Atmospheric parameters and pulsational properties for a sample of \( \delta \) Sct, \( \gamma \) Dor, and hybrid Kepler targets

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ABSTRACT

We report spectroscopic observations for 19 \( \delta \) Sct candidates observed by the Kepler satellite both in long and short cadence mode. For all these stars, by using spectral synthesis, we derive the effective temperature, the surface gravity and the projected rotational velocity. An equivalent spectral type classification has been also performed for all stars in the sample. These determinations are fundamental for modelling the frequency spectra that will be extracted from the Kepler data for asteroseismic inference. For all the 19 stars, we present also periodograms obtained from Kepler data. We find that all stars show peaks in both low- (\( \gamma \) Dor; \( g \) mode) and high-frequency (\( \delta \) Sct; \( p \) mode) regions. Using the amplitudes and considering 5 c/d as a boundary frequency, we classified 3 stars as pure \( \gamma \) Dor, 4 as \( \gamma \) Dor-\( \delta \) hybrid, Sct, 5 as \( \delta \) Sct-\( \gamma \) Dor hybrid, and 6 as pure \( \delta \) Sct. The only exception is the star KIC05296877 which we suggest could be a binary.

Key words: Stars: fundamental parameters – Stars: oscillations (including pulsations) – Stars: early-type

1 INTRODUCTION

Stellar pulsations offer a unique opportunity to constrain the intrinsic parameters of stars and, by using asteroseismology, to unveil their inner structure. In particular, the classical \( \delta \) Sct variables are late A-type and early F-type stars that populate the instability strip between the zero-age main sequence and terminal-age main sequence, with \( 3.0 \leq M_V \leq 0.5 \). They pulsate in mode of low radial order with periods ranging from about 20 min to 8 h (see Breger 2000, for a review). \( \delta \) Sct stars pulsate in both radial and non-radial \( p \) modes and \( g \) modes, driven by the \( \kappa \)-mechanism, in particular in the He\( \text{II} \) ionization zone. The \( \gamma \) Dor variables, with periods between about 0.3 and 3 d, are mostly located near the cool edge of the \( \delta \) Sct instability strip (Kaye et al. 1999). Their pulsations are driven by convective blocking at the base of their envelope convection...
Table 1. List of studied Kepler δ Sct candidates. Columns (1) and (2) show the Kepler and other identifications; Column (3) reports the origin of the spectrum: L = Loiano, OACT = INAF - OACT; Columns (4), (5), and (6) report the V magnitudes, the colour excess, and the spectral types taken from the literature.

| KIC ID | Other ID | Observ. | V    | E(B − V) | S.T. |
|--------|----------|---------|------|----------|------|
|        |          |         | (1)  | (2)      | (3)  |
| 03219256 | HD 178306 | L, OACT | 8.31 | 0.02±0.01 a | A3^1 |
| 03429637 | HD 178875 | OACT   | 7.72 | 0.04±0.02 b | A9, Am^2 |
| 03437940 | HD 181569 | L, OACT | 8.45 | 0.06±0.01 a | F0^1 |
| 04570326 | HAT 199-01905 | L | 9.77 | 0.00±0.02 c | A2^3 |
| 05296877 | HAT 199-27597 | L | 12.50 | 0.00±0.02 c | A2^3 |
| 05724440 | HD 187234 | L, OACT | 7.90 | 0.06±0.01 a | A5^3 |
| 05965837 | HAT 199-00623 | L | 9.23 | 0.01±0.02 c | F2^1 |
| 05988140 | HD 188774 | L | 8.83 | 0.07±0.01 a | F0^1 |
| 07119530 | HD 183787 | L | 8.45 | 0.02±0.01 a | A3^1 |
| 07798339 | HD 173109 | L, OACT | 7.87 | 0.00±0.01 a | F0^1 |
| 08197788 | NGC6866-V1 | L | 12.98 | 0.12±0.02 d | A3^1 |
| 08264404 | NGC6866-V3 | L | 12.22 | 0.12±0.02 d | A3^1 |
| 08264698 | NGC6866-V2 | L | 12.38 | 0.12±0.02 d | A3^1 |
| 08583770 | HD 189177 | L | 10.16 | 0.17±0.03 c | B9^5 |
| 09655114 | NGC6811-RH35 | L | 12.09 | 0.12±0.02 e | A4^6 |
| 09775454 | HD 185115 | L, OACT | 8.19 | 0.01±0.01 a | F1IV^7 |
| 11402951 | HD 183489 | L, OACT | 8.14 | 0.03±0.01 b | A9, Am^2 |
| 11445913 | HD 178327 | L, OACT | 8.46 | 0.03±0.01 b | A9, Am^2 |
| 11973705 | HD 234999 | L | 9.10 | 0.00±0.02 c | B9^1 |

a) from v(ubvy)b photometry; b) from (b − y) photometry; c) from (B − V) photometry; d) Dutra & Bica (2000); e) Glushkova et al. (1999).

1) SIMBAD; 2) Abt (1984); 3) Fehrenbach & Burnage (1990); 4) Nordstrom et al. (1997); 5) Couteau & Gili (1994); 6) Lindoff (1972); 7) Duflot et al. (1995)

zone (Guzik et al. 2000; Dupret et al. 2004; Grigahcène et al. 2004). The distinction between the two classes is clearer if we consider the value of the pulsation constant, Q (Handler & Shobbrook 2002). However, the location of the γ Dor stars in the Hertzsprung-Russell (HR) diagram suggests some relationship with the δ Sct variables. Indeed, stars exist which show simultaneously both δ Sct and γ Dor pulsations (Henry & Fekel 2005; King et al. 2006; Rowe et al. 2006; Uytterhoeven et al. 2008a; Handler 2009). These hybrid objects are in principle of great interest, because they offer additional constraints on stellar structure. Indeed, the γ Dor stars pulsate in g modes which have high amplitudes deep in the star and allow us to probe the stellar core, while the p modes, efficient in δ Sct stars, have high amplitudes in the outer regions of the star and probe the stellar envelope. Moreover, since γ Dor stars pulsate in g modes of high radial order, the asymptotic approximation predicts regular patterns in the periods which, in principle, can be used to determine the spherical harmonic degree. Hybrids thus provide a unique opportunity for asteroseismology which is not available in pure δ Sct stars (Handler & Shobbrook 2002). Recently, a large separation-like feature has been discovered in the δ Sct star HD 174936 by García Hernández et al. (2009) using CoRoT data. In that work, such a regularity was used to constrain the modelling of this star. It is extremely interesting to search for such regularities in hybrid stars, for which the presence of other frequency regimes definitely may help the overall comprehension of the pulsational behaviour of these objects.

The Kepler satellite\(^1\) was launched on 2009 March 6 and will continuously monitor the brightness of over 100 000 stars for at least 3.5 yr in a 105 square degree fixed field of view near the plane of the Milky Way between Deneb and Vega. The main aim of the mission is to detect extrasolar planets, particularly Earth-sized planets in the habitable zone of their stars, where water may be liquid, by the transit method (Borucki et al. 1997). To accomplish this goal, Kepler is capable of measuring the stellar brightnesses to \(\mu\)mag precision (Gilliland et al. 2010) which, together with the long duration of the observations, make the data ideal for asteroseismology. Most of the observations are long-cadence (29.4-min) exposures, though a small allocation is available for short-cadence (1-min) exposures. The long-cadence as well as some short-cadence data released to the Kepler Asteroseismic Science Consortium (KASC) have been surveyed for δ Sct and/or γ Dor stars. The long-cadence data are not always suitable for a detailed study of δ Sct oscillations because many of these stars have frequencies higher than the Nyquist frequency (24.5 c/d) for 29.4-min sampling. These data are, however, suitable for the detection of δ Sct − γ Dor hybrids.

The early KASC data releases led to the discovery of

\(^1\) http://kepler.nasa.gov/
the nineteen candidate \( \delta \) Sct stars listed in Table 1; many more have been found in subsequent data releases, and ground-based studies of these stars are now in progress. Interestingly, many objects show periodograms with frequencies both in the \( p \) mode \( \delta \) Sct and \( g \) mode \( \gamma \) Dor domains, i.e., they are candidate hybrid pulsators (Grigahcène et al. 2010). Dedicated short-cadence \textit{Kepler} data for the most promising hybrid candidates will be exploited for seismic studies of these stars. To this end it is extremely important to constrain the fundamental parameters of the stars (effective temperature \( T_{\text{eff}} \), surface gravity \( \log g \), projected rotational velocity \( v \sin i \), luminosity \( L/L_\odot \)) in order to limit the range of models. Measurement of \( v \sin i \) is essential to constrain the rotational velocity of the models. Stellar fundamental parameters can be obtained by using photometry, e.g., in the Strömgren system, or by means of mid- or high-resolution spectroscopic observations. Very few of the 19 \textit{Kepler} \( \delta \) Sct stars have previously been observed spectroscopically and no reliable estimates of the stellar parameters can be derived from the existing data. For this reason, we undertook a systematic spectroscopic study of these \textit{Kepler} targets and report our results here. This work fits in the ground-based observational efforts of KASC with the aim to characterize all \textit{Kepler} pulsators (Uytterhoeven et al. 2010a,b).

2 OBSERVATIONS AND DATA REDUCTION

The spectra used in our analysis were acquired with two different instruments:

(i) \textit{Loiano Observatory}: We used the Bologna Faint Object Spectrograph & Camera (BFOSC) instrument attached to the 1.5-m Loiano telescope\(^2\). We adopted the echelle configuration with Grism \#9 and \#10 (as cross dispersers). The typical resolution was \( R \sim 5000 \). Spectra were recorded on a back-illuminated (EEV) CCD with 1300 \( \times \) 1300 pixels of 20 \( \mu \)m size, typical readout noise of 1.73 e\(^-\) and gain of 2.1 e\(^-\)/ADU. Observations were carried out during the nights of 2009 September 8 – 11. The exposure times ranged from 1200 to 3600 s for the brightest and faintest targets respectively.

(ii) INAF - OACT: the 91-cm telescope of the Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Catania (INAF - OACT) was used to carry out spectroscopy of eight of the targets. The telescope is fibre linked to a REOSC\(^3\) echelle spectrograph, giving \( R \sim 20000 \) spectra in the range 4300 – 6800 Å. The resolving power was checked using the Th-Ar calibration lamp. Spectra were recorded on a thinned, back-illuminated (SITE) CCD with 1024 \( \times \) 1024 pixels of 24 \( \mu \)m size. The typical readout noise was 6.5 e\(^-\) at a gain of 2.5 e\(^-\)/ADU. Observations were carried out during five nights: 2009 September 28, 29, 30 and November 19 and 28. Exposure times were fixed for all the stars at 1 h.

The reduction of spectra, which included the subtraction of the bias frame, trimming, correcting for the flat-field and the scattered light, the extraction of the orders, and the wavelength calibration, was done by using the NOAO/IRAF package\(^4\). The amount of scattered light correction was about 10 ADU. The S/N ratio of the spectra was at least \( \sim 130 \) and 80 for Loiano and OACT observatories, respectively.

3 PHYSICAL PARAMETERS

3.1 Parameters from photometry: \( T_{\text{eff}} \) and \( \log g \)

Complete Strömgren-Crawford \( uvby\beta \) photometry is available for seven objects in our sample (stars with an “a” in column 5 of Table 1) while \( uvby \) data are present for three additional objects (stars with a “b” in column 5 of Table 1). The source of both the Strömgren and Strömgren-Crawford data is Hauck & Mermillod (1998). For the other six objects (identified with a “c” in column 5 of Table 1) plus the three stars in NGC6866, only Johnson photometry is available, mainly in \( BV \) filters. For these stars we used the values reported by SIMBAD. In the near-infrared, \( JHK \) photometry of good quality is present in the 2MASS catalogue (Skrutskie et al. 1996) for all the targets.

For the seven stars with \( uvby\beta \) photometry, \( E(b - y) \) can be estimated by using the calibration by Moon (1985), using the \textit{IDL} code \textit{UVBYBETA}. The result is reported in Table 1, where we have used the transformation \( E(B - V) = 1.4 E(b - y) \) (Cardelli et al. 1989). For the three stars without \( \beta \) indices we used the equivalent spectral type derived in Section 3.2 to derive the intrinsic \( (b - y) \) from the relation between \( (b - y)_0 \) and spectral type (Voigt 2006). Similarly, for five stars with \( (B - V) \) colours, we adopted the intrinsic \( (B - V)_0 \) colours as a function of spectral type (Schmidt-Kaler 1982). We assigned a larger error to these values than those based on \( uvby\beta \) photometry. The remaining four variables are cluster members, three belong to NGC 6866 and one to NGC 6811. The redenngs of these two clusters were adopted from Dutra & Bica (2000) for NGC 6866 and Glushkova et al. (1999) and Luo et al. (2009) for NGC 6811.

Values of \( T_{\text{eff}} \) and \( \log g \) were estimated from \( c_0 \) and \( \beta \) using the data grid by Moon & Dworetsky (1985). Typical photometric errors (0.015 and 0.03 mag in \( \beta \) and \( c_0 \) respectively) have been assumed. The derived values of \( T_{\text{eff}} \) and \( \log g \) are reported in Table 2 (columns 6 and 10, respectively). In calculating the uncertainties, we conservatively assumed an error of 250 K and 0.3 dex for \( T_{\text{eff}} \) and \( \log g \), respectively. The values of \( T_{\text{eff}} \) and \( \log g \) derived from spectroscopy (see Section 3.2 below) and \( uvby\beta \) are in good agreement, with all the differences less than 3\( \sigma \). Only KIC05724440 (HD187234) shows a difference in temperature close to the edge of this limit. We discuss this object in Section 3.3.

An additional photometric estimate of \( T_{\text{eff}} \) can be obtained from the calibrations by Masana et al. (2006). These are based on the \( (V - K)_0 \) colour as well as on \( \log g \) and \( [Fe/H] \). The \( V \) and \( K \) band were taken from the SIMBAD and 2MASS catalogues, respectively. For \( \log g \) we use the

\(^2\) http://www.bo.astro.it/loiano/index.htm

\(^3\) REOSC is the Optical Department of the SAGEM Group.

\(^4\) IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc.
value from our spectroscopy. For the metallicity, following Bruntt et al. (2008), we adopted \([Fe/H] = -0.2 \pm 0.2\). This arbitrary value has only a small impact on the results because varying \([Fe/H]\) by 2σ gives an error of only 40 K in \(T_{\text{eff}}\). To de-redden the observed \((V - K)\) colours we adopted the reddening reported in Table 1, using the relation \(E(V - K) = 3.8 E(B - V)\) (Cardelli et al. 1989) for the stars with Strömgren photometry, and \(E(V - K) = 2.8 E(B - V)\) for the other stars. The resulting \(T_{\text{eff}}\) and the relative errors are reported in Table 2 (column 5). In general, there is good agreement between the photometric and spectroscopic values.

Near infrared photometry from 2MASS, complemented by the one in the optical, can be used to derive an alternative estimate of \(T_{\text{eff}}\) by means of the Infrared Flux Method (IRFM, Blackwell & Shallis 1977). In particular, broad-band photometry (this work, plus TASS4 I-mag, NOMAD R-mag, CMC14 \(r'\) mag and 2MASS photometry) was used to estimate the total observed bolometric flux \((f_{\text{tot}})\). The photometry was converted to fluxes and the best-fitting Kurucz (1993b) model flux distribution was found and integrated to determine \(f_{\text{tot}}\). The Infrared Flux Method (Blackwell & Shallis 1977) was then used with 2MASS fluxes to determine the \(T_{\text{eff}}\) reported in Table 2 (column 7).

Finally, we inspected the \textit{Kepler} Input Catalogue (KIC\(^5\), Latham et al. 2005) where additional estimates for \(T_{\text{eff}}\) and \(\log g\) based mainly on \(u', g', r', i', z'\) are present. These values are reported in columns (8) and (11) of Table 2. It is worth noticing that the KIC catalogue was mainly aimed at separating dwarfs from giants, therefore the \(T_{\text{eff}}\) and \(\log g\) are not expected to be very precise. Since no errors are present in the KIC catalogue, we assumed uncertainties of 250 K and 0.3 dex in \(T_{\text{eff}}\) and \(\log g\), respectively.

### 3.2 Parameters from spectroscopy: \(T_{\text{eff}}, \log g\) and rotational velocities

We determined \(T_{\text{eff}}\) and \(\log g\) of the stars by minimizing the difference between the observed and the synthetic H\(\beta\) profiles. For the goodness-of-fit parameter we used \(\chi^2\) defined as

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

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. The errors have been estimated from the variation in the parameters required to increase \(\chi^2\) by one. As starting values of \(T_{\text{eff}}\) and \(\log g\), we used \(T_{\text{eff}}\) and \(\log g\) derived from the photometry, as described in the previous section. At the same time, we determined the projected rotational velocity by matching the Mg\(\text{II}\) 4481 Å profile with a synthetic profile. The synthetic profiles are

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\(^5\) accessible via http://archive.stsci.edu/kepler/kepler_fov/search.php

\(^6\) Note, however, that only 25% of the KIC stars have \(z'\) photometry, and less than 0.1% have \(u'\) (see http://nsted.ipac.caltech.edu/data/NSFED/kic_columns.html)
Physical parameters of Kepler target

Figure 1. Examples of the fitting procedure for two stars of our sample. The top panel shows three spectral regions of KIC 11402951 (HD 183489) observed with the OACT equipment, while the bottom panel shows the same spectral range, but for KIC 05988140 (HD 188774) observed with the Loiano spectrograph. Both synthetic spectra have been computed with SYNTE based on LTE ATLAS9 atmospheric models with solar ODF and metallicity.

computed with SYNTE (Kurucz & Avrett 1981) on the basis of ATLAS9 (Kurucz 1993a) LTE atmosphere models. All models are calculated using the solar opacity distribution function (ODF), solar metallicity and a microturbulence velocity of $\xi = 2 \text{ km s}^{-1}$. The atomic parameters for the spectral lines were taken from Kurucz & Bell (1995).

The derived values of $T_{\text{eff}}$, log $g$ and $v \sin i$ are reported in Table 2 (columns 4, 9, and 3, respectively). The table also shows the equivalent spectral types and luminosity classes derived by comparing these values with those derived in the present paper (column 2 of Table 2). For seven stars there is agreement. For the three stars classified as metallic-lined (Am stars) by Abt (1984), our inferred spectral type agrees with that from Balmer lines derived by this author on the basis of 1 Å resolution spectra. For the remaining five stars, the discrepancy is large, with differences of more than three or four spectral sub-types. This is not surprising because the nature of several classifications in the literature is uncertain or based on photometry. For these stars we adopt the values from our spectroscopic analysis.

3.3 Comparison between astrophysical parameters derived by different methods

For the 15 stars with spectral types available in the literature (see column 6 of Table 1) we can compare these values with those derived in the present paper (column 2 of Table 2). For seven stars there is agreement. For the three stars classified as metallic-lined (Am stars) by Abt (1984), our inferred spectral type agrees with that from Balmer lines derived by this author on the basis of 1 Å resolution spectra. For the remaining five stars, the discrepancy is large, with differences of more than three or four spectral sub-types. This is not surprising because the nature of several classifications in the literature is uncertain or based on photometry. For these stars we adopt the values from our spectroscopic analysis.

The only high-resolution study in the literature is by Nordstrom et al. (1997) for the star KIC 07798339 (HD 173109). These authors analysed echelle spectra in the narrow wavelength range $5165.77 - 5211.25$ Å to obtain $T_{\text{eff}} = 7000$ K, log $g = 3.5$ and $v \sin i = 15.4 \text{ km s}^{-1}$ (no errors available). The difference of 300 K in $T_{\text{eff}}$ is not significant within the errors.

7 KIC 05296877 (HAT 199-27597) and the three objects in NGC 6866 have no spectral type known before.
and the $\log g$ and $v\sin i$ values are in good agreement with our results.

It is useful to compare the values of $T_{\text{eff}}$ derived spectroscopically with those obtained via photometric methods (IRFM, $(V-K)$ calibration, KIC). Inspection of Fig. 2, which illustrates such a comparison, shows a general good agreement among all these values. Quantitatively, a weighted mean of such differences gives:

$$T_{\text{eff}}^{\text{Spec}} - T_{\text{eff}}^{\text{IRFM}} = -200 \pm 200;$$
$$T_{\text{eff}}^{\text{Spec}} - T_{\text{eff}}^{(V-K)} = -130 \pm 200;$$
$$T_{\text{eff}}^{\text{Spec}} - T_{\text{eff}}^{\text{KIC}} = -50 \pm 300,$$

non significant to the $1\sigma$ level. Similarly a very good agreement is found between $T_{\text{eff}}^{\text{Spec}}$ and $T_{\text{eff}}$ estimated through $uvby\beta$ photometry (see Table 2). However there are two exceptions to this trend:

**Figure 2.** Comparison of $T_{\text{eff}}$ obtained spectroscopically and photometrically via IRFM (top panel), $(V-K)$ (middle panel) and KIC (bottom panel). Filled circles, pentagons and open circles represent variables classified as pure $\delta$ Sct, pure $\gamma$ Dor, and hybrids, respectively; the cross shows the candidate W Uma variable (see section 6 and Table 5). Symbols surrounded by circles refer to stars for which Strömgren photometry is available in the literature (i.e. more precise reddening estimate). Note that for the sake of clarity, the $T_{\text{eff}}^{\text{spec}}$ of the three stars in NGC 6866 have been shifted by $\pm 25$ K. Note also that the star KIC 08583770 (HD 189177) is not visible in the figure because it lies outside the boundaries of the plots.

**Figure 3.** HR diagram for the nineteen stars investigated in this paper. Symbols are as in Fig. 2. Note that the $T_{\text{eff}}$ of KIC 05965837 (HAT199-00623) was artificially lowered by 25 K to avoid a complete overlap with the star KIC 04570326 (HAT 199-01905). The black solid line is the ZAMS from Pickles (1998); the red solid lines show the $\delta$ Sct instability strip by Breger & Pamyatnykh (1998); the blue dashed and dotted-dashed lines show the empirical and theoretical red edge of the $\gamma$ Dor instability strip by Handler & Shobbrook (2002) and Warner et al. (2003), respectively.

**4 THE HR AND $\log g - \log T_{\text{EFF}}$ DIAGRAMS**

The stellar parameters $\log g$ and $\log T_{\text{eff}}$ determined in the previous section allow us to estimate the luminosity of the investigated objects by interpolating the tables by Schmidt-Kaler (1982). The result is reported in Table 3. Note that the errors on the luminosity were evaluated through the same tables by taking into account the errors on $\log g$ and $\log T_{\text{eff}}$. Figure 3 shows the HR diagram for the nineteen stars studied in this work, in comparison with the zero-age main sequence measurements. We visually inspected both POSS II and 2MASS images of KIC 05724440 (HD 187234), where the star appears to be isolated in the near infrared. In the optical it is surrounded by a very few close faint stars whose contribution can hardly be considered significant. By using the calibration by Masana et al. (2006), the discrepancy is reduced to only 350 K, reinforcing our suspicion that there is something wrong with the $uvby\beta$ photometry of this star. KIC 08583770 (HD 189177) - The $T_{\text{eff}}=9000\pm 200$ K derived spectroscopically for this star is in good agreement with the value derived from IRFM, and consistent within the errors with the $T_{\text{eff}}$ derived from $(V-K)$ color. However there is a large discrepancy with respect to the KIC estimate. This occurrence could perhaps be explained in terms of a visual binary, with a companion star dimmer by 3 mag at a distance of 0.9 arcsec. Even if nothing is known about the companion, due to the small separation, it is likely that the photometric values are affected by the secondary star flux.
expected to be different when rotation is considered in the modeling (more details in the text). The errors on the mass and luminosity correspond to the relative precision obtained using the overshooting (physics, respectively. The errors on the mass and luminosity correspond to the relative precision obtained using the BaSTI database using non-rotating models. These errors are expected to be different when rotation is considered in the modeling (more details in the text).

Table 3. For each star the luminosity estimated on the basis of Schmidt-Kaler (1982) tables, the masses estimated from the evolutionary tracks with canonical and non-canonical (i.e. with convective overshooting) physics, respectively. The errors on the mass and luminosity correspond to the relative precision obtained using the BaSTI database using non-rotating models. These errors are expected to be different when rotation is considered in the modeling (more details in the text).

| KIC   | Luminosity | Mass Can. | Mass NonCan. |
|-------|------------|-----------|--------------|
|       | $L/L_\odot$ | $M/M_\odot$ | $M/M_\odot$ |
| 03219256 | 19.0$^{+2.9}_{-2.5}$ | 2.20$^{+0.20}_{-0.15}$ | 2.20$^{+0.10}_{-0.10}$ |
| 03429637 | 20.0$^{+6.0}_{-6.0}$ | 3.6$^{+0.70}_{-0.60}$ | 3.2$^{+0.60}_{-0.50}$ |
| 03457940 | 12.5$^{+4.0}_{-3.9}$ | 1.80$^{+0.30}_{-0.20}$ | 1.80$^{+0.10}_{-0.10}$ |
| 04570326 | 7.8$^{+3.7}_{-3.6}$ | 1.70$^{+0.20}_{-0.20}$ | 1.65$^{+0.10}_{-0.10}$ |
| 05296877 | 7.9$^{+2.6}_{-2.5}$ | 1.60$^{+0.20}_{-0.20}$ | 1.70$^{+0.15}_{-0.15}$ |
| 05724440 | 17.0$^{+4.3}_{-4.2}$ | 2.20$^{+0.40}_{-0.30}$ | 2.30$^{+0.30}_{-0.30}$ |
| 05965837 | 7.4$^{+5.0}_{-4.9}$ | 1.70$^{+0.20}_{-0.20}$ | 1.65$^{+0.15}_{-0.15}$ |
| 05988140 | 16.3$^{+4.7}_{-4.6}$ | 2.00$^{+0.40}_{-0.30}$ | 2.20$^{+0.30}_{-0.30}$ |
| 07119530 | 18.8$^{+5.4}_{-5.3}$ | 2.20$^{+0.60}_{-0.40}$ | 2.40$^{+0.40}_{-0.40}$ |
| 07798339 | 9.0$^{+2.9}_{-2.8}$ | 1.80$^{+0.30}_{-0.20}$ | 1.90$^{+0.15}_{-0.15}$ |
| 08197788 | 12.7$^{+4.9}_{-4.8}$ | 1.85$^{+0.45}_{-0.30}$ | 1.80$^{+0.30}_{-0.30}$ |
| 08264404 | 17.4$^{+5.5}_{-5.4}$ | 2.30$^{+0.60}_{-0.45}$ | 2.20$^{+0.30}_{-0.30}$ |
| 08264698 | 14.3$^{+3.8}_{-3.6}$ | 2.00$^{+0.30}_{-0.15}$ | 1.90$^{+0.20}_{-0.20}$ |
| 08583770 | 65.0$^{+19.0}_{-19.0}$ | 4.80$^{+1.00}_{-0.80}$ | 4.40$^{+0.80}_{-0.80}$ |
| 09655114 | 13.5$^{+4.7}_{-4.6}$ | 1.90$^{+0.30}_{-0.30}$ | 1.90$^{+0.30}_{-0.30}$ |
| 09775454 | 8.5$^{+3.8}_{-3.7}$ | 1.70$^{+0.20}_{-0.20}$ | 1.65$^{+0.15}_{-0.15}$ |
| 11402951 | 15.5$^{+2.4}_{-2.3}$ | 2.30$^{+0.30}_{-0.20}$ | 2.20$^{+0.10}_{-0.10}$ |
| 11445913 | 16.3$^{+3.2}_{-3.1}$ | 1.95$^{+0.30}_{-0.20}$ | 2.20$^{+0.10}_{-0.10}$ |
| 11973705 | 8.6$^{+4.2}_{-4.1}$ | 1.60$^{+0.30}_{-0.10}$ | 1.60$^{+0.15}_{-0.15}$ |

Figure 4. log g-log $T_{\text{eff}}$ diagram for the investigated stars. Symbols are as in Fig. 2. For comparison the instability strip for δ Sct stars by Breger & Pamyatnykh (1998) is shown as straight (blue) lines. The evolutionary tracks for the canonical (left panel) and non-canonical (right panel) physics are also shown. Each track is labelled with the mass (blue number) expressed in $M_\odot$.

We retrieved tracks with both canonical and non-canonical (i.e. with convective overshooting: $\lambda_{OV} = 0.2 H_p$) physics in the mass range 1-6 $M_\odot$ with $[M/H] = 0.058$, $Z = 0.0198$, $Y = 0.273$, and mixing length = 1.913 (Pietrinferni et al. 2004). In Fig. 4 we show the log $g$ − log $T_{\text{eff}}$ diagram. The left and right panels in the figure show canonical and non-canonical tracks, respectively. The resulting masses for the two cases (listed in Table 3) are very similar and agree well within 1σ. On other hand, δ Sct stars are typically fast-rotating objects, and the rotation effects on the structure and evolution might modify the estimates of global parameters of the stars (see e.g. Goupil et al. 2005; Suárez et al. 2005; Fox Machado et al. 2006). To verify if this effect is important in our case, we considered a typical case for a star with mass 1.7-1.8 $M_\odot$. According to Suárez et al. (2005), even in case of vsini~150-200 km/s, the effect on the mass estimate from the HR diagram is of few %, well within the uncertainty due to the errors on the empirical estimates of luminosity and effective temperature (see table 3).
Table 4. Comparison between the luminosity derived from present spectroscopy and Schmidt-Kaler (1982) tables and the one obtained from the HIPPARCOS parallaxes or Cluster distance (see text).

| Star               | D (pc) | L/L⊙ | L/L⊙ |
|--------------------|--------|-------|-------|
| KIC 03429637 (HD 178875) | 3.75±0.58 | 56.2±26.3 | 20.0±6.0 |
| KIC 05724440 (HD 187234) | 8.02±0.51 | 11.1±2.1 | 17.0±4.3 |
| KIC 07798339 (HD 173109) | 6.86±0.48 | 13.4±2.8 | 9.0±2.9 |
| KIC 11402951 (HD 183489) | 5.91±0.63 | 14.9±4.4 | 15.5±2.7 |
| KIC 08197788 (NGC6866-V1) | 120±120 | 10.3±3.3 | 12.7±5.0 |
| KIC 08264404 (NGC6866-V3) | 120±120 | 20.6±6.5 | 17.4±4.8 |
| KIC 08264998 (NGC6866-V2) | 120±120 | 17.9±5.7 | 14.3±3.8 |
| KIC 09655114 (NGC6811-RH35) | 1030±50 | 17.2±5.9 | 13.5±4.7 |

5 CHECKS OF THE RESULTS BY MEANS OF PARALLAXES AND CLUSTER STARS

We used the parallaxes measured by the HIPPARCOS satellite (Perryman et al. 1997) to verify the luminosities derived in the present work. We also estimated independently the luminosity of cluster stars by adopting the distances found in the literature obtained through e.g. isochrone fitting.

Only four stars in our sample are sufficiently bright for inclusion in the HIPPARCOS parallax catalogue. These are listed in Table 4 together with the parallaxes from the van Leeuwen (2007) revised catalogue. To derive the luminosity we used the $V$ and $E(B - V)$ values listed in Table 1 as well as the bolometric correction as a function of spectral type from Pickles (1998). The resulting luminosities and errors are listed in Table 4 where our spectroscopic results are also shown for comparison purposes. An inspection of the table reveals that there is agreement within the errors. The only obvious discrepancy is found for the star KIC 09655114 (NGC6811-RH35) which is reported in the last row of Table 4. Again, we note the good agreement within the errors with the spectroscopic result.

6 KEPLER OBSERVATIONS

Information on Kepler observations for the stars studied here is given in Table 5. For 15 out of 19 stars short cadence observations are available. From these data we calculated the periodograms (by using L. Balona’s custom software, based on a combination of FFT and normal periodogram) shown in Fig. 5. We note that practically all stars show peaks in both the low-frequency ($\delta$ Dor; g mode) and high-frequency ($\delta$ Sct; p mode) regions. In this sense, practically all $\delta$ Sct stars observed by Kepler are hybrids. This is a surprising finding which has been discussed in Grigahcène et al. (2010).

To make a distinction, we followed the classification scheme proposed by latter author. We visually classified the stars as $\delta$ Sct if most of the peaks are in the $\delta$ Sct region and as $\delta$ Sct – $\gamma$ Dor if most of the peaks are in the $\delta$ Sct region but with a significant contribution from the $\gamma$ Dor region. The frequency $5c/d$ was taken as the boundary between the two regions. Following similar arguments, we classify a star as $\gamma$ Dor or $\gamma$ Dor – $\delta$ Sct. There appears to be physical significance to such a scheme, as discussed by Grigahcène et al. (2010). We applied these classification criteria to the stars of this study, and classified six targets as $\delta$ Sct stars, five stars as $\delta$ Sct – $\gamma$ Dor hybrids, four stars as $\gamma$ Dor – $\delta$ Sct hybrids, and three stars as pure $\gamma$ Dor pulsators (see also Table 5). Below we discuss the targets that show particularities in their periodogram (Fig. 5).

KIC 03429637 (HD 178875): As noted above, this star shows a $>1\sigma$ difference between the luminosity values derived from the HIPPARCOS parallax and from spectroscopy (see Table 4). Binarity is a possible explanation for this discrepancy. The frequency spectrum shows two dominant peaks near 10 and 12 d-1. A model in terms of $\delta$ Sct pulsations, rotation and/or binarity needs to be investigated.

KIC 05296877 (HAT 199-27597): This star is the coolest star in the sample and lies outside the instability strip. The periodogram shows a single strong peak at $f = 5.302c/d$. KIC 5296877 is probably a contact binary with an orbital period of $2f = 0.38d$. The late spectral type of F4.5IV and the large value $\nu \sin i = 200 \text{ km s}^{-1}$ suggest that it is a high amplitude ellipsoidal variable.
**Physical parameters of Kepler target**

**KIC 07119530 (HD 183787):** This star has been classified as pure \( \gamma \) Dor as the frequencies are predominantly in the \( \gamma \) Dor range and those in the \( \delta \) Sct region have low amplitude. However, the star lies in the middle of the \( \delta \) Sct instability strip. All the temperature indicators adopted in this paper agree very well with each other and indicate a \( T_{\text{eff}} > 7500 \) K, i.e. a bit too hot for a pure \( \gamma \) Dor variable. We conclude that the variability classification of this star is uncertain since it could be a \( \gamma \) Dor – \( \delta \) Sct Hybrid.

**KIC 08583770 (HD 189177):** This star is the hottest star in the group, and lies outside the instability strip (see Fig 4). The periodogram shows significant power at very low frequency. The light curve of KIC 08583770 is presented in Fig. 6. No specific period can be deduced, but it is clear that there is something peculiar about this star, which needs further investigation.

**KIC 09775454 (HD 185115):** The frequency spectrum of KIC 09775454 shows one dominant peak in the \( \delta \) Sct region, and several - seemingly equidistant - peaks at lower frequencies. Further investigation of the *Kepler* light curves will clarify if this star is a \( \delta \) Sct star with rotational modulation effects.

**KIC 11973705 (HD 234999):** The light curves of KIC 11973705 show a periodic long-term behaviour, with \( P \approx 4 \) d (Fig. 6). The spectral type B9, recorded in the Henry Draper catalogue, is a full spectral class too early...
Table 5. Information on *Kepler* photometry. The first column is the KIC identification. In the second column the proposed classification is given. The third column gives the number of photometric observations, *N*. In the fourth column SC signifies short-cadence (1-min exposures) and LC long cadence (29.4-min exposures). The last column gives the length of the data set, ∆*t*, in days.

| KIC ID    | Type   | N     | Cad  | ∆t (d) |
|-----------|--------|-------|------|--------|
| 03219256  | δ Sct  | 43974 | SC   | 30.03  |
| 03429637  | δ Sct  | 9870  | LC   | 217.98 |
| 03437940  | δ Sct  | 43989 | SC   | 30.03  |
| 04570326  | γ Dor – δ Sct | 44010 | SC | 29.97  |
| 05298877  | -      | 14245 | SC   | 9.72   |
| 05724440  | δ Sct  | 43093 | SC   | 30.34  |
| 05965837  | γ Dor  | 14204 | SC   | 9.70   |
| 05988140  | δ Sct – γ Dor | 2099  | LC | 44.44  |
| 07119530  | γ Dor  | 10340 | LC   | 228.95 |
| 07798339  | γ Dor  | 43254 | SC   | 29.97  |
| 08197788  | γ Dor – δ Sct | 43370 | SC | 29.97  |
| 08264404  | δ Sct – γ Dor | 43375 | SC | 29.97  |
| 08264698  | γ Dor – δ Sct | 43348 | SC | 29.97  |
| 08583770  | δ Sct – γ Dor | 41807 | SC | 30.79  |
| 09655114  | δ Sct  | 38340 | SC   | 27.11  |
| 09775454  | δ Sct – γ Dor | 10341 | LC | 228.95 |
| 11402951  | δ Sct  | 14240 | SC   | 9.72   |
| 11445913  | δ Sct – γ Dor | 14244 | SC | 9.72   |
| 11973705  | γ Dor – δ Sct | 14212 | SC | 9.72   |

compared to our classification of A9.5V. It is most likely a δ Sct star in a binary system.

7 SUMMARY

We presented a spectroscopic analysis of 19 candidate δ Sct variables observed by *Kepler* both in long and short cadence mode. The analysis is based on medium- to high-resolution spectra obtained at the Loiano and INAF - OACT observatories. For each star we derived *T*<sub>eff</sub>, log *g* and *v* sin *i* by matching the observed spectra with synthetic spectra computed from the SYNTHE code (Kurucz & Avrett 1981) and using the LTE atmospheric models calculated by ATLAS9 (Kurucz 1993a). The typical errors are about 200 K, 0.2 dex, and 10 km s<sup>−1</sup> for *T*<sub>eff</sub>, log *g*, and *v* sin *i*, respectively. Equivalent spectral types and luminosity classes were also derived. The luminosities of the stars were obtained using the tables of Schmidt-Kaler (1982).

For ten stars we used Strömgren photometry from the literature to estimate the reddening. For seven stars for which β photometry was also available, *T*<sub>eff</sub> and log *g* could be obtained for comparison with our spectroscopic values. In addition, *V* – *K* colours, the IFRM method and values listed in the KIC were used to obtain independent estimates of *T*<sub>eff</sub>. We find a general good agreement between photometric and spectroscopic results. Four stars with significant parallaxes and four cluster member objects were used to check our estimate of the luminosities. We obtain consistent results for all the stars, with the exception of KIC 03429637 (HD 178875), which is a binary and may have an erroneous parallax determination. Moreover, for KIC 05724440 (HD 187234) we suspect a problem with the *uvbyβ* photometry, since *T*<sub>eff</sub> derived from the *V* – *K* index is in agreement with our estimate within the errors.

Finally, we present the periodograms for the 19 investigated stars, based on the *Kepler* satellite photometry. These beautiful data allowed us to classify the type of variability of each star, including KIC 05296877, which is a high amplitude ellipsoidal variable candidate. As a result, we find six pure δ Sct, 3 pure γ Dor and nine hybrid pulsators. This classification is consistent with the derived physical parameters and their position in the HR diagram. As already noted by Grigahcène et al. (2010), we were surprised by the large number of hybrid pulsators. An asteroseismic study of these objects will have a strong impact on our knowledge of the evolution and internal structure of A/F stars. A more in depth study of the pulsational behaviour of the 18 pulsators is out of the scope of this paper, and will be presented in a forthcoming paper.

The stellar parameter estimates for the 18 investigated pulsating stars, presented in this work, will be a fundamental starting point for building proper asteroseismic models aimed at interpreting the frequency spectra extracted from the exceptionally good *Kepler* data.

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REFERENCES

Abt, H. A., 1984, ApJ, 285, 247
Blackwell D.E., Shallis M.J., 1977, MNRAS 180, 177
Borucki W.J., Koch D.G., Dunham E.W., et al., 1997, ASP Conf. Ser. 119, 153
Breger M., 2000, ASP Conf. Ser. 210, 3
Breger, M., Pamyatnykh, A. A., 1998, A&A, 332, 958
Bruntt, H., De Cat, P., Aerts, C., 2008, A&A, 478, 487
Cardelli, J. A., Clayton, G. C., Mathis, J.S., 1989, ApJ, 345, 245
Chieffi, A., Straniero, O., 1989, ApJS, 71, 47
Couteau, P., Gili, R., 1994, A&AS, 106, 377
Dommnaget J., Nys O., 1994, Com. de l’Observ. Royal de Belgique, 115, 1
Duflot M., Figon P., Meyssonnier N. 1995, A&AS, 114, 269
Dupret M.-A., Grigahc`ene A., Garrido R., Gabriel M., & Scuflaire R., 2004, A&A, 414, L17
Dutra C. M., Bica E., 2000, A&A, 359, 347
Fehrenbach, Ch., Burnage, R., 1990, A&AS, 83, 91
Fox Machado L., Pérez Hernández F., Suárez J. C., Michel E., Lebreton Y., 2006, A&A, 446, 611
García Hernández A., Moya A., Michel E., et al., 2009, A&A, 506, 79
Gilliland R.L., Jenkins J.M., Borucki W.J., et al., 2010, ApJ 712, 160
Glushkova E.V., Batyrshinova V.M., Ibragimov M.A., 1999, Astron. Letters 25, 86
Goupil M.-J., Dupret M. A., Samadi R., et al., 2005, JApA, 26, 249
Grigahcène A., Antoci V., Balona L., et al., 2010, ApJL, 713, 192
Grigahcène A., Dupret M.A., Garrido R., Gabriel M., Scuflaire R., 2004, CoAst, 145, 10
Guzik J.A., Kaye A.B., Bradley P.A., Cox A.N., & Neuforge C., 2000, ApJ, 542, L57
Handler G., 2009, MNRAS, 398, 1339
Handler G., Shobbrook R. R., 2002, MNRAS, 333, 2, 251
Hauck B., Mermillod M., 1998, A&AS, 129, 31
Henry G.W, Fekel F.C., 2005, AJ 129, 2026
Jordi C., Figueras F., Torra J., Asiain R., 1996, A&AS, 115, 401
Kaye A.B., Handler G., Krischiunas K., Poretti E., & zerbi F.M., 1999, PASP, 111, 840
King H., Matthews J.M., Rowe J.F., et al. 2006, CoAst 148, 28
Kurucz R. L., Bell B., 1995, Kurucz CD-ROM No. 23. Cambridge, Mass.: Smithsonian Astrophysical Observatory.
Kurucz R.L., 1993, A new opacity-sampling model atmosphere program for arbitrary abundances. In: Peculiar versus normal phenomena in A-type and related stars, IAU Colloquium 138, M.M. Dworetsky, F. Castelli, R. Faraggiana (eds.), A.S.P Conferences Series Vol. 44, p.87
Kurucz R.L., 1993, Kurucz CD-ROM 13: ATLAS9, SAO, Cambridge, USA
Kurucz R.L., Avrett E.H., 1981, SAO Special Rep., 391
Latham D.W., Brown T.M., Monet D.G., Everett M., Esquerdo G. A., Hergenrother C. W., 2005, AAS 37, 1340
Lindoff, U. 1972, A&A, 16, 315
Luo Y. P., Zhang X. B., Luo C. Q., Deng L. C., Luo Z. Q., 2009, NewA, 14, 584
Masana E., Joedi C., Ribas I., 2006, A&A, 450, 735
Molenda-Zakowicz J., Kopacki G., Steślicki M., Narwid A., 2009, AcA, 59, 193
Moon, T.T., 1985, Ap&SS, 117, 261
Moon, T. T., Dworetsky, M. M., 1985, MNRAS, 217, 305
Nordstrom, B., Stefanik, R. P., Latham, D. W., Andersen, J., 1997, A&AS, 126, 21
Olsen, E.H., 1983, A&AS, 54, 550
Perryman, M.A.C., Lindegren, L., Kovalevsky, J., et al. 1997, A&A 323, L49
Pickles A. J., 1998, PASP, 110, 863
Pietrinferni A., Cassisi S., Salaris M., Castelli F., 2004, ApJ, 612 168
Rowe J.F., Matthews J. M., Cameron C., et al. 2006, CoAst 148, 34
Scargle, J. D. 1982, ApJ, 263, 835
Schmidt-Kaler T., 1982, in “Landolt-Börnstein”, Vol 2b Group IV, Springer-Verlag
Skrutskie, M. F., Cutri, R.M., Stiening, R., Weinberg, M.D., Schneider, S. et al., 2006, AJ, 131, 1163
Suárez J.-C., Bruntt H., Buzasi D., 2005, A&A, 438, 633
Uytterhoeven K., Mathias P., Poretti E., et al., 2008, A&A 489, 1213
Uytterhoeven K., Briquet M., Bruntt H., et al., 2010, AN, submitted (arXiv:1003.6093)
Uytterhoeven, K., Szabo, R., Southworth, J., et al., 2010, AN, submitted (arXiv:1003.6089)
van Leeuwen, F., 2007, A&A, 474, 653
Voigt, H. H., 2006, in “Landolt-Börnstein”, Vol 3b Group VI, Springer-Verlag
Warner, P. B., Kaye, A. B.; Guzik, J. A., 2003, ApJ, 593, 1049