LOOKING FOR A CONNECTION BETWEEN THE Am PHENOMENON AND HYBRID δ Sct –γ Dor PULSATION: DETERMINATION OF THE FUNDAMENTAL PARAMETERS AND ABUNDANCES OF HD 114839 AND BD +18 4914*

M. HARETER1, L. FOSSATI2, W. WEISS3, J. C. SUÁREZ3, K. UYTTERHOEVEN4,5,6, M. RAINER7, AND E. PORETTI7

1 Department of Astronomy, University of Vienna, Türkenschanzstrasse 17, A-1180 Wien, Austria; hareter@astro.univie.ac.at
2 Department of Physics and Astronomy, Open University, Walton Hall, Milton Keynes MK6 7AA, UK
3 Instituto de Astrofísica de Andalucía (CSIC), Glorieta de la Astronomía S/N, 18008, Granada, Spain
4 Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, D-79104 Freiburg, Germany
5 Instituto de Astrofísica de Canarias, 38200 La Laguna, Tenerife, Spain
6 Departamento de Astrofísica, Universidad de La Laguna, 38205 La Laguna, Tenerife, Spain
7 INAF-Osservatorio Astronomico di Brera, Via E. Bianchi 46, 23807, Merate (LC), Italy

Received 2011 August 4; accepted 2011 August 29; published 2011 December 2

ABSTRACT

δ Sct–γ Dor hybrids pulsate simultaneously in p- and g-modes, which carry information on the structure of the envelope as well as to the core. Hence, they are key objects for investigating A and F type stars with asteroseismic techniques. An important requirement for seismic modeling is small errors in temperature, gravity, and chemical composition. Furthermore, we want to investigate the existence of an abundance indicator typical for hybrids, something that is well established for the roAp stars. Previous to the present investigation, the abundance pattern of only one hybrid and another hybrid candidate has been published. We obtained high-resolution spectra of HD 114839 and BD +18 4914 using the SOPHIE spectrograph of the Observatoire de Haute-Provence and the HARPS spectrograph at ESO La Silla. For each star we determined fundamental parameters and photospheric abundances of 16 chemical elements by comparing synthetic spectra with the observations. We compare our results to that of seven δ Sct and nine γ Dor stars. For the evolved BD +18 4914 we found an abundance pattern typical for an Am star, but could not confirm this peculiarity for the less evolved star HD 114839, which is classified in the literature as uncertain Am star. Our result supports the concept of evolved Am stars being unstable. With our investigation we nearly doubled the number of spectroscopically analyzed δ Sct–γ Dor hybrid stars, but did not yet succeed in identifying a spectroscopic signature for this group of pulsating stars. A statistically significant spectroscopic investigation of δ Sct- γ Dor hybrid stars is still missing, but would be rewarding considering the asteroseismological potential of this group.

Key words: stars: abundances – stars: individual (BD +18 4914, HD 114839) – stars: variables: delta Scuti – techniques: spectroscopic

Online-only material: color figures

1. INTRODUCTION

δ Sct stars are main sequence or evolved stars (up to luminosity class III), which pulsate in low-order radial and non-radial p-modes with typical pulsation frequencies of 5 to 50 d⁻¹. They occupy the lower Cepheid instability strip extended toward the main sequence (see Breger 2000 for a detailed review). The class of γ Dor stars was defined in 1999 by Kaye et al. (1999) and, in contrast to δ Sct stars, they pulsate in high-order g-modes with typical frequencies of 0.3 to 3 d⁻¹. The instability strip of γ Dor stars is rather narrow and partly overlaps the larger δ Sct instability strip. Given the overlap between the δ Sct and γ Dor instability strips, a search for hybrid pulsators began in the last few years, which was driven by the fact that p-modes are sensitive to the envelope, whereas g-modes are sensitive to the core. Hence, hybrids are key objects for testing stellar models from core to the photosphere with asteroseismic techniques.

The space missions MOST (Microvariability and Oscillation of STars; Walker et al. 2003), CoRoT (Convection, ROtation, and planetary Transits; Baglin et al. 2006), and Kepler (Borucki et al. 2010) increased the number of known hybrid stars significantly, because observations of low-frequency pulsation with low amplitudes are easier from space (see, e.g., King et al. 2006; Rowe et al. 2006; Hareter et al. 2010; Grigahcène et al. 2010; Uytterhoeven et al. 2011).

Am stars are chemical peculiar early F- to A-type stars, characterized by an underabundance of C, N, O, Ca, and Sc, as well as by a general overabundance of Fe-peak and Rare Earth Elements. Am stars do not host large-scale magnetic fields (Aurière et al. 2010) and are often in binary systems (see, e.g., recent review by Iliev & Budaj 2008, and references therein). Compared to the vast majority of the chemically normal stars of the same temperature, Am stars are slow rotators, allowing diffusion processes to produce the chemical peculiarities (Michaud 1970).

The aim of this work is to investigate a potential link between chemical peculiarities such as metallic line A/F stars to the hybrid pulsation. Furthermore, we intend to provide accurate fundamental parameters of our two stars for further modeling of this type of pulsator.

With HD 8801 Henry & Fekel (2005) discovered the first δ Sct-γ Dor hybrid. Based on the Ca K line intensity relative to hydrogen and metallic lines they classified HD 8801 as an Am star. Hence, it was obvious to check if the two δ Sct–γ Dor hybrids discovered by Rowe et al. (2006, HD 114839) and by King et al. (2006, BD +18 4914) with MOST photometry share this chemical peculiarity.

* Based on observations made at the Observatoire de Haute-Provence and with HARPS at the 3.6 m ESO telescope under the Large Programme LP185.D-0056.
HD 114839 (R.A.: 13h12m47.43 and decl.: +26°52′52″19, epoch 2000; \( V = 8.46 \) mag) was classified by Hill et al. (1976) and Clausen & Jensen (1979) as an uncertain Am star. Pribulla et al. (2009) analyzed two spectra obtained at the David Dunlap Observatory in the spectral region of the Mg i triplet at \( \lambda \lambda 5167, 5173, \) and 5184 Å, from which they deduced that HD 114839 is a metallic line star of spectral type F4/5. They measured a \( \upsilon \sin i \) of 70 km s\(^{-1}\), low enough to allow HD 114839 to be an Am star (Charbonneau & Michaud 1991). BD +18 4914 (R.A.: 22h02m37s70 and decl.: +18°54′02′′62, epoch 2000) is a fainter star (\( V = 10.6 \) mag), for which the MOST photometry (Rowe et al. 2006) showed clearly two distinct groups of frequencies. This star was also included in the survey by Pribulla et al. (2009), who derived a spectral type of F5/6 and a \( \upsilon \sin i \) of 40 km s\(^{-1}\).

As a side comment we want to mention HD 49434, for which a ground-based photometric and spectroscopic campaign was organized and published by Uytterhoeven et al. (2008). However, the hybrid nature of this star has not yet been established beyond doubt, because this star might rotate fast and a spread of frequencies over a larger range may mimic hybrid characteristics. The abundance analysis for this star did not show significant peculiarities.

2. OBSERVATIONS AND DATA REDUCTION

Four spectra of HD 114839 were obtained between 2008 April 13 and May 2, while two spectra of BD +18 4914 were obtained in 2008 August 7 and 8 with the SOPHIE spectrograph.

SOPHIE is a cross-dispersed échelle spectrograph mounted at the 1.93 m telescope of the Observatoire de Haute-Provence (OHP). The spectra cover the wavelength range of 3872–6943 Å without gaps and we used it in the medium spectral resolution (\( R \approx 40,000 \)) mode.

The orders of the individual SOPHIE spectra were averaged, the blaze function removed, and the individual orders merged to a single spectrum. The lowest quality spectrum of HD 114839 was ignored in this process. The removal of the blaze function containing hydrogen lines (HD 114839 and BD +18 4914 in our case) and the subsequent continuum normalization is a challenge for spectra obtained with échelle spectrographs, because for A to F stars these lines extend over adjacent orders. We corrected for the blaze function of orders containing the hydrogen lines by using the artificial flat-fielding technique described, e.g., by Barklem et al. (2002). This approach assumes that the blaze shape of the different échelle orders change smoothly with the order number and one can reconstruct missing blaze shapes by fitting polynomials to continuum points identified in several adjacent orders blue- and redward of the hydrogen line containing order. A two-dimensional polynomial surface is fitted to these empirical blaze functions and the blaze in the orders containing the hydrogen lines is determined by interpolation. The accuracy of this technique is confirmed by an excellent agreement of the normalized hydrogen lines obtained with SOPHIE and HARPS spectrographs (see Figure 1) having a clearly different blaze characteristic and different position of the hydrogen lines within the orders.

The \( \upsilon \sin i \) of the two stars (\( \approx 70 \) and 40 km s\(^{-1}\)) makes the continuum normalization a critical step of the reduction procedure. We normalized the combined, blaze removed orders without the use of any automatic continuum fitting procedure and by comparing with suited synthetic spectra. For wavelengths shorter than the \( H_\gamma \) line it was not possible to determine the correct level of the continuum, as there were not enough continuum windows in the spectrum at these wavelengths due to the strong line blending. Therefore, we did not include this part of the spectrum in our analysis. Finally, we obtained a signal-to-noise ratio (S/N) per pixel of 121 at \( \approx 5800 \) Å for HD 114839 and of 56 for BD +18 4914.

Two spectra of HD 114839 were obtained with HARPS two years later on 2010 June 21 and 22, and one of BD +18 4914 in the same year on July 2, in the framework of a program complementary to the extensive monitoring of the hybrid \( \delta \) Sct- \( \gamma \) Dor variables observed with the CoRoT satellite. We processed the HARPS data in a manner similar to the SOPHIE spectra and achieved an S/N per wavelength pixel for HD 114839 of 200 at \( \approx 5800 \) Å and for BD +18 4914 of 92. The HARPS spectra were obtained in the EGGS mode, which delivers a resolution of 80,000.

Table 1 presents the observing log with our measured stellar radial velocities (\( \upsilon_r \)). The star BD +18 4914 might be the primary star in a binary system, given the difference in \( \upsilon_r \) obtained between the SOPHIE and HARPS spectra in 2008 and 2010. However, from ground-based observations (Mathias et al. 2004) it is known that \( \gamma \) Dor stars may show significant RV variations due to pulsation. None of our spectra shows spectral lines from a secondary, hence the assumption of a single star or a single-lined binary is justified.

3. PARAMETER DETERMINATION AND ABUNDANCE ANALYSIS

To compute model atmospheres we employed a modified version of ATLAS9 (Kurucz 1993), which uses a model of convection based on Canuto & Mazzitelli (1991, 1992). More details can be found in Heiter et al. (2002). The initial atmospheric parameters for HD 114839 were derived from Strömgren photometry by Hauck & Mermilliod (1998) employing the calibration by Balona (1994). We obtained \( T_{\text{eff}} = 7400 \) K and \( \log g = 4.20 \). For BD +18 4914 no narrowband photometry was available. Based on a comparison of the spectra we decided to use the same parameters as those used for HD 114839.

In the temperature range of HD 114839 and BD +18 4914, the hydrogen line wings are sensitive to \( T_{\text{eff}} \), making them very good temperature indicators. We fitted synthetic hydrogen line profiles, calculated with SYNTH3 (Kochukhov 2007), to the
values of 68 ± 6.24 ... parameters were obtained from the hydrogen line fitting. The atomic line parameters (SOPHIE for HD 114839, top, and HARPS for BD +18 4914, bottom) Hβ line profiles for the two stars with synthetic profiles calculated with the final adopted Teff (solid lines), and uncertainty (dashed lines).

Figure 1. Comparison of the Hβ line profiles (wide gray solid lines) to synthetic profiles calculated with the final adopted Teff (solid lines), and uncertainty (dashed lines).

(A color version of this figure is available in the online journal.)

observations. Figure 1 shows the comparison of the observed (SOPHIE for HD 114839, top, and HARPS for BD +18 4914, bottom) Hβ line profiles for the two stars with synthetic profiles calculated with the stellar Teff value of 7100 K for HD 114839 and 6900 K for BD +18 4914. We also show synthetic line profiles calculated with a Teff differing by 1σ (±200 K).

The Fe i and Fe ii excitation equilibrium confirms the Teff obtained from the hydrogen line fitting. The atomic line parameters were obtained from the VALD database (Piskunov et al. 1995; Kupka et al. 1999; Ryabchikova et al. 1999). By requiring ionization equilibrium for Fe i and Fe ii we derived log g values of 4.0 ± 0.2 and 3.8 ± 0.2 for HD 114839 and BD +18 4914, respectively.

Van Leeuwen (2007) reported for HD 114839 a parallax of 6.24 ± 0.85 mas, which puts the star at a distance between 140 and 185 pc. The bolometric correction of 0.033 (see Flower 1996) was neglected, because the uncertainty of the parallax plays a much larger role. From this distance and making use of isochrones by Marigo et al. (2008) (see Section 5), we derived a stellar gravity of 4.00±0.12, in agreement with what we obtained by imposing the ionization equilibrium.

The median radial velocities and u sin i values were derived from fitting synthetic spectral lines to observed profiles. Our measured u sin i values are listed in Table 1 and we obtained u sin i values of 68 ± 2 km s⁻¹ and 38 ± 2 km s⁻¹, respectively, for HD 114839 and BD +18 4914.

Due to the rather high u sin i of both stars, it was not possible to reliably measure equivalent widths for the metallic lines. Therefore, we derived the line abundances by line core fitting in the same way as described by Fossati et al. (2008a). The microturbulence velocity was determined using only Fe lines, because the high u sin i and rather low S/N did not allow us to measure enough lines of other elements. We derived the line abundances for the selected Fe lines at different vσmic values and plotted the standard deviation from the mean abundance as a function of vσmic (Figure 2). The minimum of this curve gives the vσmic value, which fits the observation best. From the SOPHIE spectra of HD 114839 and BD +18 4914 we derived vσmic of 2.6 and 2.9 km s⁻¹, respectively, with an uncertainty of 0.7 km s⁻¹. The values agree within the quoted errors; however, we remark that the HARPS spectra have a better S/N ratio.

The abundances we obtained for the two stars are listed in Tables 2 and 3. We also checked for rare Earth element overabundances, but none was found. Due to the presence of artifacts in the SOPHIE spectra at wavelengths close to the Li i line at λ6707 Å, we were not able to measure the Li abundance from these spectra. The analysis of the Li line was done with the HARPS spectra.

The uncertainty of Teff was derived directly from hydrogen line fitting with σTeff of 200 K for both stars. Due to the rather low Teff and high u sin i of the two stars, only a few Fe ii lines could be measured compared to Fe i lines resulting in a σlogg of 0.2. A smaller error for log g was derived for HD 114839 using its parallax and evolutionary models as was described at the beginning of this section. Iron was the only element for which we were able to use enough lines of two ionization stages for determining log g.

The abundance uncertainties listed in Tables 2 and 3 are the standard deviations of the mean abundances derived from the individual line abundances, which include also the errors from oscillator strengths and continuum normalization (Fossati et al. 2009). The standard deviations of the mean abundances underestimate the actual abundance uncertainty, since uncertainties of the fundamental parameters should also be taken into account.

Table 4 displays the fundamental parameters of the two program stars. The error bars used for Figure 3 were computed from the
| Element  | log(N/N$_{\text{Sun}}$) | SOPHIE | HARPS | Sun |
|----------|------------------------|--------|-------|-----|
| Li       | $\cdots (\cdots;0)$    | $-8.91(\cdots;1)$ | $-10.99$ |
| C        | $-3.36(\cdots;1)$      | $-3.36(\cdots;1)$ | $-3.65$ |
| Na       | $-5.82(16;2)$          | $-5.68(11;2)$ | $-5.87$ |
| Mg       | $-4.44(27;9)$          | $-4.55(12;5)$ | $-4.51$ |
| Si       | $-4.22(21;6)$          | $-4.37(23;8)$ | $-4.53$ |
| S        | $-4.60(\cdots;1)$      | $-4.75(12;4)$ | $-4.90$ |
| Ca       | $-5.81(22;19)$         | $-5.81(12;12)$ | $-5.73$ |
| Sc       | $-9.13(37;6)$          | $-9.11(05;6)$ | $-8.99$ |
| Ti       | $-7.16(31;10)$         | $-7.10(34;9)$ | $-7.14$ |
| Cr       | $-6.37(21;15)$         | $-6.37(28;10)$ | $-6.40$ |
| Mn       | $-6.63(16;2)$          | $-6.75(01;2)$ | $-6.65$ |
| Fe       | $-4.57(13;79)$         | $-4.57(12;96)$ | $-4.59$ |
| Ni       | $-5.84(21;16)$         | $-5.78(22;16)$ | $-5.81$ |
| Zn       | $-8.04(23;2)$          | $-8.06(29;2)$ | $-7.44$ |
| Y        | $-9.45(21;5)$          | $-9.53(19;3)$ | $-9.83$ |
| Ba       | $-8.95(20;4)$          | $-9.00(06;3)$ | $-9.87$ |

Notes. The estimated internal errors in units of 0.01 dex and the number of lines measured for each element are given in parenthesis. For comparison, the last column shows the solar abundances by Asplund et al. (2005). Abundances obtained from just one line have no error (\(\cdots;1\)).

Table 3
As in Table 2, but for BD +18 4914

| Element  | log(N/N$_{\text{Sun}}$) | SOPHIE | HARPS | Sun |
|----------|------------------------|--------|-------|-----|
| Li       | $\cdots (\cdots;0)$    | $-9.80(\cdots;1)$ | $-10.99$ |
| C        | $-3.59(12;5)$          | $-3.60(15;3)$ | $-3.65$ |
| Na       | $-5.29(\cdots;1)$      | $-5.43(04;2)$ | $-5.87$ |
| Mg       | $-4.69(17;6)$          | $-4.62(18;6)$ | $-4.51$ |
| Si       | $-4.15(13;7)$          | $-4.37(19;9)$ | $-4.53$ |
| S        | $-4.60(\cdots;1)$      | $-4.60(09;4)$ | $-4.90$ |
| Ca       | $-6.19(21;15)$         | $-6.18(19;19)$ | $-5.73$ |
| Sc       | $-10.05(30;7)$         | $-10.18(38;4)$ | $-8.99$ |
| Ti       | $-7.20(28;18)$         | $-7.28(15;20)$ | $-7.14$ |
| Cr       | $-6.33(25;20)$         | $-6.40(18;21)$ | $-6.40$ |
| Mn       | $-6.69(18;8)$          | $-6.67(21;7)$ | $-6.65$ |
| Fe       | $-4.52(18;204)$        | $-4.53(15;110)$ | $-4.59$ |
| Ni       | $-5.53(18;25)$         | $-5.50(10;19)$ | $-5.81$ |
| Zn       | $-7.32(10;2)$          | $-7.43(01;2)$ | $-7.44$ |
| Y        | $-9.56(18;3)$          | $-9.56(07;5)$ | $-9.83$ |
| Ba       | $-9.57(08;2)$          | $-9.61(02;3)$ | $-9.87$ |

Note. The Li abundance is an upper limit.

Table 4
Final Parameters of the Program Stars

| Star     | Teff (K) | log g (cm s$^{-2}$) | $v_{\text{mic}}$ (km s$^{-1}$) | $v\sin i$ (km s$^{-1}$) |
|----------|----------|---------------------|-------------------------------|-------------------------|
| HD 114839 | 7100 ± 200 | 4.0 ± 0.15   | 2.7 ± 0.5            | 68 ± 2                |
| BD +18 4914 | 6900 ± 200 | 3.8 ± 0.20 | 3.2 ± 0.7          | 38 ± 2                |

Figure 4. Observed SOPHIE spectrum of HD 114839 and HARPS spectrum of BD +18 4914 compared to synthetic spectra around the Sc ii line at 5031 Å and of three iron lines at 5027.5 Å. The dashed line is for solar Sc abundance and the full lines are for the abundance derived by us. The spectra for HD 114839 are offset by 0.3 for better visibility. (A color version of this figure is available in the online journal.)

The results we obtained from the SOPHIE and HARPS spectra are in comfortably good agreement, confirming our continuum normalization, determination of the fundamental parameters and abundances, and their uncertainties, as shown in Figure 3. Note that the same lines have not always been selected for the same star observed with the two spectrographs.

4. SPECTROSCOPIC CHARACTERISTICS OF HD 114839 AND BD +18 4914

Figure 4 shows the spectral region around the Sc ii line at 5031 Å and of three iron lines at 5027.5 Å for the two stars in comparison with synthetic spectra calculated once with the Sc solar abundance (dashed line) and a second time with the Sc abundance obtained individually for each star (full line). The star BD +18 4914 clearly shows a strong Sc underabundance, while HD 114839 presents a solar Sc abundance. This confirms abundance to 0.20 dex for HD 114839 and to 0.23 dex for BD +18 4914.

The square root of the sum of squared abundance changes resulting from varying fundamental parameters by 1σ.

For iron, e.g., the abundance changes by 0.12 dex, if we change Teff by 1σ (= 200 K). In the case of $v_{\text{mic}}$ the abundance changes by 0.09 dex when changing $v_{\text{mic}}$ by 1σ (= 0.7 km s$^{-1}$), while the uncertainty of log g increases the abundance error only by 0.01 dex. All these uncertainties add up for the iron
BD +18 4914 being an Am star, which is corroborated by the Ca underabundance and the significant overabundance of Ni and Y.

In Figures 5 and 6 we compare the abundances obtained for HD 114839 and BD +18 4914 with the average abundances published by Fossati et al. (2008b) for seven nearby field δ Sct stars. This comparison is straightforward because parameters and abundances were obtained with similar methods and codes. We do not find any systematic difference between the mean abundances of the field δ Sct stars and of HD 114839, while BD +18 4914 clearly shows its Am nature. Additionally, the results were compared to that of nine γ Dor stars obtained by Bruntt et al. (2008). These authors did not find any typical abundance pattern among γ Dor stars, however they found a larger scatter in the abundances compared to the reference stars. With a reanalysis of two reference stars used by Bruntt et al. (2008), Fossati et al. (2011) showed that the methodology for parameter determination adopted by Bruntt et al. (2008) led them to erroneous results. Consequently, the abundances of the nine γ Dor stars might not be reliable and conclusions from this comparison should be taken with caution.

Very recently, Balona et al. (2011) presented the analysis of 10 Am stars observed by Kepler of which HD 178327 shows hybrid pulsation. But with a mild overabundance of Ca and Sc, HD 178327 misses an important classification criterion for Am stars where the mentioned elements should be significantly underabundant. The abundances of 14 elements determined by Balona et al. (2011) for this hybrid star are included in our Figures 5 and 6, hence increasing the total number of hitherto spectroscopically investigated hybrid stars to five.

Figure 7 shows the HARPS spectra in the region of the Li line at 6707 Å in comparison with a synthetic spectrum calculated with the Li abundance obtained for HD 114839 (top). For this star the Li line is clearly visible and leads to an abundance of −8.91 dex. For BD +18 4914 (bottom) the Li line is not visible and we obtain an upper limit of −9.80 dex. The synthetic spectrum for BD +18 4914 is computed with this abundance.

Burkhart et al. (2005) and Fossati et al. (2007) derived the Li abundance in a set of chemically normal A-type stars and compared it to Am stars, concluding that Am stars have a lower Li abundance compared to chemically normal A-type stars. The Li abundance we obtained for HD 114839 and BD +18 4914 reproduces this pattern and strengthens our classification of HD 114839 as a chemically normal star and of BD +18 4914 as an Am star.

A very recent study of δ Sct, γ Dor, and hybrid stars (Uytterhoeven et al. 2011) observed by the space mission Kepler indicates that possibly two more hybrid candidate stars are chemically peculiar: HD 181206 (Ap or Am) and HD 178327 (Am). For 58 other hybrid candidate stars spectral types based on published spectral classifications are available, but with no indication of peculiarity.

5. EVOLUTIONARY STATUS OF HD 114839 AND BD +18 4914

Figure 8 shows HD 114839 and BD +18 4914 in the $T_{\text{eff}}$–log g plane with the respective error boxes derived in Section 3. The figure also shows isochrones from Marigo et al. (2008), for ages between 1 and 1.4 Gyr, from left to right. Solar metallicity was chosen, because we obtained solar Fe abundance for both stars. The error boxes for both stars cover part of the cool δ Sct and...
the $\gamma$ Dor instability regions and a range of evolutionary stages, masses, and radii (and thereby mean densities).

We used a grid of A-F models$^8$ provided by one of us (J.C.S.) using the evolutionary code CESAM (Morel 1997) to explore the given parameter space in more detail. We used different values for the mass, convection efficiency, and overshoot parameters within ranges typical for these stars (see, e.g., Suárez et al. 2005; Bruntt et al. 2007; Rodríguez et al. 2006a, 2006b, for $\delta$ Sct and $\gamma$ Dor stars). Metallicity was fixed to the solar value. Numerics were optimized following the prescriptions suggested by Moya et al. (2008) within ESTA/CoRoT activities.$^9$ Rotation may play an important role for detailed asteroseismic studies of these stars (Goupil et al. 2005; Suárez et al. 2006), but was not taken into account for the used models.

We found representative models for HD 114839 with masses between 1.52 and 1.71 $M_\odot$, radii between 1.72 and 2.26 $R_\odot$, and ages between 905 and 1405 Myr, respectively. Those for BD $+$18 4914 were found to have masses between 1.6 and 2.10 $M_\odot$, radii between 2.69 and 4.43 $R_\odot$, and ages between 935 and 1782 Myr. In all cases, the best model fit was obtained for the mixing-length parameter ($\alpha_{\text{MLT}}$) = 0.5, which is the value found by Casas et al. (2006) for this type of stars using asteroseismic techniques. Overshoot values range from 0.1 to 0.3 for fitting models.

Turcotte et al. (2000) investigated the effect of diffusion on pulsation for upper main-sequence stars. They concluded that young Am stars are stable against pulsation, but become unstable during evolution toward the red edge of the $\delta$ Sct instability strip. The chemical and evolutionary characteristics of BD $+$18 4914 presented here are consistent with Turcotte et al. (2000)’s conclusion.

$^8$ This model grid is part of the Spanish Virtual Observatory Project: VOTA (Virtual Observatory Tools for asteroseismology, J. C. Suárez et al. (2011, in preparation)) to be released during 2011.

$^9$ http://www.astro.up.pt/corot/

6. CONCLUSIONS

Only one hybrid star, HD 49434, was investigated spectroscopically in detail before we started our study of $\delta$ Sct--$\gamma$ Dor hybrids. However, its hybrid nature is still uncertain and needs confirmation. HD 49434 did not show chemical peculiarities. Hybrid pulsators and stable stars populate the same region of the HR diagram, a situation that is similar to roAp stars (Ryabchikova et al. 2004). For the latter a clear spectroscopic signature could be detected which allows even prediction of pulsation in CP stars (Kochukhov et al. 2002). A similar feature for hybrid pulsators would be extremely important.

A link between the Am phenomenon and hybrid pulsation was speculated, because of the first detected hybrid, HD 8801, being an Am star. Furthermore, early in the literature significant overabundances of iron and/or iron-peak elements were expected as spectroscopic indicators for the driving mechanism. However, our comparison with seven $\delta$ Sct (Fossati et al. 2008b) and nine $\gamma$ Dor stars (Bruntt et al. 2008) does not indicate any significant chemical difference between these groups of stars.

With the present paper we nearly doubled the number of spectroscopically investigated hybrid stars, but have not yet succeeded in identifying a particular spectroscopic signature for this group of pulsating stars. For the evolved BD $+$18 4914 we found an abundance spectrum typical for an Am star, but could not confirm this peculiarity for the less evolved star HD 114839, which is classified in the literature a mild (or marginal) Am star. $\delta$ Sct--$\gamma$ Dor hybrids pulsate simultaneously in $p$- and $g$-modes, which are sensitive to the envelope as well as to the core. Hence, they are key objects for investigating A and F type stars with asteroseismic techniques. Accurate values for temperature, gravity, and chemical composition are needed as boundary conditions for stellar models used for fitting the observed eigenfrequencies. We provide such boundary conditions for a seismic modeling of HD 114839 and BD $+$18 4914, as well as $v$ sin $i$ and $v_{\text{mic}}$.

A statistically significant spectroscopic investigation of $\delta$ Sct--$\gamma$ Dor hybrid stars still is missing, but would be rewarding considering the asteroseismic potential of this group of pulsators.

The authors gratefully acknowledge the development of the tools by C. Stütz and D. Shulyak used for this research and to T. Lüftinger for valuable discussion. This project was supported by the Austrian Fonds zur Förderung der wissenschaftlichen Forschung (FWF, project P 22691-N16) and by an STFC Rolling Grant (LF). E.P. acknowledges support from the PRIN-INAF 2010 Asteroseismology: looking inside the stars with space and ground-based observations. J.C.S. was supported by the “Instituto de Astrofísica de Andalucía (CSIC)” by an “Excellence Project post-doctoral fellowship” financed by the Spanish “Conjerería de Innovación, Ciencia y Empresa de la Junta de Andalucía” under project “FQM4156-2008.” K.U. acknowledges financial support by the Deutsche Forschungsgemeinschaft (DFG) in the framework of project UY 52/1-1, and by the Spanish National Plan of R&D for 2010, project AYA2010-17803. This work made use of the SIMBAD database, operated at the CDS, Strasbourg, France, and is based on observations collected at the ESO 3.6 m telescope at La Silla (Chile), and at the Observatoire de Haute Provence (France). We acknowledge the OPTICON programme (Ref number: 2008/053).

Facilities: OHP:1.93m (SOPHIE), ESO:3.6m (HARPS).

Figure 8. Position of HD 114839 (full line error box) and BD $+$18 4914 (dash-dotted line errorbox) in the $T_{\text{eff}}$--log $g$ diagram, in comparison with solar metallicity isochrones by Marigo et al. (2008). The isochrone crossing the center of the HD 114839 errorbox (full line) corresponds to a 1.2 Gyr old isochrone. The dotted line represents 1.0, 1.1, 1.3, and 1.4 Gyr isochrones, from left to right. The zero-age main sequence is also indicated by a full line. The dashed lines show the blue and red edges of the $\gamma$ Sct–$\delta$ Sct–$\gamma$ Dor instability regions and a range of evolutionary stages, masses, and radii (and thereby mean densities).
REFERENCES

Asplund, M., Grevesse, N., & Sauval, A. J. 2005, in ASP Conf. Ser. 336, Cosmic Abundances as Records of Stellar Evolution and Nucleosynthesis in Honor of David L. Lambert, ed. T. G. Barnes, III & F. N. Bash (San Francisco, CA: ASP), 25

Au`riere, N., Wade, G. A., Ligni`eres, F., et al. 2010, A&A, 523, 40

Baglin, A., Auvergne, M., Barge, P., et al. 2006, in ESA SP-1036, The CoRoT Mission, Pre-Launch Status, Stellar Seismology, and Planet Finding, ed. M. Fridlund, A. Baglin, J. Lochard, & L. Conroy (Noordwijk: ESA), 33

Balona, L. A. 1994, MNRAS, 268, 119

Balona, L. A., Ripepi, V., Catanzaro, G., et al. 2011, MNRAS, 414, 792

Barklem, P. S., Stempels, H. C., Allende Prieto, C., et al. 2002, A&A, 385, 951

Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977

Bruntt, H., De Cat, P., & Aerts, C. 2008, A&A, 478, 487

Bruntt, H., Su´arez, J. C., Bedding, T. R., et al. 2007, A&A, 461, 619

Burkhart, C., Coupry, M. F., Faraggiana, R., & Gerbaldi, M. 2005, A&A, 429, 1043

Canuto, V. M., & Mazzitelli, I. 1991, ApJ, 370, 295

Canuto, V. M., & Mazzitelli, I. 1992, ApJ, 389, 724

Casas, R., Su´arez, J. C., Moya, A., & Garrido, R. 2006, A&A, 455, 1019

Charbonneau, P., & Michaud, G. 1970, ApJ, 160, 641

Clausen, J. V., & Jensen, K. S. 1979, in IAU Colloq. 47: Spectral Classification of the Future, 9, 479

Flower, P. J. 1996, ApJ, 496, 355

Fossati, L., Bagnulo, S., Landstreet, J., et al. 2008a, A&A, 483, 891

Fossati, L., Bagnulo, S., Monier, R., et al. 2007, A&A, 476, 911

Fossati, L., Kolenberg, K., Reegen, P., & Weiss, W. 2008b, A&A, 485, 257

Fossati, L., Ryabchikova, T., Bagnulo, S., et al. 2009, A&A, 503, 945

Fossati, L., Ryabchikova, T., Shulyak, D. V., et al. 2011, MNRAS, in press (arXiv:1106.4406)

Goupil, M.-J., Dupret, M. A., Samadi, R., et al. 2005, A&A, 437, 249

Grigahc`ene, A., Antoci, V., Balona, L., et al. 2010, ApJ, 713, 192

Hareter, M., Reegen, P., Miglio, A., et al. 2010, arXiv:1007.3176

Haug, B., & Mermilliod, M. 1998, A&AS, 129, 431

Heiter, U., Kupka, F., van’t Veer-Mennenet, C., et al. 2002, A&A, 392, 619

Henry, G. W., & Fekel, F. C. 2005, AJ, 129, 2026

Hill, G., Allison, A., Fisher, W. A., et al. 1976, Mem. R. Astron. Soc., 82, 69

Iliev, I. K., & Budaj, J. 2008, Contrib. Astron. Obs. Skalnate Pleso, 38, 129

Kaye, A. B., Handler, G., Krisciuonas, K., Poretti, E., & Zerbi, F. M. 1999, PASP, 111, 840

King, H., Matthews, J. M., Row, J. F., et al. 2006, Commun. Asteroseismol., 148, 28

Kochukhov, O. 2007, Physics of Magnetic Stars, ed. I. I. Romanyuk & D. O. Kudryavtsev, 109

Kochukhov, O., Landstreet, J. D., Ryabchikova, T., Weiss, W. W., & Kupka, F. 2002, MNRAS, 337, 1

Kupka, F., Piskunov, N., Ryabchikova, T. A., Stempels, H. C., & Weiss, W. W. 1999, A&AS, 138, 119

Kurucz, R. 1993, ATLAS9: Stellar Atmosphere Programs and 2 km s\(^{-1}\) Grid. Kurucz CD-ROM No. 13 (Cambridge: Smithsonian Astrophysical Observatory)

Marigo, P., Girardi, L., Bressan, A., et al. 2008, A&A, 482, 883

Mathias, P., Le Contel, J.-M., Chapellier, E., et al. 2004, A&A, 417, 189

Michaud, G. 1970, ApJ, 160, 641

Morel, P. 1997, A&AS, 124, 597

Moya, A., Christensen-Dalsgaard, J., Charpinet, S., et al. 2008, Ap&SS, 316, 213

Piskunov, N. E., Kupka, F., Ryabchikova, T. A., Weiss, W. W., & Jeffery, C. S. 1995, A&AS, 112, 525

Pribulla, T., Rucinski, S. M., Kuschnig, R., Ogloza, W., & Pilecki, B. 2009, MNRAS, 392, 847

Rodríguez, E., Amado, P. J., Suárez, J. C., et al. 2006a, A&A, 450, 715

Rodríguez, E., Costa, V., Zhou, A.-Y., et al. 2006b, A&A, 456, 261

Rowe, J. F., Matthews, J. M., Cameron, C., et al. 2006, Commun. Asteroseismol., 148, 34

Ryabchikova, T., Nesvacil, N., Weiss, W. W., Kochukhov, O., & Stütz, Ch. 2004, A&A, 423, 705

Ryabchikova, T. A., Piskunov, N. E., Stempels, H. C., Kupfa, F., & Weiss, W. W. 1999, Phis. Scr., T83, 162

Suárez, J. C., Bruntt, H., & Buzasi, D. 2005, A&A, 438, 633

Suárez, J. C., Goupil, M. J., & Morel, P. 2006, A&A, 449, 673

Turcotte, S., Richer, J., Michaud, G., & Christensen-Dalsgaard, J. 2000, A&A, 360, 603

Uytterhoeven, K., Mathias, P., Poretti, E., et al. 2008, A&A, 489, 2213

Uytterhoeven, K., Moya, A., Grigahcène, A., et al. 2011, A&A, in press (arXiv:1107.0335)

van Leeuwen, F. 2007, Hipparcos, the New Reduction of the Raw Data (UK Series; Cambridge: Institute of Astronomy, Cambridge Univ. (Astrophysics and Space Science Library, Vol. 350; Dordrecht: Springer, 20)

Walker, G., Matthews, J., Kuschnig, R., et al. 2003, PASP, 115, 1023