KIC 11402951) in Balona et al. (2011), and HD 71297 in Catanzaro, Ripepi & Bruntt (2013), for which fundamental astrophysical quantities, such as effective temperatures, gravities and metallicities have been derived. The addition of these three stars does not alter the homogeneity of our sample, since all of them have been observed with the same instrumentation and the spectra were reduced and analysed with the same procedure that we will describe in Section 2. Such kind of studies are crucial in order (i) to put constraints on the processes occurring at the base of the convection zone in non-magnetic stars and (ii) to try to define the locus on the HR diagram occupied by pulsating Am stars.

With these goals in mind, we present a complete analysis of other eight stars previously classified as Am stars. Four of them belong to the sample observed by the *Kepler* satellite (Balona et al. 2011) and other four are Am stars discovered to be pulsating from ground-based observations. For our purposes high-resolution spectroscopy is the best tool principally for two reasons, (i) the blanketing due to the chemical peculiarities in the atmospheres of Am stars alters photometric colours and then fundamental stellar parameters based on them may not be accurate (see Catanzaro & Balona 2012, and Section 3.3 for details) and (ii) the abnormal abundances coupled with rotational velocity result in a severe line blending which makes difficult the separation of the individual lines. Both problems could be overcome only by matching synthetic and observed spectra.

For the confirmed Am stars we will compare the observed abundance with the predictions of the models and we will place them on the HR diagram by evaluating their luminosities.

## 2 OBSERVATION AND DATA REDUCTION

Spectroscopic observations of our sample of Am stars (see Table 1 for the list of targets) were carried out with the SARG spectrograph, which is installed at the *Telescopio Nazionale Galileo*, located in La Palma (Canarias Islands, Spain). SARG is a high-resolution cross-dispersed echelle spectrograph (Gratton et al. 2001) that operates in both single-object and longslit observing modes and covers a spectral wavelength range from 370 nm up to about 1000 nm, with a resolution ranging from $R = 29,000$ to 164,000.

Our spectra were obtained in service mode in 2011, between February 21 and June 12, at $R = 57,000$ using two grisms (blue and yellow) and two filters (blue and yellow). These were used in order to obtain a continuous spectrum from 3600 Å to 7900 Å with significant overlap in the wavelength range between 4620 Å and 5140 Å. We acquired the spectra for the stars with a signal-to-noise ratio (S/N) of at least 100 in the continuum.

The reduction of all spectra, which included the subtraction of the bias frame, trimming, correcting for the flat-field and the scattered light, the extraction for the orders, and the wavelength calibration, was done using the NOAO/IRAF packages. The IRAF package *rvcorrect* was used to make the velocity corrections due to Earth’s motion to transform the spectra to the barycentric rest frame. The radial velocities of our targets have been derived by cross-correlating each observed spectrum with synthetic one. Results of this correlation, performed using the IRAF package *fxcor*, together with the heliocentric Julian day, have been reported in Table 2.

## 3 PHYSICAL PARAMETERS

Temperatures and gravities for our sample stars have been derived by spectral synthesis, as described in Section 3.2. In order to speed up the iterative calculations, we needed starting values for both parameters that have been estimated from photometric calibrations, as described in the following Section 3.1. In the same section we estimate the infrared excess and the bolometric corrections, needed to compute stellar luminosities of our stars (see Section 5).

### 3.1 Parameters from photometry: $T_{\text{eff}}$ and $\log g$

For five out of eight stars in our sample (HD 104513, HD 113878, HD 114839, HD 118660, and HD 179458) complete Strömgren-Crawford $uvby\beta$ photometry is available (Hauck & Mermillod 1998). For the remaining three objects (HD 176843, HD 187254, and HD 190165), only Johnson photometry is available, mainly in $BV$ filters. For these stars we derived the Johnson $B$, $V$ magnitudes from Tycho ($B_I$, $V_I$) photometry adopting the transformations into the standard system provided by Bessell (2000). The same procedure was applied to all the other stars for homogeneity. The resulting $B$, $V$ magnitudes are listed in Table 1 (Columns 2 and 3). In the

In Table 1 we present the physical parameters estimated from photometry and parallaxes. The different columns show: (1) and (2) the HD number and an alternative name (if any) for the target star; (3) and (4) the $B$ and $V$ magnitudes adopted ($\sigma_{B-V} \sim 0.020,0.015$ mag, respectively); (5) the $K_\text{s}$ photometry from 2MASS ($\sigma_{K_\text{s}} \sim 0.015$ mag); (6) the $b-y$ colour ($\sigma_{b-y} \sim 0.01$ mag); (7) the parallax (after van Leeuwen 2007); (8) the $E(B-V)$ values (the uncertainty is 0.01 mag for the first four stars, 0.02 mag for the remaining four objects; (9) the bolometric correction in the $V$ band (after Bessell, Castelli & Plez 1998); (10) and (11) the $T_{\text{eff}}$ estimated from ($V-K_\text{s}$) and $uvby\beta$ photometry, respectively; (12) and (13) the $\log g$ estimated from $uvby\beta$ photometry and equation (1), respectively.

### Table 1

| HD       | Alt. name | $B$ mag | $V$ mag | $K_\text{s}$ mag | $b-y$ mag | $\pi$ mas | $E(B-V)$ mag | $BC_\text{V}$ mag | $T_{E(V-K_\text{s})}$ K | $T_{uvby\beta}$ K | $\log g_{\text{HIP}}$ cm s$^{-2}$ | $\log g_{\text{HIP}}$ cm s$^{-2}$ |
|----------|-----------|---------|---------|-----------------|-----------|-----------|-------------|----------------|----------------|----------------|----------------|----------------|
| 104513   | DP UMa    | 5.475   | 5.207   | 4.553           | 0.171     | 0.00      | 0.092      | 7300±130       | 7380±120       | 4.09±0.14      | 4.18±0.07      |
| 113878   |           | 8.622   | 8.240   | 7.407           | 0.219     | 0.01      | 0.056      | 6930±130       | 7090±160       | 3.84±0.15      | 3.5±0.3        |
| 114839   | NW Com    | 8.750   | 8.453   | 7.828           | 0.179     | 0.00      | 0.053      | 7420±130       | 7360±130       | 4.18±0.11      | 4.13±0.15      |
| 118660   | HR 5129   | 6.250   | 6.489   | 5.853           | 0.150     | 0.00      | 0.054      | 7340±130       | 7500±120       | 4.05±0.16      | 4.07±0.07      |
| 176843   | KIC 9204718 | 9.053 | 8.745   | 8.043           | 0.074     | 0.04      | 0.016      | 8150±230       | 8320±140       | 4.04±0.09      | 4.07±0.06      |
| 179458   | KIC 9272082 | 9.154 | 9.854   | 8.568           | 0.074     | 0.04      | 0.095      | 7610±210       | 7700±210       | 4.16±0.07      |
| 187254   | KIC 8703413 | 8.938 | 8.712   | 8.227           | 0.064     | 0.04      | 0.083      | 7460±210       | 7500±210       | 4.16±0.07      |
| 190165   | KIC 9117875 | 7.821 | 7.495   | 6.747           | 0.106     | 0.06      | 0.083      | 7460±210       | 7500±210       | 4.16±0.07      |

1 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc.
Table 2. Results obtained from the spectroscopic analysis of the sample of Am stars presented in this work. The different columns show: (1) identification; (2) effective temperatures; (3) gravity (log g); (4) microturbulent velocity (ξ); (5) rotational velocity (vsin i); (6) Heliocentric Julian Day of observation; (7) radial velocity (V rad); (8) indication of binarity (Y=binary; N=not binary; U=data insufficient to reach a conclusion); (9) indication of belonging to the Am star class (Y=Am; N=not Am); (10) indication of presence of pulsation (Y=pulsating; N=not pulsating; after Balona et al. 2011, and references therein).

| HD    | T eff  | log g | ξ   | vsin i | HJD  | V rad  | Binary | Am | Pulsating |
|-------|--------|-------|------|--------|-------|--------|--------|----|-----------|
| 104513| 7200 ±200 | 3.6 ±0.1 | 2.6 ±0.2 | 72 ±7  | 5614.5119 | −3.12 ±1.71 | Y   | Y | Y         |
| 113878| 6900 ±200 | 3.4 ±0.1 | 2.6 ±0.2 | 65 ±6  | 5615.6761 | −2.78 ±1.53 | Y   | Y | Y         |
| 114839| 7200 ±200 | 3.8 ±0.1 | 2.5 ±0.2 | 65 ±7  | 5615.6388 | −2.87 ±1.72 | U   | N | N         |
| 118660| 7200 ±200 | 3.9 ±0.1 | 2.4 ±0.2 | 100 ±10| 5615.6490 | −1.70 ±0.25 | N   | Y | Y         |
| 176843| 7600 ±150 | 3.8 ±0.1 | 2.7 ±0.2 | 27 ±3  | 5696.6652 | −26.42 ±0.56 | −    | Y | −         |
| 179458| 8400 ±200 | 4.1 ±0.1 | 2.7 ±0.3 | 75 ±7  | 5697.6103 | −15.37 ±0.57 | −    | N | N         |
| 187254| 8000 ±150 | 4.1 ±0.1 | 2.5 ±0.2 | 15 ±2  | 5697.6471 | −39.68 ±1.08 | Y   | Y | Y         |
| 190165| 7400 ±150 | 4.1 ±0.1 | 2.3 ±0.2 | 58 ±6  | 5696.7086 | −7.45 ±0.45 | U   | Y | N         |

nearly-infrared, $JHK$, photometry of good quality is present in the 2MASS catalogue (Skrutskie et al. 1996) for all the targets.

We adopted an updated version of the $\text{TEMPLOG}^2$ software (Rogers 1995) to estimate $T_{\text{eff}}$ and log g by using the calibrations present in the package, namely Balona (1984), Moon (1985), Moon & Dworetsky (1985), Napiwotzki, Schoenberner & Wenske (1993), Ribas et al. (1997). In addition, we considered the results by Smalley & Kupka (1997) and Heiter et al. (2002) who provided $uvby$ grids based on the Kurucz model atmospheres but with different treatment of the convection. In particular, we used Smalley & Kupka (1997) grids built using Canuto & Mazzitelli (1991) convection treatment and two choices for the grids\(^1\) by Heiter et al. (2002): (i) standard mixing-length theory (MLT);\(^2\) (ii) the Canuto, Goldman & Mazzitelli (1996) treatment of the convection. For each star, the different determinations $T_{\text{eff}}$ and log g were comparable with each other and we decided to simply average them. The result is shown in Table 1 (Columns 9 and 10).

As for the reddening estimate, we have adopted different methods, depending on the data available.

(i) For the five stars possessing $uvby$ photometry, we used $\text{TEMPLOG}$ to estimate the values of $E(b - y)$, that were converted into $E(B - V)$ using the transformation $E(B - V) = 1.36 E(b - y)$ (Cardelli, Clayton & Mathis 1989).

(ii) We inspected the spectra of all our targets looking for the presence of the interstellar lines Na i 5890.0 Å (D1) and K i 7699 Å. The equivalent widths (EWs) of these lines can be converted into $E(B - V)$ according to e.g. Munari & Zwitter (1997). As a result of this procedure, the only measurable lines were Na i in HD 187254 (EW ~ 140 mÅ) and K i in HD 179458 (EW ~ 15 mÅ), corresponding to $E(B - V) = 0.04 ± 0.02$ mag for both stars. For the remaining objects the interstellar lines were not measurable because they were too small (compatible with the almost zero absorption in the direction of HD 104513, HD 113878, HD 114839, and HD 118660 as derived from $uvby$ photometry) or completely embedded into the photospheric line. Is it worth noticing that for HD 179458 the $uvby$ photometry provided a different reddening estimate than that estimated from K i, and precisely $E(B - V) = 0.01 ± 0.01$ mag. Since we judge that the Munari & Zwitter (1997) calibration are reliable, for HD 179458 we decided to adopt the reddening evaluated from the interstellar lines.

(iii) For the two remaining stars devoid of reddening estimate through the aforementioned methods (namely HD 176843, HD 190165), we adopted the tables by Schmidt-Kaler (1982) in conjunction with the spectroscopic $T_{\text{eff}}$ and log g (see the next section) to estimate their intrinsic colour ($B - V_b$). A simple comparison with the observed ones gives an estimate of the reddening for these stars.

The adopted reddening estimated are reported in Table 1 (Column 6).

To estimate a star’s fundamental parameters from photometry and parallax, we need to evaluate first the visual bolometric correction $BC_V$. To this aim we adopted the models by Bessell et al. (1998) where it is assumed that $M_{\text{bol},\odot} = 4.74$ mag. We interpolated their model grids adopting the correct metal abundance that we derived in Section 4 as well as the values of $T_{\text{eff}}$ and log g derived spectroscopically (see the next section). The result of this procedure is reported in Table 1 (Column 7).

An additional photometric estimate of $T_{\text{eff}}$ can be derived for all the targets using the relation $T_{\text{eff}} = T_{\text{eff}}((V - K_s), \log g$ and [Fe/H]) published by e.g. Masana, Joedi & Ribas (2006) or Casagrande et al. (2010). Both works give similar results and we decided to use Masana et al. (2006)’s calibration for homogeneity with our previous papers (e.g. Catanzaro et al. 2011). As quoted above, the photometry in V and $K_s$ is available from Tycho and 2MASS, respectively. As for log g and [Fe/H] we used the values from our spectroscopy. To de-redden the observed ($V - K_s$) colours we adopted the reddening reported in Table 1, (Column 4) using the relation $E(V - K_s) = 2.8 E(B - V)$ (Cardelli et al. 1989). The resulting $T_{\text{eff}}$ and the relative errors are reported in Table 1 (Column 8).

Concerning log g, it is possible to estimate with good accuracy this quantity independently from both spectroscopy and Strömgren photometry if the parallax is known with sufficient precision (i.e. $\leq 10$ per cent). As shown in Table 1 (Column 5), this is the case for three stars in our list, namely HD 104513, HD 114839, and HD 118660, whereas for HD 113878 the error on the parallax is of

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\(^2\) Available through http://www.univie.ac.at/asap/manuals/tipstricks/templogg.localaccess.html

\(^3\) These grids are available on the NEMO site www.univie.ac.at/nemo/gci-bin/dive.cgi

\(^4\) Defined as the ratio $\sigma = lH_p$, of convective scale length $l$ and local pressure scale height $H_p$. 

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the order of 30 per cent. To estimate \( \log g \) we used the following expression:

\[
\log g = 4 \log(T_{\text{eff}}/T_{\text{eff, \odot}}) + \log(M/M_{\odot}) + 2 \log(\pi) + 0.4(V + BC_{V} + 0.26) + 4.44.
\]

(1)

where the different terms of the above relationship have the usual meaning and \( M/M_{\odot} \) is the mass of the star in solar unit. Before using equation (1), we have to evaluate the mass of the three stars. This can be done by adopting the calibration mass–\( M_{V} \) by Malkov (2007) that was derived on the basis of a large sample of eclipsing binaries stars. Hence, by using our \( M_{V} \) estimate discussed in Section 5, we evaluated \( \log(M/M_{\odot}) = 0.20, 0.24, \) and 0.15 dex with a common error of 0.05 dex (dominated by the dispersion of the mass–\( M_{V} \) relation) for HD 104513, HD 114839, and HD 118660, respectively. For HD 113878 we obtained \( \log(M/M_{\odot}) = 0.50 \pm 0.11 \) dex, being the error dominated by the large uncertainty on the parallax. Finally, the log \( g \) resulting from the above procedure are listed in Column 11 of Table 1.

3.2 Atmospheric parameters from spectroscopy

In this section we present the spectroscopic analysis of our sample of Am stars in order to derive fundamental astrophysical quantities, such as: effective temperatures, surface gravities, rotational velocities and chemical abundances.

The approach used in this paper has been successfully used in other papers devoted to this topics [see e.g. Catanzaro et al. (2011, 2013); Catanzaro & Balona (2012)]. In practice, the procedure used for our targets was to minimize the difference among observed and synthetic spectrum, using as goodness-of-fit parameter the \( \chi^{2} \) defined as

\[
\chi^{2} = \frac{1}{N} \sum \left( \frac{I_{\text{obs}} - I_{\text{th}}}{\delta I_{\text{obs}}} \right)^{2}
\]

(2)

where \( N \) is the total number of points, \( I_{\text{obs}} \) and \( I_{\text{th}} \) are the intensities of the observed and computed profiles, respectively, and \( \delta I_{\text{obs}} \) is the photon noise. Synthetic spectra were generated in three steps. First, we computed LTE atmospheric models using the ATLAS9 code (Kurucz 1993a,b). Secondly, the stellar spectra were then synthesized using SYNTHE (Kurucz & Avrett 1981). Thirdly, the spectra were convolved for the instrumental and rotational broadenings.

We computed the \( \sin i \) of our targets by matching synthetic lines profiles from SYNTHE to a number of metallic lines. The Mg \( i \) triplet at \( \lambda \lambda 5167–5183 \) Å was particularly useful for this purpose. The results of these calculations are reported in Table 2.

To determine stellar parameters as consistently as possible with the actual structure of the atmosphere, we performed the abundances analyses by the following iterative procedure:

(i) \( T_{\text{eff}} \) was estimated by computing the ATLAS9 model atmosphere which gave the best match between the observed H\( \alpha \) and H\( \beta \) lines profile and those computed with SYNTHE. The models were computed using solar opacity distribution functions (ODF) and microturbulence velocities according to the calibration \( \xi = \xi(T_{\text{eff}}, \log g) \) published by Allende Prieto et al. (2004). For what concerns the treatment of convection, models cooler than 8000 K were computed using the classical MLT with fixed \( \alpha = 1.25 \) (Castelli, Gratton & Kurucz 1997). The effects of different convection treatment on the Balmer lines profiles has already been investigated in Catanzaro et al. (2013), for the specific case study of HD 71297. In that paper we concluded that theoretical profiles change according to the convection treatment, in the sense that the separation between the two profiles increases from the line core towards the wings. However, the maximum difference is very low, of the order of 1.5 per cent, really indistinguishable at our level of S/N and for our resolving power. Since the star analysed in that paper share the same classification (Am) of the targets presented here, and it has been observed with the same equipment (SARG@TNG) and in the same observing run, we are confident that the conclusions obtained in Catanzaro et al. (2013) continue to apply here.

These two Balmer lines are located far from the echelle orders edges so that it was possible to safely recover the whole profiles. The simultaneous fitting of two lines led to a final solution as the intersection of the two \( \chi^{2} \) iso-surfaces. An important source of uncertainties arises from the difficulties in normalization as is always challenging for Balmer lines in echelle spectra. We quantified the error introduced by the normalization to be at least 100 K, that we summed in quadrature with the errors obtained by the fitting procedure. The final results for effective temperatures and their errors are reported in Table 2.

The surface gravity was estimated according to the effective temperature of the star: for HD 179458 and HD 187254, i.e. the only stars of our sample hotter than 8000 K, we used the wings of Balmer lines as a diagnostic tool, while for the others, we derived \( \log g \) from fitting the wings of broad lines of Mg \( i \) triplet at \( \lambda \lambda 5167, 5172, \) and 5183 Å, which are very sensitive to \( \log g \) variations. As an example, we show in Fig. 1 the fit for three stars of our sample, with different rotational velocities. In practice, we have first derived the magnesium abundances through the narrow Mg \( i \) lines at \( \lambda \lambda 4571, 4703, 5528, 5711 \) Å (not sensitive to \( \log g \)), and then we fitted the wings of the triplet lines by fine-tuning the \( \log g \) value. To accomplish this task is mandatory to take into account very accurate measurements of the atomic parameters of the transitions, i.e. \( \log gf \) and the radiative, Stark and Van der Waals damping constants. Regarding \( \log gf \) we used the values of Aldenius et al. (1997), Van der Waals damping constant is that calculated by Barklem, Piskunov & O’Mara (2000) \( (\log \gamma_{\text{Waals}} = -7.37) \), the Stark damping constant...
is from Fossati et al. (2011) \( \log g_{\text{Stating}} = -5.44 \), and the radiative damping constant is from NIST data base \( \log g_{\text{rad}} = 7.99 \).

The values of \( g \), derived with this methods, have been checked by the ionization equilibrium between Fe I lines (not sensitive to gravity change) and Fe II (very sensitive to log \( g \)). This procedure results in the final values reported in Table 2.

Uncertainties in \( T_{\text{eff}} \), log \( g \), and \( v \sin i \) were estimated by the change in parameter values which leads to an increase of \( \chi^{2} \) by unity (Lampton, Margon & Bowyer 1976).

(iii) As a second step we determine the stellar abundances by spectral synthesis. Therefore, we divide each of our spectra into several intervals, 50 Å wide each, and derived the abundances in each interval by performing a \( \chi^{2} \) minimization of the difference between the observed and synthetic spectrum. The minimization algorithm has been written in IDL language, using the AMOeba routine. We adopted lists of spectral lines and atomic parameters from Castelli & Hubrig (2004), who updated the parameters listed originally by Kurucz & Bell (1995).

For each element, we calculated the uncertainty in the abundance to be the standard deviation of the mean obtained from individual determinations in each interval of the analysed spectrum. For elements whose lines occurred in one or two intervals only, the error in the abundance was evaluated by varying the effective temperature and gravity within their uncertainties given in Table 2, \( T_{\text{eff}} \pm 8 T_{\text{eff}} \) and \( \log g \pm 0.5 \log g \), and computing the abundance for \( T_{\text{eff}} \) and log \( g \) values in these ranges. We found a variation of \( \sim 0.1 \) dex due to temperature variation, while we did not find any significant abundance change by varying log \( g \). The uncertainty in the temperature is the main error source in our analyses.

3.3 Comparison between astrophysical parameters derived by different methods

It is useful to compare the values of \( T_{\text{eff}} \) and log \( g \) derived spectroscopically (see Table 2) with those obtained via photometric methods (see Table 1). Quantitatively, a weighted mean of the differences gives: \( T_{\text{eff}}^{\text{Spec}} - T_{\text{eff}}^{\text{Phot}} = -50 \pm 130 \) K, \( \log g^{\text{Spec}} - \log g^{\text{Phot}} = -150 \pm 140 \) K. Similarly, for log \( g \): \( \log g^{\text{Spec}} - \log g^{\text{Phot}} = -0.25 \pm 0.25 \) dex; \( \log g^{\text{Spec}} - \log g^{\text{Visual}} = -0.27 \pm 0.24 \) dex, or \( -0.15 \pm 0.11 \) dex if we exclude the deviant star HD 104513.

From an analysis of these results it appears that the \( T_{\text{eff}}^{\text{Spec}} \) are in good agreement within the errors with the \( T_{\text{eff}}^{\text{Phot}} \) estimated from \( (V - K_s) \) colour, whereas they are colder than \( T_{\text{eff}}^{\text{Phot}} \) by about 150 K, even if the significance of this value is only marginal \((\sim 1 \sigma)\). Similarly, the log \( g^{\text{Spec}} \) seems to be systematically smaller than log \( g^{\text{Phot}} \) and, to a smaller extent, than log \( g^{\text{Visual}} \). In the first case the discrepancy is not significant at 1σ level. In the second case, with the exception of HD 104513, there is agreement within the errors.

The star discrepant star HD 104513 merits some further discussion. We have carefully checked our photometric and spectroscopic data to try to understand the \( \sim 0.6 \) dex difference in log \( g \) between the spectroscopic estimate and that derived from parallax. We have not found errors in our procedures, and the star spectrum clearly shows that HD 104513 is evolved off the Main Sequence. A possible solution to the puzzle comes from the fact that HD 104513 is a triple system (see e.g. Tokovinin 2008). This occurrence could affect the parallax measure and naturally explain the observed discrepancy.

The above results for \( u\text{vby}\beta \) photometry are in agreement with those by Catanzaro & Balona (2012) who showed how the Strömgren indices are correlated with effective temperature and log \( g \) and how they are affected by blanketing in Am stars. These authors concluded that effective temperature can be reliably derived by Strömgren photometry, but because of the sensitivity of \((b-y)\) to abundances, it is in general higher than about 200 K. The situation is worst for the gravities. Indeed, given the strong effect of blanketing on the \( c_f \) index, the gravities, and, in turn, the luminosities, are completely unreliable.

4 CHEMICAL ABUNDANCES

In this section we present the results of the abundance analysis obtained for each star in our sample. The derived abundances and the estimated uncertainties, expressed as log \( \Delta \frac{N}{N_{\odot}} \), are reported in Table 3. The abundance patterns for each star, expressed in terms of solar values (Grevesse et al. 2010), are shown in Fig. 2. We also searched for binarity among our sample, combining our own measurements of radial velocity (reported in Table 2) with those found in literature, when available.

At the end of this section, we will discuss separately lithium abundance in Am stars with respect the normal A-type stars.

4.1 Individual stars

4.1.1 HD 104513

This star is known to be a metallic enhanced star since the pioneering work of Morgan (1932), who has noticed a strong Europium line at \( \lambda 4129 \) Å. Cowley et al. (1969), by using metal spectral lines, classified this star as A7 marginal metallic star, that is in agreement with that found later by Hauck (1973). This author, in his ‘Catalogue of Am stars with known spectral types’, reported HD 104513 to be an A7 from the Ca II K line. Abt (1975) found \( v \sin i = 65 \pm 10 \) km s\(^{-1}\).

Radial velocity measurements have been found in the literature; Abt & Levy (1985) published 23 velocities that are in agreement with the one measured by us and reported in Table 2. These velocities suggest a possible orbital motion, but since the amplitude is too low \((\sim 5 \) km s\(^{-1}\)) compared to errors on each measurements, we cannot conclude anything on the binarity of this object.

HD 104513 was the first marginal Am star discovered to pulsate (Kurtz 1978). He found indication of multiple periodicities in the \( \delta \) Scuti regime, with periods ranging from 0.81 to 1.90 hr.

To our knowledge, this is the first extensive abundances analysis so far published in the literature for HD 104513. We estimated \( T_{\text{eff}} = 7100 \pm 200 \) K and log \( g = 3.6 \pm 0.1 \) dex, that are typical for an F0/1 star, and a \( v \sin i = 72 \pm 7 \) km s\(^{-1}\) totally consistent with that published by Abt (1975). Moreover, we found moderate overabundances of about 1 dex for P, Sr, Y, and Ba, a slight overabundance of iron and iron peak elements and moderate underabundances of Ca and Sc, about 0.2 dex and 1 dex, respectively. Thus, we confirm the classification of a marginal Am star, but from the Balmer and metallic lines we suggest it could be a star with a spectral type of F0/1.

4.1.2 HD 113878

HD 113878 was first classified as Am by Olsen (1980), who estimated its spectrum peculiarity on the basis of Strömgren photometric indices. Later on, this classification has been confirmed spectroscopically by Abt (1984), who define it as a \( \text{K}f\text{hF3VmF3} \) marginal Am star, because of its strong Sr II lines and weak Ca i \( \lambda 4026 \) Å line.
Table 3. Abundances inferred for the Am stars of our sample. Values are expressed in the usual form \( \frac{N_i}{N_{\text{tot}}} \).

|        | HD 104513 | HD 113878 | HD 114839 | HD 118660 | HD 176843 | HD 179458 | HD 187254 | HD 190165 |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Li     | –         | –9.89 ± 0.10 | –         | –         | –8.90 ± 0.10 | –         | –8.40 ± 0.10 | –9.00 ± 0.10 |
| C      | −3.46 ± 0.11 | −3.63 ± 0.13 | −3.71 ± 0.17 | −3.50 ± 0.13 | −3.70 ± 0.11 | −3.14 ± 0.10 | −3.48 ± 0.11 | −3.46 ± 0.12 |
| O      | –         | –         | –         | –         | –         | −3.07 ± 0.13 | −3.14 ± 0.13 | –         |
| Na     | −5.67 ± 0.13 | −5.57 ± 0.14 | −5.14 ± 0.17 | −5.62 ± 0.19 | −4.96 ± 0.13 | −4.44 ± 0.15 | −5.18 ± 0.14 | −5.41 ± 0.13 |
| Mg     | −4.50 ± 0.15 | −4.57 ± 0.14 | −4.10 ± 0.06 | −4.59 ± 0.10 | −4.40 ± 0.15 | −4.32 ± 0.17 | −3.86 ± 0.14 | −4.41 ± 0.15 |
| Al     | –         | –         | –         | –         | −5.20 ± 0.14 | −4.04 ± 0.14 | −4.81 ± 0.09 | –         |
| Si     | −4.49 ± 0.11 | −4.62 ± 0.09 | −4.46 ± 0.10 | −4.41 ± 0.12 | −4.41 ± 0.12 | −4.21 ± 0.10 | −4.11 ± 0.12 | −4.24 ± 0.14 |
| P      | −5.44 ± 0.15 | –         | –         | −5.22 ± 0.08 | –         | –         | –         | –         |
| S      | −4.51 ± 0.12 | −4.65 ± 0.10 | −4.52 ± 0.18 | −4.36 ± 0.12 | −4.61 ± 0.11 | −4.00 ± 0.12 | −4.44 ± 0.11 | −4.11 ± 0.09 |
| Ca     | −5.93 ± 0.16 | −5.72 ± 0.13 | −5.59 ± 0.13 | −5.85 ± 0.10 | −5.87 ± 0.17 | −5.45 ± 0.16 | −5.90 ± 0.09 | −6.28 ± 0.15 |
| Sc     | −9.70 ± 0.15 | −9.41 ± 0.09 | −9.53 ± 0.17 | −9.00 ± 0.08 | −9.17 ± 0.10 | −8.50 ± 0.16 | −8.93 ± 0.07 | −9.32 ± 0.15 |
| Ti     | −7.31 ± 0.15 | −7.26 ± 0.12 | −7.18 ± 0.11 | −7.37 ± 0.12 | −6.99 ± 0.11 | −6.83 ± 0.14 | −6.49 ± 0.11 | −6.90 ± 0.15 |
| Cr     | −6.19 ± 0.19 | −6.26 ± 0.14 | −6.29 ± 0.18 | −6.15 ± 0.03 | −5.87 ± 0.12 | −6.25 ± 0.17 | −5.56 ± 0.10 | −5.98 ± 0.17 |
| Mn     | −6.42 ± 0.13 | −5.89 ± 0.09 | −6.51 ± 0.11 | −6.20 ± 0.15 | –         | −6.39 ± 0.14 | −6.19 ± 0.11 | −6.12 ± 0.11 |
| Fe     | −4.20 ± 0.18 | −4.62 ± 0.10 | −4.60 ± 0.17 | −4.10 ± 0.12 | −4.07 ± 0.15 | −4.30 ± 0.13 | −3.84 ± 0.07 | −4.16 ± 0.17 |
| Co     | −6.29 ± 0.13 | −6.45 ± 0.14 | −6.45 ± 0.14 | −6.37 ± 0.06 | −5.83 ± 0.08 | −5.87 ± 0.07 | −6.10 ± 0.05 | –         |
| Ni     | −5.77 ± 0.10 | −5.61 ± 0.12 | −5.72 ± 0.14 | −5.78 ± 0.12 | −5.40 ± 0.14 | −5.58 ± 0.11 | −5.02 ± 0.13 | −5.45 ± 0.15 |
| Cu     | −6.00 ± 0.12 | –         | –         | −7.22 ± 0.10 | −6.98 ± 0.10 | –         | –         | –         |
| Zn     | −7.52 ± 0.10 | –         | –         | −7.08 ± 0.10 | –         | –         | –         | –         |
| Ge     | −7.43 ± 0.10 | –         | –         | −7.57 ± 0.06 | –         | –         | –         | –         |
| Sr     | −8.08 ± 0.33 | −8.33 ± 0.10 | −8.53 ± 0.06 | −8.89 ± 0.10 | −8.22 ± 0.08 | −8.45 ± 0.13 | −7.82 ± 0.16 | −7.76 ± 0.13 |
| Y      | −9.10 ± 0.17 | −9.10 ± 0.09 | −9.67 ± 0.15 | −9.59 ± 0.06 | −9.02 ± 0.13 | –         | −8.73 ± 0.14 | −9.06 ± 0.12 |
| Zr     | −8.80 ± 0.06 | –         | −8.77 ± 0.08 | −8.76 ± 0.19 | −8.69 ± 0.07 | −8.29 ± 0.08 | –         | –         |
| Ba     | −8.76 ± 0.04 | −8.56 ± 0.14 | −8.30 ± 0.04 | −9.49 ± 0.07 | −7.71 ± 0.07 | −9.20 ± 0.05 | −7.42 ± 0.13 | −8.46 ± 0.14 |

Figure 2. Chemical pattern for our targets, ordered by increasing effective temperature, from the coolest (top) to the hottest (bottom). Horizontal dashed line corresponds to solar abundance (Grevesse et al. 2010).

From the pulsational point of view this star has been intensively studied in a series of papers by Joshi and collaborators. Joshi (2005), in his photometric search for variability in Ap and Am stars, discovered this star to pulsate with a period of about 2.3 h, which is typical of \( \delta \) Scuti stars. This period has been refined later by Joshi et al. (2006), who found \( P = 2.31 \) hr. Further observations carried out by Joshi et al. (2009) led the authors to conclude that HD 113878 is an evolved star.

Regarding binarity, Gouthcharov (2006) reported \( -18.10 \pm 0.90 \) km s\(^{-1}\) and Grenier et al. (1997) measured \( -12.50 \pm 1.20 \) km s\(^{-1}\). Our value, \( -2.78 \pm 1.53 \) km s\(^{-1}\), confirmed the presence of a variation.
Recently, Casagrande et al. (2011), from spectroscopic observations, have derived the following astrophysical parameters for HD 113878: \( T_{\text{eff}} = 7072 \pm 210 \) K, log \( g = 3.36 \), and \([\text{Fe/H}] = 0.74 \).

From our analysis, we found \( T_{\text{eff}} = 6900 \pm 200 \) K and log \( g = 3.4 \pm 0.1 \) dex, that are typical for an F1 evolved star, confirming both the results obtained by Joshi et al. (2009) and those from Casagrande et al. (2011). Regarding the abundance pattern, we found a slight underabundance of scandium of \( \approx 0.5 \) dex, and a moderate overabundance of manganese, cobalt, germanium, strontium, yttrium, zirconium and barium, all ranging from 0.4 to \( \approx 1 \) dex. A strong overabundance of copper, \( \approx 1.8 \) dex, has also been observed. This pattern confirms the classification of this star as a marginal Am star.

4.1.3 HD 114839

Following Hill et al. (1976), this object is reported in the ‘General Catalogue of Ap and Am stars’ (Renson, Gerbaldi & Catalano 1991) as an uncertain Am star. Pribulla et al. (2009) carried out medium-resolution (\( R = 12000 \)) spectroscopic observations at the David Dunlop Observatory, centred on the Mg I triplet at \( \lambda \lambda 5167-5184 \) Å, from which they measured \( v \sin i = 70 \) km s\(^{-1} \) and they concluded that it is a metallic line star of spectral type F4/F5. Balona et al. (2011) reported a spectral type of K3/F5mF3.

Only one measurement of radial velocity is reported in Gouthcharov (2006): \(-5.60 \pm 1.40 \) km s\(^{-1} \). This value is in agreement with our own reported in Table 2, at least within the experimental errors.

HD 114839 has been discovered as hybrid pulsator by King et al. (2006) by using space-based data carried out with the MOST satellite. They identify 15 frequencies, of which four are in the range between 1 and 2.5 c/d, consistent with \( \gamma \) Dor g-mode pulsations, while the remaining are between 6.5 and 22 c/d, typical for \( \delta \) Sct p modes.

For this star, we derived \( T_{\text{eff}} = 7100 \pm 200 \) K, log \( g = 3.8 \pm 0.1 \) dex, and \( v \sin i = 70 \pm 7 \) km s\(^{-1} \). These parameters led to a moderate (~0.5 dex) overabundances of Na, Mg, S, Co, and Sr and only a strong (~1.8 dex) overabundance of Ba. For what concerns the characteristic elements of the Am classification, we found only a moderate underabundance of scandium, while other light and iron-peak elements are almost solar. Thus, in conclusion we cannot confirm the Am peculiarity for this star.

A similar conclusion has been reached by Hareter et al. (2011). They performed an extensive spectroscopic study of HD 114839 with the aim to search for a link between the Am phenomenon and hybrid pulsators. Their effective temperature, surface gravity and rotational velocity are consistent with those derived in this study.

4.1.4 HD 118660

Barry (1970) was the first who noted marginal characteristic of Am phenomenology in the spectrum of HD 118660. Later on, Cowley & Bidelman (1979) gave the first spectral classification relying on their H\_\alpha spectrograms, denoting the star as a marginal A5m.

Two measurements of radial velocity have been reported in literature for HD 118660, Gouthcharov (2006) (~1.7 ± 2.9 km s\(^{-1} \)) and Wilson (1953) (~1.7 km s\(^{-1} \)). Those values are in perfect agreement with our measured velocity, so we can confirm the absence of variability.

Joshi et al. (2006) discovered \( \delta \) Sct-like pulsations in this star, with a dominant period of about 1 hr and another prominent period of about 2.52 hr.

To our knowledge, this is the first detailed abundance analysis performed for HD 118660. Atmospheric parameters are: \( T_{\text{eff}} = 7200 \pm 200 \) K and log \( g = 3.9 \pm 0.1 \) dex, and \( v \sin i = 100 \pm 10 \) km s\(^{-1} \). Rotational velocity is consistent with the value reported by Royer et al. (2002) of 94 km s\(^{-1} \). By using these values in our synthetic analysis, the most overabundance inferred was that of phosphorus of ~1.5 dex. Moderate overabundances in the range 0.2–0.6 dex have been found for S, Sc, iron-peak elements, Sr, Y, Zr and Ba. Solar to about ~0.2 dex have been derived for other elements, including calcium and scandium. This result led us to conclude that HD 118660 is a marginal Fm star.

This conclusion is corroborated by the work of Charbonneau & Michaud (1991), who established a rotational velocity limit of 90 km s\(^{-1} \) above which diffusion processes cannot cause Am peculiarities.

4.1.5 HD 176843

HD 176843 has been classified as kA3mF0, that is a marginal Am star, by Floquet (1975), but no studies are present in the recent literature regarding its astrophysical parameters.

Observed by the Kepler satellite, its periodogram has been presented first by Balona et al. (2011), who discovered excess power at two frequencies in the \( \delta \) Sct domain, about at 34.4 c/d and 37.7 c/d. Uytterhoeven et al. (2011) classify this object as a binary star with a \( \delta \) Sct component. Unfortunately, we did not find any other measurements of radial velocity in literature, so we cannot verify the possible binarity.

Even for this star, our study is the first ever reported in literature. Using the parameters we found, i.e. \( T_{\text{eff}} = 7600 \pm 150 \) K, log \( g = 3.8 \pm 0.1 \) dex and \( v \sin i = 27 \pm 3 \) km s\(^{-1} \), we found slight underabundances of Ca and Sc, normal values for C, Mg, Si, and Ti, and overabundances for the heavier elements of about 0.5–1 dex. Strong overabundance of Ba (~2 dex) have been observed, as well.

In conclusion, this star shows the typical pattern of Am stars.

4.1.6 HD 179458

The nature of this star has been debated in the past years, but in spite of this discussion, its classification is still doubtful. MacRae (1952) noted its possible peculiar spectrum, but he did not give any details.

Then the star was observed by Floquet (1970), who classified it as a normal A7 star. The uncertain nature is reported also in the ‘General Catalogue of Ap and Am stars’ (Renson et al. 1991). No measurements of radial velocity are present in literature.

Observed by Kepler, its periodogram does not show any sign of variability (Balona et al. 2011).

Our study shows that HD 179458 is an A4 main-sequence star, with \( T_{\text{eff}} = 8400 \pm 200 \) K, log \( g = 4.1 \pm 0.1 \) dex and \( v \sin i = 75 \pm 7 \) km s\(^{-1} \). The most part of chemical elements observed in this star shows overabundances, if compared with the respective solar values, from about 0.2 dex to about 1.5 dex. Besides, its chemical pattern is far from the solar one; it is not typical for Am stars, so we can conclude that HD 179458 is not belonging to this class of peculiarity.

4.1.7 HD 187254

Reported as a metallic star by Mendoza (1974), HD 187254 has been then classified as kA2mF0 by Floquet (1975).

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Seven radial velocities have been reported by Fehrenbach et al. (1997). Our measurement of radial velocity is compatible with those data, so that we confirm the presence of an orbital motion since the amplitude is $\approx 3\text{6 km s}^{-1}$, but we cannot attempt for a search of orbital parameters due to the lack of a sufficient number of data.

From the pulsational point of view, this star has been studied by Balona et al. (2011) who analysed the periodogram obtained with photometric data taken by the Kepler satellite. They concluded that it does not show any significant power excess in the $\beta$ Sct or $\gamma$ Dor range, though clear low-frequency variability is present. Some of this low-frequency variability may be of instrumental origin as long-term trends in Kepler data are not fully corrected. However, intrinsic variability could arise as a result of rotational modulation, for example. While no Am star is known to vary in this way from ground-based observations, it cannot be ruled out in Kepler photometry due to the extraordinary high precision.

Our study is the first ever detailed spectroscopic study, at least to our knowledge. From our spectrum we obtained: $T_{\text{eff}} = 8000 \pm 150\,\text{K}$, $\log g = 4.1 \pm 0.1\,\text{dex}$ and $v\sin i = 15 \pm 2\,\text{km s}^{-1}$. The only elements that appear to be solar are carbon and scandium, while a slight underabundance of $\approx 0.2\,\text{dex}$ has been observed for calcium. Iron and iron-peak elements are slightly overabundant, and as well are light elements. Strong overabundances have been observed for Cu, Sr, Y, and Zr almost 1 dex, and for Ba, about 2.4 dex. Therefore no doubt that it is an Am star.

4.1.8 HD 190165

This star is known to belong to the Am group since the work of Mendoza (1974), who carried out multicolour photometry for a sample of metallic stars. One year later, it was classified as kA2mF2 by Flocquet (1975). Despite the fact that its nature has been known for a long time, both a detailed spectroscopic studies aimed at computing its chemical pattern and a measurement of the rotational velocity for HD 190165 are missing.

Regarding binarity, besides the fact that the two radial velocities reported in the literature are in agreement with each other, $v_{\text{rad}} = -16.90\,\text{km s}^{-1}$ (Wilson 1953; Gouthcharov 2006), we found a discrepant value of $v_{\text{rad}} = -7.45 \pm 0.45\,\text{km s}^{-1}$. In any case we cannot make any conclusion about its variability.

Kepler observations have been analysed by Balona et al. (2011) and, like the case of HD 187254, they found only low-frequency variability.

From our spectrum we obtained $T_{\text{eff}} = 7400 \pm 150\,\text{K}$ and $\log g = 4.1 \pm 0.1\,\text{dex}$, and $v\sin i = 58 \pm 6\,\text{km s}^{-1}$. The chemical pattern computed by using these parameters showed underabundances of about 0.5 dex for calcium and scandium, while heavy elements are all overabundant, from 0.4 dex for iron-peak elements to about 1.4 dex for barium.

In conclusion the Am nature of HD 190165 is confirmed.

4.2 Lithium abundance

The lithium abundance in Am stars is a topic that has been discussed in several papers in the recent literature. Burkhart & Coupry (1991) and then Burkhart et al. (2005) concluded that, in general, lithium in Am stars is close to the cosmic value of $\log N_{\text{Li}}/N_{\text{Tot}} \approx -9.04$ dex, although a small fraction of them are Li underabundant. Fossati et al. (2007) analysed a sample of eight Am stars, belonging to the Praesepe cluster, in the range of temperature between 7000 and 8500 K. By using the $\text{Li} \lambda 6707$ Å line, they were able to compute abundances that appear to be higher than the cosmic value. Catanzaro & Balona (2012) computed the abundance of lithium in the Am star HD 27411, deriving a value of $\log N_{\text{Li}}/N_{\text{Tot}} = -8.42 \pm 0.10$, in agreement with the values reported by Fossati et al. (2007).

In this study we derived the lithium abundances for our Am stars (when possible) and we compared them with those reported in various literature sources for normal A-type stars.

To estimate the lithium abundance we applied the spectral synthesis method to the $\text{Li} \lambda 6707$ Å line, taking into account the hyperfine structure (Andersen, Gustafson & Lambert 1984), as well. Due to the high rotational velocity of some stars, we detected the line and then we were able to compute the relative abundance for only five stars: HD 113878, HD 176843, HD 187254, HD 190165 (see Table 3), and HD 71297 ($\log N_{\text{Li}}/N_{\text{Tot}} = -8.78 \pm 0.11$). Lithium abundances for these objects are shown (red filled circles) in Fig. 3 as a function of the effective temperature. For comparison purposes we plotted in the same figures the lithium abundances for various samples of Am stars. In particular we show with cyan filled triangles the results by Burkhart & Coupry (1991) and Burkhart et al. (2005) and with blue filled squares the data for Am belonging to Praesepe cluster (Fossati et al. 2007).

With the aim of comparing the Lithium abundances in Am and normal A stars, we computed the abundances for a sample of these latter objects in two ways: (i) converting the EW of the $\text{Li} \lambda 6707$ Å line taken from various sources: Coupry & Burkhart (1992), Glaspey, Pritchet & Stetson (1994), Balachandran, Mallik & Lambert (2011) or (ii) measured by us in spectra available on the Elodie archive (Observatoire de Haute Provence). For homogeneity purpose, all the computations have been performed for all the stars by Fig. 3. Lithium abundances plotted as a function of effective temperature. Filled symbols refer to Am stars, in particular circles (red) represent our data, triangles (cyan) are from Burkhart & Coupry (1991) and Burkhart et al. (2005), squared (blue) are from Fossati et al. (2007), and asterisk (magenta) are from Catanzaro & Balona (2012). Open circles refer to normal A-type stars taken from various literature sources as outlined in the text. Typical errors are indicated in the bottom right corner of the plot.
Table 4. Normal A-type stars and their Li abundances. For each star we reported its ID, effective temperature, EW of the Li i 6707 Å and the relative abundance expressed in the usual form log \( \frac{N_i}{N_\text{tot}} \).

| HD     | \( T_{\text{eff}} \) K | EW mÅ | Abun dex |
|--------|----------------|--------|----------|
| 739    | 6440           | 23.0   | −9.78    |
| 2628   | 7270           | 3.2    | −10.21   |
| 8829   | 7090           | 32.0   | −9.18    |
| 30652  | 6480           | 20.0   | −9.90    |
| 32537  | 7050           | 9.3    | −9.78    |
| 33959  | 7670           | 25.0   | −8.94    |
| 40136  | 7030           | 30.0   | −9.27    |
| 43760  | 7170           | 29.0   | −9.18    |
| 159834 | 8030           | 13.0   | −9.01    |
| 205939 | 7910           | 27.0   | −8.75    |
| 214994 | 9650           | 1.3    | −8.55    |
| 24936  | 7510           | 16.0   | −9.26    |
| 79636  | 7100           | 2.0    | −10.50   |
| 79765  | 7030           | 25.0   | −9.36    |
| 80390  | 6720           | 6.0    | −10.20   |
| 106749 | 7330           | 42.0   | −8.97    |
| 112327 | 6720           | 2.0    | −10.80   |
| 134360 | 7420           | 13.0   | −9.41    |
| 217602 | 7470           | 12.0   | −9.43    |
| 11636  | 8510           | 9.8    | −8.75    |
| 25867  | 7030           | 59.0   | −8.92    |
| 26322  | 7075           | 74.6   | −8.77    |
| 27819  | 8280           | 22.4   | −8.55    |
| 27962  | 9020           | 5.6    | −8.55    |
| 37788  | 7230           | 38.3   | −9.03    |
| 40932  | 8230           | 16.2   | −8.75    |
| 50062  | 9120           | 13.0   | −8.04    |
| 58946  | 7070           | 48.4   | −9.00    |
| 89021  | 9250           | 2.9    | −8.61    |
| 112412 | 6990           | 35.8   | −9.20    |
| 132145 | 9470           | 3.3    | −8.39    |
| 142908 | 6990           | 70.3   | −8.85    |
| 150557 | 7150           | 48.0   | −8.95    |
| 152598 | 7100           | 50.7   | −8.95    |
| 166230 | 8360           | 33.5   | −8.28    |
| 167858 | 7180           | 37.9   | −9.05    |
| 177552 | 6950           | 65.5   | −8.91    |
| 180777 | 7160           | 54.9   | −8.87    |
| 217754 | 7170           | 7.2    | −9.85    |
| 218396 | 7370           | 24.9   | −9.13    |
| 219080 | 7300           | 40.9   | −8.94    |
| 222603 | 8030           | 31.5   | −8.56    |

4From Coupry & Burkhart (1992).
5From Glaspey et al. (1994).
6From Elodie archive.

using WIDTH9 (Kurucz & Avrett 1981) applied to ATLAS9 models (Kurucz 1993a,b). These stars are listed in Table 4, together with their effective temperatures, derived by using Strömgren photometry as we described in Section 3.1, EWs and Li abundances. The normal A-type stars are shown in Fig. 3 with empty circles.

An inspection of Fig. 3 allows us to make some reflections. First, the lithium abundance estimated in our sample of Am stars is on average lower by \( \approx 0.2 \) dex with respect to that measured in the Am stars belonging to Praesepe cluster (Fossati et al. 2007). Secondly, albeit our targets fall in the range of effective temperatures of the so-called Li dip, a region of the diagram \( T_{\text{eff}} - \log N_i/N_\text{tot} \) between the temperatures 6600 to 7600 K, where lithium shows a sudden drop of about 1.6–1.8 dex (Boesgaard & Tripicco 1986), none of them present abundances lower than the cosmic value (see the dotted line in Fig. 3). Thirdly, it appears clear that there is no difference between the peculiar and normal A-type stars. Even the Li dip is present both in Am and in normal stars.

5 POSITION IN THE HR DIAGRAM

In principle, the stellar parameters \( \log g \) and \( T_{\text{eff}} \) determined in the previous section allow us to estimate the luminosity of the investigated objects. In a previous paper (Catanzaro et al. 2011), we accomplished this task by interpolating the tables by Schmidt-Kaler (1982). However, it can be noticed that the space of parameters \( \log g \), \( \log L/L_\odot \), \( \log T_{\text{eff}} \) (spectral type) adopted by Schmidt-Kaler (1982) is rather poorly sampled. To improve this situation we decided to use a different calibration \( \log L/L_\odot = \log L/L_\odot(\log g, \log T_{\text{eff}}) \) whose derivation is described in a different paper (Ripepi et al., in preparation). Here we only show the final equation (valid in the intervals \( 3.2 < \log g < 4.7 \), \( 3.690 < \log T_{\text{eff}} < 3.934 \)):

\[
\log L/L_\odot = (-15.46 \pm 0.34) + (5.185 \pm 0.080) \log T_{\text{eff}} - (0.913 \pm 0.014) \log g \text{ rms} = 0.093 \text{dex}. \tag{3}
\]

Hence, we estimated the values of \( \log L/L_\odot \) for the eight stars studied in this paper by inserting in the above equation the spectroscopically derived values for \( \log g \), \( \log T_{\text{eff}} \) as reported in Table 2. The result of this procedure is listed in Table 5 where we report in Columns 2 to 4 the \( \log L/L_\odot \), the distance and the \( M_\odot \) respectively. The last two quantities were derived from the estimate of \( \log L/L_\odot \) by means of simple algebraic passages and the information included in Table 1.

As a check for these estimates, we derived the same quantities directly from the parallax measured by Hipparcos for four stars in our sample (see Table 1). The results are shown in Column 5 to 7 of Table 5. A comparison between Columns 2 and 5 reveals that the two independent \( \log L/L_\odot \) estimates are in good agreement within the errors, with the exception of HD 104513, which appears to be too bright if luminosity is estimated by means of equation (3). We have already discussed in Section 3.3 the possible origin of this discrepancy. In any case, in the following we adopted the parallax-based \( \log L/L_\odot \) for HD 104513, HD 114839 HD 118660 and HD 190165, whereas for HD 113878 we preferred to adopt the estimate from equation (3), given the large error on parallax.

One of the aims of this paper is to try to constrain the locus occupied by the pulsating Am star in the HR diagram. This is done in Fig. 4 where we plotted the eight stars analysed in this paper (\( \log T_{\text{eff}} \) from Column 2 of Table 2; \( \log L/L_\odot \) from Column 2 or 5 of Table 5). In the same figure we added the three pulsating Am stars analysed in our previous works, namely: HD 71297 (after Catanzaro et al. 2013), HD 178327 and HD 183489 (after Balona et al. 2011). Note that for the latter two stars, the value of \( \log L/L_\odot \) was recalculated. In particular, for HD 183489, we used the Hipparcos parallax value (\( \pi = 5.91 \pm 0.63 \); van Leeuwen 2007) to estimate its luminosity, obtaining \( \log L/L_\odot = 1.11 \pm 0.09 \text{ dex} \). Unfortunately, Hipparcos did not observe HD 178327. However, this star appears to be a twin of HD 183489, showing exactly the same \( \log g \) or \( \log T_{\text{eff}} \) and chemical abundance (within the errors; see Catanzaro et al. 2013) of this object. Hence, we decided to assign to HD 178327 the same luminosity of HD 183489, but increasing the error by 50 per cent to

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The values of $T_{\text{eff}}$ and $\log g$ derived here have been used to determine the luminosity of the stars and to place them on the HR diagram.

To overcome the problem arising from blending of spectral lines, we applied the synthesis method by using SYNTHETE (Kurucz & Avrett 1981) and ATLAS9 (Kurucz 1993a) codes. The typical errors were about 200 K for $T_{\text{eff}}$, 0.1 dex for $\log g$, and a few km s$^{-1}$ for the $\sin i$.

The values of $T_{\text{eff}}$ and $\log g$ derived here have been used to determine the luminosity of the stars and to place them on the HR diagram.

According to our analysis, we ruled out two stars from the group of the Am stars, namely: HD 114839 and HD 179458. The reasons for this choice are that HD 114839 and HD 179458 stand too far from the ZAMS (solid line) and the isochrones for 0.5, 0.7 and 1.0 Gyr (dotted line) are from the BaSTI data base.

6 http://albione.oa-teramo.inaf.it/

6 DISCUSSION AND CONCLUSION

In this work we presented a spectroscopic analysis of a sample of eight stars classified in literature as to belong to the class of the metallic Am stars. The analysis is based on high-resolution spectra obtained at the Telescopio Nazionale Galileo with the SARG spectrograph. For each spectra we obtained fundamental parameters such as effective temperatures, gravities, rotational and radial velocities, and we performed a detailed computation of the chemical pattern, as well. To overcome the problem arising from blending of spectral lines, we applied the synthesis method by using SYNTHETE (Kurucz & Avrett 1981) and ATLAS9 (Kurucz 1993a) codes. The typical errors were about 200 K for $T_{\text{eff}}$, 0.1 dex for $\log g$, and a few km s$^{-1}$ for the $\sin i$.

The values of $T_{\text{eff}}$ and $\log g$ derived here have been used to determine the luminosity of the stars and to place them on the HR diagram.

According to our analysis, we ruled out two stars from the group of the Am stars, namely: HD 114839 and HD 179458. The reasons for this choice are that HD 114839 and HD 179458 stand too far from the ZAMS (solid line) and the isochrones for 0.5, 0.7 and 1.0 Gyr (dotted line) are from the BaSTI data base. We also show in the figure the comparion with the edges of the $\delta$ Sct (after Breger & Pamyatnykh 1998) and $\gamma$ Dor (after Warner, Kaye & Guzik 2003) instability strips, respectively.

An analysis of the figure shows that only the cooler part of the $\delta$ Sct instability strip is occupied by the pulsating Am stars investigated here, whereas no object falls in the region where only $\gamma$ Dor pulsation is allowed. Only HD 104513 (among the pulsating Am stars) lies in the region where both $\delta$ Sct and $\gamma$ Dor variability are excited. Moreover, all the stars have an age between 0.5, 0.7 and 1.0 Gyr.

For comparison purposes, Fig. 4 shows with small yellow filled circles the location of the stars investigated in this paper plus HD71297 (after Catanzaro et al. 2013), HD 178327 and HD 183489 (after Balona et al. 2011). The red dashed lines show the $\delta$ Sct instability strip by Breger & Pamyatnykh (1998); the blue dot-dashed lines show the theoretical edges of the $\gamma$ Dor instability strip by Warner et al. (2003). The evolutionary tracks (thin solid lines) for the labelled masses as well as the ZAMS (thick solid line), and the isochrones for 0.5, 0.7 and 1.0 Gyr (dotted lines) are from the BaSTI data base.
In the scenario described by the diffusion models developed by Richer et al. (2000), stars in the range of temperature and age compatible with those of our sample should have underabundances of about 0.1 to 0.3 dex for elements such as C, N, O, Na, Mg, K, and Ca, normal abundance for Si and S, while Al, Ti, Cr, Mn, Fe, and Ni overabundant of about 0.1 to 0.8 dex.

For lithium, Richer et al. (2000) models predict anomalies of $\approx-0.2$ dex with respect the cosmic value. For our stars, in general we obtained abundances almost 0.2 dex over the cosmic value, a result in agreement with the abundances found in the Am star HD 27411 (Catanzaro & Balona 2012) and in the Praesepe cluster (Fosset al. 2007). In conclusion we measured more lithium than that predict by theory.

Recently, Vick et al. (2010), in the context of the project to explore various macroscopic processes which compete with atomic diffusion in Am/Fm stars, computed a grid of models in which mass-loss has been used instead of turbulence. Those models predict at the side of Li, where our objects lie, a smaller anomaly but still not sufficient to explain our observations. As the authors suggested, it is likely that more than one mechanism compete to diffusion, i.e. mass-loss in combination with turbulence, but at the moment it is not possible to conclude about one of this possibility.

In any case, our detailed abundance analysis can help theorist in setting more constraints in their diffusion models.

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