Spectroscopic metallicities of Vega-like stars

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ABSTRACT

Aims. To determine the metallicities of 113 Southern Hemisphere Vega-like candidate stars in relation to the Exoplanet host group and field stars.

Methods. We applied two spectroscopic methods of abundance determinations: equivalent width measurements together with the ATLAS9 (Kurucz 1993) model atmospheres and the WIDTH9 program, and a comparison of observed spectra with the grid of synthetic spectra of Munari et al. (2005).

Results. For the Vega-like group, the metallicities are indistinguishable from those of field stars not known to be associated with planets or disks. This result is quite different from the metallicities of Exoplanet host stars which are metal-rich in comparison to field stars.

Key words. Techniques: spectroscopic – Stars: abundances – Stars: late-type

1. Introduction

It is well established that Exoplanet host stars are, on average, metal-rich in comparison to stars that do not harbor Doppler detected planets (see, for example, Santos et al. 2004). Two hypotheses have been put forward to explain this peculiarity of the Exoplanet host stars a) a primordial origin and b) a pollution of the convective zone of the star. In the first case the "excess" of metallicity was already present in the parent cloud from which the star bearing planet/s was formed (see, for example, Santos et al. 2001). In the pollution scenario the convective zone of the star is contaminated by the infall or accretion of planets and/or planetesimals (see, for example, González et al. 2001). Santos et al. (2004) found a lack of correlation between the thickness of the convective zone and the metallicity for a sample of FG dwarfs with planets. As the convective zone acts as a diluting medium, for a given amount of accreted material, F dwarfs with thinner convective zones should exhibit a greater degree of pollution than G dwarfs with thicker zones. On average, F and G dwarfs

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exhibit similar metallicities and the pollution hypothesis is not favored by these observations. The primordial origin of the "excess" remains an alternative to explain the relatively high metallicity of stars with planets with respect to field stars.

However, Pasquini et al. (2007) compared the metallicities of giant and dwarf stars with planets and found that the first group has, on average, lower metallicities than the dwarfs. The smaller mass of the convective zone of the dwarfs with respect to the giants provides a plausible explanation for this difference. The diluting effect of the convective zone is efficient for the giants and tends to lower the metallicity to its primordial value. In this case, the pollution scenario is favored (over the primordial origin) since it can explain the observed difference in metallicities between dwarfs and giants with planets. Even when the origin or the cause of the "excess" of metallicity of stars with planets is not well understood, the Exoplanet host stars are metal-rich and this is a feature that distinguishes this group among stars with similar physical properties and no giant planets detected.

Vega-like stars are a group of objects that show infrared excesses in their spectral energy distributions that can be attributed to the presence of dust in circumstellar disks. The first members or candidate members of the class were selected by IRAS and had mainly A-F spectral types (Aumann et al. 1984; Gillett 1986; Backman & Paresce 1993; Sylvester et al. 1996; Mannings & Barlow 1998; Fajardo-Acosta et al. 1999; Sylvester & Mannings 2000; Habing et al. 2001; Laureijs et al. 2002; Sheret et al. 2003). Vega (α Lyr) is one of the four prototypes of the group or the "fabulous four" (Vega, β Pictoris, Fomalhaut = α PsA and ǫ Eridanis; Gillett 1986) and has given the name to the class.

More recently, Spitzer has contributed with the detection of G dwarfs with infrared excesses (Meyer et al. 2004; Rieke et al. 2005; Kim et al. 2005; Chen et al. 2005; Uzpen et al. 2005; Beichman et al. 2006; Bryden et al. 2006; Silverstone et al. 2006; Su et al. 2006; Trilling et al. 2008). Since the excesses come from distances similar to the Kuiper-Belt to the Sun, these stars have also received the designation of Kuiper-Belt analogs or Kuiper-Belt-like stars. In this contribution we adopt the term "Vega-like stars" to refer to both IRAS and Spitzer detections.

The metallicity of Vega-like stars has previously been investigated by Greaves et al. (2006) and Chavero et al. (2006), deriving nearly solar values. However these works analyzed relatively small samples of objects. Greaves et al. (2006) studied a group of 18 FGK Vega-like stars whereas Chavero et al. (2006) included 42 FG dwarfs with infrared excesses in their metallicity determination. In addition these previous works do not include stars of A spectral type which represent the bulge of IRAS detections. Greaves et al. (2006) derived their sample from the Doppler searches for planets that in general include solar type stars. Chavero et al. (2006) used the Strömgren photometry to determine the metallicity. These authors were also restricted to late spectral types.

Both the stars with planets and the Vega-like stars have evidence of the presence of circumstellar material, in the form of planet/s, in the first case, or dust in a circumstellar disk, in the second. As mentioned before, the Exoplanet hosts are metal-rich. This fact may have facilitated the formation of planets (Pollack et al. 1996). In this contribution we determine spectroscopic metallicities of a large sample of Vega-like stars to compare with the Exoplanet host group. We include objects of B–K spectral types, observable from the Southern Hemisphere.
2. The sample

We compiled a total of 113 Southern Hemisphere Vega-like candidate stars from the literature, based on their infrared or submillimetric excess emissions (Backman & Paresce 1993; Sylvester et al. 1996; Mannings & Barlow 1998; Fajardo-Acosta et al. 1999; Sylvester & Mannings 2000; Habing et al. 2001; Laureijs et al. 2002; She et al. 2004). This compilation also includes G dwarfs with infrared excess recently detected by Spitzer (Beichman et al. 2005, 2006; Bryden et al. 2006; Su et al. 2006; Trilling et al. 2008). Specifically the list comprises objects with BAFGK spectral types (22, 38, 28, 17 and 8, respectively). All the stars are luminosity class V (Hipparcos catalogue) and have distances between 5 and 300 pc. Table 1 lists the observed objects.

Table 1 includes a sub-sample of stars that were originally selected by IRAS as candidate Vega-like stars. However, when observed by Spitzer the infrared excesses were deemed to be of little significance. These objects are: HD 10800, HD 20794, HD 38393, HD 41700, HD 68456, HD 160691, HD 169830, HD 203608, and HD 216437 (Beichman et al. 2005, 2006; Bryden et al. 2006; Hillenbrand et al. 2008; Trilling et al. 2008). For example, Bryden et al. (2006) found that for HD 10800 $f_{\text{MIPS}70 \mu m}/f^* = 1.3$ (the observed flux over the photospheric emission at 70 $\mu$m) and $f_{\text{MIPS}70 \mu m}/f^* = 1.2$ for HD 68456. This group of objects should be considered with caution.

3. Observations and data reduction

The stellar spectra were obtained at the Complejo Astronomico El Leoncito (CASLEO), using the Jorge Sahade 2.15-m telescope equipped with a REOSC echelle spectrograph and a TEK 1024x1024 CCD detector. The REOSC spectrograph uses gratings as cross dispensers. We used a grating with 400 lines mm$^{-1}$, covering the spectral range $\lambda \lambda 3500$–6500, giving a resolving power of $\sim 12500$. Three individual spectra for each object were obtained in four observing runs: August 05–08 2005, August 18–22 2005, February 18–25 2006 and May 04–07 2007 and have S/N ratio of about 300.

The spectra were reduced using IRAF standard procedures for echelle spectra. We applied bias and flat corrections and then normalized order by order with the continuum task, using 7–9 order Chebyshev polynomials. We also corrected by the scattered light in the spectrograph (apscatter task). We fitted the background with a linear function on both sides of the echelle apertures, using the task apall. The resolution of the reduced spectra is 0.17 Å/pix.

4. Metallicity determinations

We used two different methods of abundance determination: 1) Fe lines equivalent width measurements together with the ATLAS9 (Kurucz 1993) model atmosphere corresponding to a given star and the WIDTH9 program. 2) A comparison of the observed and synthetic spectra using the Downhill method (Gray et al. 2001). In particular we used the grid of synthetic spectra calculated

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3 http://kurucz.harvard.edu/programs.html
4.1. Metallicity determinations using the WIDTH program

To determine abundances by this method it is necessary to estimate the stellar parameters $T_{\text{eff}}$ and $\log g$, by means of the Strömgren photometry, for example. With these quantities we adopt the Kurucz (1993)’s model atmosphere appropriated to each star. The model that initially is chosen has solar metallicity. Finally the Kurucz’s model together with the measured equivalent widths are used by the WIDTH9 program (Kurucz 1992, 1993) to derive the metallicity.

To obtain $T_{\text{eff}}$ and $\log g$, we have used the uvby$\beta$ mean colors of Hauck & Mermilliod (1998) with two different calibrations: Napiwotzki et al. (1993) and Castelli et al. (1997) and Castelli (1998) (hereafter N93 and C97, respectively), with the TEMPLOGG code (Rogers et al. 1995). This program has been used in the COROT mission preparation (see, for example, Lastennet et al. 2001; Guillon & Magain 2006) and includes reddening corrections, according to Domingo & Figueras (1999) for stars in the range A3–F0, and to Nissen (1988) for spectral types F0–G2.

We have compared the temperatures and gravities derived using both calibrations (N93 and C97) and noticed some differences particularly in the later parameter. For this reason we initially determined metallicities using values derived from both calibrations and later on considered if they significantly affect the final metallicity values. We have also confronted the obtained $T_{\text{eff}}$ with those published by Nordström et al. (2004). We found a good agreement in particular with the N93 calibration. With the values of $T_{\text{eff}}$ and $\log g$ derived for each object, we have chosen the corresponding model atmosphere using the Kurucz ATLAS9 (Kurucz 1993) code.

The stellar lines were identified using the general references of *A multiplet table of astrophysical interest* (Moore 1945) and *Wavelengths and transition probabilities for atoms and atomic ions - Part I: Wavelengths* (Reader et al. 1980), as well as more specialized references for the Fe $\text{II}$ lines (Johansson 1978). The equivalent widths were measured by fitting Gaussian profiles through the stellar metallic lines using the IRAS *splot* task. There is no more than a 15% difference among the equivalent widths of the same lines, measured in different spectra. We have excluded from our abundance determinations seriously blended lines.

To determine the abundances we need an initial estimation of the microturbulent velocity ($\xi$). For this estimation we have used the standard method. We computed the abundances from the Fe lines for a range of possible values of $\xi$ satisfying two conditions: a) that the abundances of Fe lines were not dependent on the equivalent widths and b) that the rms errors were minima. To achieve the first condition the slope in the plot abundance vs $\xi$ must be zero. We tried different $\xi$ values to fulfill this requirement. In this sense the abundance and microturbulent velocity determinations are recursive and simultaneous. Once a $\xi$ value has been fixed the corresponding abundances to all chemical species measured are determined using the WIDTH9 code.

The WIDTH9 code requires the model atmosphere calculated by the ATLAS9 program, the equivalent width of each line as well as atomic constants such as oscillator strength (Log $gf$) values, excitation potentials, damping constants, etc. In particular for the Log $gf$ we used Fuhr et al. (1988) and Kurucz (1992). This code calculates the theoretical equivalent widths for an initial
input abundance and compares these values with the measured equivalent widths. Then the code modifies the abundance to achieve a difference between theoretical and measured equivalent widths < 0.01 mÅ. The final values of the metallicities corresponding to the N93 and C97 calibrations, are listed in Table 2. We have included the number of lines used in each determination as well as the rms of the average.

To estimate errors for our WIDTH metallicities we consider the following facts. The most significant contribution to the final uncertainties, probably, comes from the equivalent width measurements. We assume a 5% error due to the continuum level determination. This translates into 20% maximum uncertainties in the metallicity estimation. The atomic constants may also have uncertainties. In particular we estimate that the oscillator strength values may cause differences of about 10% in the calculated metallicity. Finally to provide an estimation of "typical" errors introduced by the WIDTH method we increased the $T_{\text{eff}}$ by 150 K and the $\log g$ by 0.15, and recalculated the metallicity value for each star. We derived a median difference of 0.20 dex. The largest difference corresponds to HD 28978 (0.55 dex).

4.2. Metallicity derivations from synthetic spectra: The Downhill method

The WIDTH method is not practical when the number of stars is large. For each object, we need to identify and measure many spectral lines. An alternative would be to compare the observed spectra with a grid of synthetic ones corresponding to different values of the metallicites and choose from the grid the spectrum that better reproduces the observed data [Gray et al. 2001]. This comparison has the advantage that the complete profiles of the lines and not only the equivalent widths are used in the metallicity determinations.

In general synthetic spectra depend on four parameters: $T_{\text{eff}}$, surface gravity ($\log g$), metallicity ([Fe/H]) and microturbulent velocity ($\xi$). Following [Gray et al. 2001], we applied a multidimensional Downhill Simplex technique, in which the observed spectrum is compared to a grid of synthetic spectra. The "final" synthetic spectrum is an interpolation of spectra, rather than a single point in the grid. As we are working with four variables ($T_{\text{eff}}$, $\log g$, [Fe/H] and $\xi$) the interpolation is done in 4d, minimizing the square differences in each wavelength (i.e., the $\chi^2$ statistics). The stellar parameters are determined with a higher accuracy than the steps in the grid since they correspond to interpolated values.

The grid of synthetic spectra was taken from [Munari et al. 2005]. The parameters range covered by the grid is the following:

- $3500 \, \text{K} < T_{\text{eff}} < 40000 \, \text{K}$, with steps of 250 K,
- $0.0 \, \text{dex} < \log g < 5.0 \, \text{dex}$, with steps of 0.5 dex,
- $-2.5 \, \text{dex} < [\text{Fe/H}] < 0.5 \, \text{dex}$, with steps of 0.5 dex,
- $\xi$ values of 0, 1, 2, and 4 km/s.

In addition to these parameters, the synthetic spectra are calculated for 15 different rotation velocities, ranging 0 – 500 km/s. In all, Munari et al. [2005]'s library contains 625000 different spectra. These authors calculated the complete synthetic spectral library for four resolving powers: 20000, 11500 (GAIA), 8500 (RAVE) and 2000 (SLOAN). To our request, Dr. U. Munari kindly provided a grid corresponding to the REOSC/CASLEO resolving power (12500).
Synthetic spectral lines were convolved with the instrumental line profile corresponding to the REOSC/CASLEO. Finally they were also convolved with a Gaussian profile corresponding to the rotational velocities of the sample stars, taken from the literature (Glebocki et al. 2000; Mora et al. 2001; Yudin 2001; Rover et al. 2002; Cutispoto et al. 2002, 2003; Pizzolato et al. 2003; Strom et al. 2003; Reiners 2006). We weighted the synthetic spectra by the blaze function of each of the REOSC spectrograph order. Finally we normalized and re-sampled our data to compare them with Munari et al. (2005)'s grid. The spectral sampling of the synthetic spectra is 0.02 Å.

We have implemented the Downhill method (Gray et al. 2001) by means of a Fortran program. From the stellar spectral type or the Strömgren photometry it is possible to estimate "a starting point" in the 4d grid. The Downhill method provides a searching algorithm within the 4d grid and finds the best match, minimizing the $\chi^2$. In our case, the final spectrum is obtained by an interpolation of 16 spectra of Munari et al. (2005)'s grid. In general it takes 15 – 20 min for each star (50 – 60 iterations) in a Pentium IV 2.0 GHz to find the best interpolated spectrum. Table 3 lists the metallicities obtained with the Downhill method for our sample of Vega-like stars.

To estimate the uncertainties in the metallicities obtained by the Downhill method, we carried out a few tests. We first applied this method to 30 synthetic spectra of known metallicities. The median difference between the derived and known metallicities is 0.2 dex.

The internal consistency of the method has been checked, by fixing one of the four variables and comparing the resultant metallicities. Fixed values for each variable were obtained, for example, from an adopted calibration:

a) $T_{\text{eff}}$ was taken from the N93 calibration,
b) $\log g$ was adopted from the N93 calibration,
c) $\xi$ was fixed at 2.9 km/s, the solar value.

The median difference, calculated by fixing 3 of the 4 variables with respect to the "standard" procedure (i.e., with 4 variable), was 0.05 dex. Considering this value and the median difference derived from the comparison with 30 synthetic spectra of known metallicities (0.2 dex), we estimate a "typical" uncertainty of 0.06 dex for the metallicities derived by the Downhill method.

We have also compared the Downhill method derived metallicities with those obtained by Nordström et al. (2004) and Fischer & Valenti (2005). We first noticed a systematic difference of $\sim 0.09$ dex between these two determinations. Fischer & Valenti (2005)'s determinations are, on average, larger than those from Nordström et al. (2004)'s. Our Downhill method derived metallicities show a better agreement with Nordström et al. (2004)'s value than with Fischer & Valenti (2005)'s. However this later comparison is based on a relatively small number of common stars.

In the work of Nordström et al. (2004)'s the metallicities are derived as a secondary parameter obtained photometrically. In the case of Fischer & Valenti (2005), the metallicities are obtained by a comparison with synthetic spectra but using only a small range of wavelengths (6000 – 6200 Å). With these limitations in mind, we consider that the external consistency of the Downhill method derived metallicities is acceptable.

We finally mention two parameters taken as fixed by the Downhill method, the radial and the rotational velocities. Radial velocities are initially determined, minimizing the $\chi^2$ with an accuracy of 0.1 km/s or a median value of 0.03 dex in metallicity. Rotational velocities ($v \sin i$) from
Table 4. Medians and dispersions of the metallicities for the Vega-like sample

| Method      | Median $\frac{[\text{Fe}/\text{H}]}{[\text{Fe}/\text{H}]}$ | Dispersion $\frac{[\text{Fe}/\text{H}]}{[\text{Fe}/\text{H}]}$ | N   |
|-------------|----------------------------------------------------------|---------------------------------------------------------------|-----|
| WIDTH+N93   | $-0.14$                                                  | 0.28                                                          | 113 |
| WIDTH+C97   | $-0.11$                                                  | 0.26                                                          | 113 |
| Downhill    | $-0.11$                                                  | 0.27                                                          | 113 |

Note - N93: Napiwotzki et al. (1993)’s calibration; C97: Castelli et al. (1997) and Castelli (1998)’s calibration.

In summary, we have estimated an internal uncertainty of 0.06 dex for metallicities derived from the Downhill method. A more conservative estimation would indicate a value of 0.1 dex. This corresponds to half of the uncertainty calculated for the WIDTH method (0.2 dex). In this manner, the Downhill method allows a more precise determination of the metallicities for our sample of Vega-like objects.

4.3. Comparison of metallicity determinations by the WIDTH and the Downhill methods

Table 4 lists the medians and the dispersions of the metallicities derived by applying the WIDTH and the Downhill methods for the Vega-like group. In the case of the WIDTH method we present the results corresponding to the two calibrations used (N93 and C97). The derived median values are practically indistinguishable.

Figure 1 compares the metallicity distributions calculated with the WIDTH method plus the N93 calibration (histogram shaded at 0 degree) and the C97 calibrations (histogram shaded at 45 degrees), respectively. The empty histogram shows the distribution derived with the Downhill method for the Vega-like sample. Vertical lines indicate the medians of each distribution. The left line corresponds to the WIDTH+N93 median, and the right line shows (superimposed) the WIDTH+C97 and Downhill medians (see Table 4). The KS-test (Press 1992) indicates that these distributions are similar and represent the same parent population.

We finally adopt the metallicities calculated with the Downhill method for the sample of Vega-like stars, as these determinations use the complete line profiles and not only the equivalent widths. In addition “typical” uncertainties are smaller than those estimated for the WIDTH method.

5. Discussion of the results

The metallicity of the Solar Neighborhood is usually represented by a control sample of stars, which should exclude, in our case, known Vega-like stars. The selection of the control sample is important, because different groups of objects (i.e., stars selected by different criteria) may have different metallicities. For example, Fischer & Valenti (2005) compared two different control samples, with the metallicity distribution of Exoplanet host stars. Their control sets are volume-limited and magnitude-limited. The medians of the metallicity “excess” of the Exoplanet host stars com-
Fig. 1. Metallicity distributions for the Vega-like sample. Histograms shaded at 0 and 45 degrees correspond to the WIDTH method derivations using N93 (Napiwotzki et al. 1993) and C97 (Castelli et al. 1997; Castelli 1998) calibrations, respectively. The empty histogram shows the metallicity distribution derived by the Downhill method. The vertical lines indicate the medians of each distribution. The left line corresponds to the WIDTH+N93 median, and the right line shows (superimposed) the WIDTH+C97 and Downhill medians (see Table 4).

pared with the two groups, are 0.13 and 0.226 dex, respectively. In other words, the "excess" is real, but the amount depends on the control sample used. The two control sets contain different classes of stars. The magnitude-limited sample includes more massive and metal-rich stars than the volume-limited set.

The metallicity distribution of Exoplanet host stars is usually compared with a volume-limited group of solar neighborhood stars (González 1998, 1999; González et al. 2001; Santos et al. 2000, 2003; Santos et al. 2004; Sadakane et al. 2002; Laws et al. 2003). We compared the metallicity distribution of our Vega-like sample with a volume-limited sample of 71 stars, without Doppler detected Exoplanets (Santos et al. 2001; Gilli et al. 2006) and with 98 Exoplanets host stars (Santos et al. 2004). Metallicity values for these two comparison samples were obtained from Nordström et al. (2004). As discussed in Section 4.2, the agreement between our metallicities and those obtained by these authors is acceptable. Figure 2 shows these distributions. Vega-like stars are represented by the empty histogram, stars with planets by the histogram shaded at 0 degree and stars known not to harbor planets detected by the Doppler technique, by the histogram shaded at 45 degrees. The KS test shows no significant difference between the metallicities distributions of the Vega-like stars and stars without planets. On the other hand, the Vega-like stars metallicity distribution is different from the metallicity distribution for stars with planets with a high level of confidence.

Fischer & Valenti (2005) obtained that the probability that a FGK star harbors a giant planet/s increases as $P(Z) \propto (10^Z)^2$, where $Z$ is the stellar metallicity (see also Wyatt et al. 2007b). If this
relation is also applicable to A stars (the bulge of IRAS detected Vega-like stars), the low median value of the metallicity for the Vega-like group (−0.11 dex, see Table 5) indicates that the probably for these stars to host a planet/s of the type detected by radial velocity surveys is also low. We note, however, that the dispersion of metallicities within the Vega-like stars is also significant (0.26 dex) and at least a fraction of these stars has metallicities high enough to host giant planets, assuming the ”excess” of metallicity/presence of a giant planet/s holds for A spectral type stars. In addition it is worthwhile to mention that Doppler searches do not achieve the required precision to detect planets in A stars as metal lines practically disappear.

We also compared the metallicity distribution of Vega-like stars, with a sample of 115 stars without excess at 24 or 70 µm, observed by Spitzer (Beichman et al. 2005, 2006, Bryden et al. 2006, Su et al. 2006). Figure 3 shows these distributions. Vega-like stars are indicated by the empty histogram whereas the stars without excess at 24 or 70 µm are shown by the histogram shaded at 45 degrees. The KS test shows no significant difference between the two distributions. Table 5 lists the medians and the dispersions of the four samples compared in Figures 2 & 3.

The results in Table 5 indicate that, on average, the Vega-like group has metallicities similar to the stars in the Solar Neighborhood without detected planets or disks, in contrast to the Exoplanet host stars group. This result confirms and extends previous works by Greaves et al. (2006) and Chavero et al. (2006), based on relatively small numbers of FG Vega-like stars.

In Figure 4 we analyze the metallicity distribution of Vega-like stars of different spectral types. The number of objects corresponding to each spectral type is indicated between brackets. The vertical bars are the dispersions within the spectral types. A-spectral-type stars still dominate the Vega-like group although Spitzer has significantly contributed with F and G stars during the last
Fig. 3. Metallicity distributions for the Vega-like sample, empty histogram, and for stars without excess at 24 or 70 \( \mu \)m (Beichman et al. 2005, 2006; Bryden et al. 2006; Su et al. 2006). The vertical lines (almost superimposed) indicate the medians of each distribution.

Table 5. Medians and dispersions of the Vega-like sample and three comparison groups

| Sample                                      | Median [Fe/H] | Dispersion [Fe/H] | N   |
|---------------------------------------------|--------------|------------------|-----|
| Vega-like stars                             | −0.11        | 0.27             | 113 |
| Exoplanet host stars                        | +0.17        | 0.22             | 98  |
| Volume-limited sample without planets      | −0.16        | 0.25             | 71  |
| Stars without excess at 24 or 70 \( \mu \)m | −0.12        | 0.24             | 115 |

As suggested by Greaves et al. (2006) the relatively high metallicity of Exoplanet host stars as well as the solar metallicity value for the Vega-like stars can be understood within the core accumulation model of Pollack et al. (1996). The high metal content of the disk favors the fast formation of giant planets, which needs to accrete an atmosphere and migrate inward before the gas is dissipated from the disk. On the contrary, for Vega-like objects no giant planet needs to be formed and/or migrate inward. The gas may dissipate and still the planetesimal in the external part of the disk may produce dust by collisions.

We tentatively analyzed two small sub-sets of Vega-like objects: the Vega-like stars with planets and the Vega-like group with no Doppler detected planets. The first group is composed of 7 stars: 6 with 70 \( \mu \)m excess detected by Spitzer (HD 33636, HD 50554, HD 52265, HD 82943, HD 128311 and HD 117176; Beichman et al. 2006) and \( \epsilon \) Eri with infrared and submillimeter excesses (Greaves et al. 1998; Zuckerman 2001). In the second group we include 5 stars without
Fig. 4. Metallicity of Vega-like stars of different spectral types. Between brackets is indicated the number of objects in each spectral type bin. The vertical lines are the corresponding dispersions.

Exoplanets detected by the Doppler technique and showing infrared excess in 24 or 70 µm (HD 7570, HD 38858, HD 69830, HD 76151 and HD 115617; Beichman et al. 2006; Bryden et al. 2006). The median metallicity of Vega-like stars with planets is +0.07 dex and the dispersion is 0.16 dex. For the Vega-like objects without planets these values are: −0.08 and 0.18 dex, respectively. It seems that when a Vega-like star has a planet the metallicity increases slightly. However the small number of objects available as well as the dispersions prevent us from giving any statistical significance to this initial trend.

Greaves et al. (2007) proposed that the solid-mass (i.e., metals) content in primordial disks, called $M_S$, is the fundamental parameter that regulates the planet/disk formation. If $M_S$ is small, the star will form a Vega-like disk, while if $M_S$ is larger, a giant planet may be formed. Table 1 of Greaves et al. (2007) shows the range of metallicity and the final configurations (planet+debris, debirs, etc.) derived by these authors. The medians of the metallicities of Vega-like stars with and without planets agree with Greaves et al. (2007)’s Table 1. However this can only be considered as an initial trend that needs to be confirmed by increasing the number of Vega-like objects with planets as well as objects known not to harbor Doppler detected planetary mass objects.

6. Summary and Conclusions

We derived spectroscopic metallicities for a group of 113 Southern Hemisphere Vega-like stars. We applied two methods to determine metallicities: the “classical” WIDTH method and a comparison with the grid of synthetic spectra of Munari et al. (2005) by means of the Downhill algorithm. The later method offers the advantage that the complete profile of the line is used in the metallicity
derivation and not only the equivalent width. In addition we estimated smaller uncertainties in the metallicities derived by the Downhill method (0.1 dex) than with the WIDTH code (0.2 dex).

Vega-like stars have metallicities similar to Solar Neighborhood stars without planets or disks and significantly different from the Exoplanet host stars. This result confirms previous estimations by Greaves et al. (2006) and Chavero et al. (2006), based on comparatively smaller samples.

The low metallicities for the Vega-like group (median = −1.11 dex) in relation to the Exoplanet host stars (median = + 0.17, see for example, Fischer & Valenti 2005), may indicate that the probability for these stars to host a planet/s of the type detected by radial velocity surveys is also low. However the dispersion of metallicities within the Vega-like stars is also significant (0.26 dex) and thus a fraction of these objects may have metallicities high enough to form giant planets. We caution that Exoplanet host stars are mainly of FGK spectral types whereas the bulge of IRAS detected Vega-like stars has A spectral type which are, in general, excluded from radial velocity searches since high precisions are not feasible. In this we are assuming that the probability of a A star to be associated with a giant planet depends on the metallicity as is the case for FGK stars.

We find no trend in the metallicities of Vega-like objects with the spectral type. Greaves et al. (2006) suggestion make compatible the relative high metallicity of Exoplanet host stars and the solar Neighborhood value for Vega-like stars with the core accumulation model of Pollack et al. (1996).

Analyzing two relatively small sub-samples, we find that Vega-like stars with a Doppler detected planet have slightly higher metallicities than Vega-like stars known not to harbor such a planet. However this must be considered only as an initial trend that needs to be confirmed by increasing both samples to achieve a statistical significant result.

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Table 1. Sample of Vega-like stars observed at the CASLEO

| Star   | Distance [pc] | V   | Spectral Type | Reference                      |
|--------|---------------|-----|---------------|--------------------------------|
| HD 105 | 40            | 7.51| G0V           | DEC03 HILO8                    |
| HD 142 | 26            | 5.70| G1V           | BE05 TR08                      |
| HD 2623| 365           | 7.93| K2            | SB91                           |
| HD 3003| 46            | 5.07| A0V           | MB98 O92 SB91 WY07             |
| HD 9672| 61            | 5.62| A1V           | MB98 O92 SB91 PW91 WW88 SN86 WY07 |
| HD 10647| 17           | 5.52| F8V           | MB98 O92 SB91 DEC03 TR08       |
| HD 10700| 4            | 3.49| G8V           | MB98 HDJL01 DEC03              |
| HD 10800| 27           | 5.88| G2V           | MB98 BE06 BR06                 |
| HD 17206| 14           | 4.47| F5V           | O92 SB91                       |
| HD 17848| 51           | 5.25| A2V           | MB98                           |
| HD 18978| 26           | 4.08| A4V           | SCBS01                         |
| HD 20010| 14           | 3.80| F8V           | O92 WW88                       |
| HD 20794| 6            | 4.26| G8V           | DEC03 BE06                     |
| HD 21563| 182          | 6.14| A4V           | MB98                           |
| HD 22049| 3            | 3.72| K2V           | SB91 WW88 HDJL01 DEC03         |
| HD 22484| 14           | 4.29| F9V           | DEC03 TR08                     |
| HD 23362| 309          | 7.91| K2            | SB91                           |
| HD 25457| 19           | 5.38| F5V           | DEC03 PAS06 HILO8              |
| HD 28375| 118          | 5.53| B3V           | O92 SB91 TR08                  |
| HD 28978| 125          | 5.67| A2V           | BP93                           |
| HD 30495| 13           | 5.49| G3V           | HDJL01 DEC03 TR08              |
| HD 31295| 37           | 4.64| A0V           | SN86 WY07                      |
| HD 33262| 12           | 4.71| F7V           | BR06 TR08                      |
| HD 33636| 29           | 7.00| G0            | BE05 TR08                      |
| HD 33949| 172          | 4.36| B7V           | MB98 O92 SB91 PW91 SN86        |
| HD 35850| 27           | 6.30| F7V           | DEC03 PAS06 AP08               |
| HD 36267| 88           | 4.20| B5V           | BP93                           |
| HD 37484| 60           | 7.26| F3V           | PAS06 HILO8                    |
| HD 38206| 69           | 5.73| A0V           | MB98 DEC03 WY07                |
| HD 38385| 53           | 6.25| F3V           | MB98                           |
| HD 38393| 9            | 3.59| F7V           | MB98 HDJL01 SH03 BE06          |
| HD 38678| 22           | 3.55| A2V           | MB98 O92 PW91 AP91 C87 HDJL01 DEC03 SU06 WY07 |
| HD 39014| 44           | 4.34| A7V           | O92 SB91 C87 JU04              |
| HD 39060| 19           | 3.85| A3V           | MB98 O92 C92 SB91 PW91 AP91 WW88 C87 JJE86 HDJL01 DEC03 WY07 |
| HD 40136| 15           | 3.71| F1V           | MB98 BE06b                     |
| HD 41700| 27           | 6.35| G0V           | DEC03 HILO8                    |
| HD 41742| 27           | 5.93| F4V           | MB98                           |
| HD 43955| 305          | 5.51| B3V           | MB98                           |
## Table 1. Continued.

| Star      | Distance [pc] | V  | Spectral Type | Reference          |
|-----------|---------------|----|---------------|--------------------|
| HD 65591  | 166           | 4.81 | B3V           | MB98               |
| HD 68456  | 21            | 4.74 | F5V           | BR06 TR08          |
| HD 69830  | 13            | 5.95 | K0V           | MB98 BE06 BR06     |
| HD 71043  | 73            | 5.89 | A0V           | WY07               |
| HD 71155  | 38            | 3.91 | A0V           | PW91 C87 WY07      |
| HD 75416  | 97            | 5.46 | B9V           | MB98 SU06 WY07     |
| HD 76151  | 17            | 6.01 | G3V           | BE06 BR06          |
| HD 79108  | 115           | 6.14 | A0V           | WY07               |
| HD 80950  | 81            | 5.86 | A0V           | MB98 WY07          |
| HD 82943  | 27            | 6.54 | G0            | BE05 TR08          |
| HD 86087  | 98            | 5.71 | A0V           | BP93               |
| HD 88955  | 32            | 3.85 | A2V           | MB98               |
| HD 98800  | 47            | 8.89 | K4V           | MB98 SB91 WW88 MA05 |
| HD 99211  | 26            | 4.06 | A9V           | MB98               |
| HD 102647 | 11            | 2.14 | A3V           | O92 C92 SB91 PW91 WW88 C87 HDJL01 DEC03 |
| HD 105211 | 20            | 4.14 | F2            | BE06b              |
| HD 105686 | 101           | 6.16 | A0V           | MB98               |
| HD 108257 | 123           | 4.82 | B3Vn          | BP93               |
| HD 108483 | 136           | 3.91 | B3V           | MB98               |
| HD 109085 | 18            | 4.30 | F2V           | MB98 SB91 SH03 BE06b |
| HD 109573 | 67            | 5.78 | A0V           | TE00               |
| HD 111786 | 60            | 6.14 | A0            | WY07               |
| HD 113766 | 131           | 7.48 | F5V           | MB98 O92 CH06      |
| HD 115617 | 9             | 4.74 | G5V           | BR06               |
| HD 115892 | 18            | 2.75 | A2V           | MB98 SU06 WY07     |
| HD 117176 | 18            | 4.97 | G5V           | BE05 BR06          |
| HD 117360 | 35            | 6.52 | F6V           | MB98               |
| HD 121847 | 104           | 5.20 | B8V           | MB98 PW91          |
| HD 123160 | 8.66          | K5  | SB91          |                    |
| HD 124771 | 169           | 5.06 | B4V           | MB98               |
| HD 128311 | 17            | 7.48 | K0            | BE05 BE06          |
| HD 131885 | 121           | 6.91 | A0V           | MB98               |
| HD 135344 | 78            | 7.91 | F3V           | MB98 O92 WW88      |
| HD 136246 | 143           | 7.18 | A1V           | WY07               |
| HD 139365 | 136           | 3.66 | B2.5V         | MB98               |
| HD 139664 | 18            | 4.64 | F5V           | O92 PW91 WW88 HDJL01 DEC03 CH06 BE06b |
| HD 141569 | 99            | 7.11 | B9            | O92 SB91 WW88 JJE86 SH03 CL03 |
| HD 142096 | 109           | 5.04 | B3V           | MB98 O92 SB91      |
| HD 142114 | 133           | 4.59 | B2.5V         | MB98 O92           |
Table 1. Continued.

| Star      | Distance [pc] | V    | Spectral Type | Reference       |
|-----------|---------------|------|---------------|-----------------|
| HD 142165 | 127           | 5.38 | B5V           | MB98            |
| HD 14432  | 253           | 8.19 | F0V           | MB98 O92 WW88   |
| HD 145482 | 143           | 4.58 | B2V           | MB98            |
| HD 150638 | 240           | 6.46 | B8V           | PW91            |
| HD 152391 | 17            | 6.65 | G8V           | DEC03 BR06 TR08 |
| HD 158643 | 131           | 4.78 | A0V           | O92             |
| HD 158793 | 8.83          |      |               | BP93            |
| HD 159082 | 152           | 6.42 | B9.5V         | BP93            |
| HD 160691 | 15            | 5.12 | G5V           | MB98 BE05       |
| HD 161868 | 29            | 3.75 | A0V           | O92 C87 SN86    |
| HD 164249 | 47            | 7.01 | F5V           | PW91 DEC03      |
| HD 164577 | 81            | 4.42 | A2V           | WA95            |
| HD 165341 | 5             | 4.03 | K0V           | DEC03           |
| HD 166841 | 214           | 6.32 | B9V           | MB98            |
| HD 169830 | 36            | 5.90 | F8V           | BE05            |
| HD 176638 | 56            | 4.74 | A0V           | MB98            |
| HD 177817 | 274           | 6.00 | B7V           | DEC03           |
| HD 178253 | 40            | 4.11 | A0V           | MB98 PW91       |
| HD 181296 | 48            | 5.03 | A0V           | BP93 MB98       |
| HD 181327 | 51            | 7.04 | F6V           | MB98 SCH06 CH06 |
| HD 181869 | 52            | 3.96 | B8V           | MB98 WY07       |
| HD 183324 | 59            | 5.79 | A0V           | WY07            |
| HD 185507 | 209           | 5.18 | B3V           | BP93 FR96       |
| HD 188228 | 33            | 3.97 | A0V           | SU06            |
| HD 191089 | 54            | 7.18 | F5V           | MB98 HILL08 CH06|
| HD 198160 | 73            | 5.67 | A2            | RI05            |
| HD 199260 | 21            | 5.70 | F7V           | BE06b           |
| HD 203608 | 9             | 4.21 | F6V           | MB98 BE06 BR06  |
| HD 206893 | 39            | 6.69 | F5V           | DEC03           |
| HD 207129 | 16            | 5.57 | G2V           | MB98 O92 WW88 O86HDJL01 DEC03 SH03 TR08|
| HD 209253 | 30            | 6.63 | F7V           | DEC03 PAS06 HILL08|
| HD 216435 | 33            | 6.03 | G3V           | BP93            |
| HD 216437 | 27            | 6.04 | G4V           | BE06 BR06       |
| HD 216956 | 8             | 1.17 | A3V           | MB98 O92 C92 SB91 WW88 C87 HDJL01 DEC03 HO98|
| HD 221853 | 71            | 7.35 | F0            | DEC03           |
| HD 224392 | 49            | 5.00 | A1V           | MB98 O92       |
Note - The distances, visual magnitudes and spectral types are taken from the Hipparcos catalog.

References (alphabetically sorted): AP08 = Apai et al. (2008), BE05 = Beichman et al. (2005), BE06 = Beichman et al. (2006), BE06b = Beichman et al. (2006b), BP93 = Backman & Paresce (1993), BR06 = Bryden et al. (2006), C87 = Cote (1987), C92 = Cheng et al. (1992), CH06 = Chen et al. (2006), CL03 = Clampin et al. (2003), DEC03 = Decin et al. (2003), FR96 = Friedemann et al. (1996), HDJL01 = Habing et al. (2001), HILL08 = Hillenbrand et al. (2008), HO98 = Holland et al. (1998), JJE86 = Jaschek et al. (1986), JU04 = Jura et al. (2004), MA05 = Mamajek et al. (2005), MB98 = Mannings & Barlow (1998), O92 = Oudmaijer et al. (1992), PAS06 = Pascucci et al. (2006), PW91 = Patten & Willson (1991), RI05 = Rieke et al. (2005), SB91 = Stencel & Backman (1991), SCBS01 = Song et al. (2001), SH03 = Sheret et al. (2003), SCH06 = Schneider et al. (2006), SN86 = Sadakane & Nishida (1986), SU06 = Su et al. (2006), TE00 = Telesco et al. (2000), TR08 = Trilling et al. (2008), WA95 = Waters et al. (1995), WW88 = Walker & Wolstencroft (1988), WY07 = Wyatt et al. (2007a).
Table 2. Metallicities, dispersion ($\delta$) and number of lines (N) used with the WIDTH9 program, applying the N93 and C97 calibrations for the Vega-like sample

| Star     | [Fe/H]  | $\delta$[Fe/H] | [Fe/H]  | $\delta$[Fe/H] | N  |
|----------|---------|----------------|---------|----------------|----|
| HD 105   | −0.37   | 0.26           | −0.33   | 0.26           | 15 |
| HD 142   | −0.45   | 0.27           | −0.27   | 0.25           | 20 |
| HD 2623  | −0.20   | 0.26           | 0.09    | 0.20           | 23 |
| HD 3003  | 0.17    | 0.22           | 0.07    | 0.31           | 17 |
| HD 9672  | −0.32   | 0.26           | −0.31   | 0.21           | 24 |
| HD 10647 | 0.12    | 0.22           | −0.07   | 0.28           | 29 |
| HD 10700 | −0.73   | 0.29           | −0.67   | 0.23           | 17 |
| HD 10800 | 0.16    | 0.27           | 0.12    | 0.26           | 30 |
| HD 17206 | −0.22   | 0.27           | 0.03    | 0.21           | 22 |
| HD 17848 | −0.02   | 0.28           | −0.17   | 0.20           | 21 |
| HD 18978 | −0.39   | 0.25           | −0.11   | 0.23           | 22 |
| HD 20010 | −0.64   | 0.20           | −0.62   | 0.30           | 27 |
| HD 20794 | −0.17   | 0.29           | −0.58   | 0.24           | 17 |
| HD 21563 | −0.41   | 0.30           | −0.10   | 0.26           | 19 |
| HD 22049 | −0.08   | 0.25           | −0.13   | 0.27           | 22 |
| HD 22484 | −0.22   | 0.28           | −0.19   | 0.26           | 21 |
| HD 23362 | −0.07   | 0.25           | −0.47   | 0.29           | 25 |
| HD 25457 | 0.18    | 0.21           | −0.22   | 0.22           | 29 |
| HD 28375 | 0.10    | 0.29           | −0.19   | 0.26           | 23 |
| HD 28978 | 0.20    | 0.22           | 0.33    | 0.24           | 18 |
| HD 30495 | 0.11    | 0.29           | 0.13    | 0.24           | 23 |
| HD 31295 | −0.68   | 0.24           | −0.76   | 0.25           | 27 |
| HD 33262 | 0.07    | 0.25           | −0.09   | 0.24           | 27 |
| HD 33636 | 0.03    | 0.20           | −0.09   | 0.27           | 16 |
| HD 33949 | 0.00    | 0.21           | −0.23   | 0.27           | 19 |
| HD 35850 | −0.23   | 0.27           | −0.12   | 0.24           | 26 |
| HD 36267 | −0.23   | 0.23           | −0.02   | 0.23           | 21 |
| HD 37484 | −0.17   | 0.31           | −0.25   | 0.30           | 28 |
| HD 38206 | −0.06   | 0.21           | 0.32    | 0.23           | 23 |
| HD 38385 | 0.09    | 0.25           | 0.12    | 0.30           | 24 |
| HD 38393 | 0.30    | 0.21           | 0.21    | 0.27           | 26 |
| HD 38678 | −0.13   | 0.21           | −0.35   | 0.28           | 29 |
| HD 39014 | −0.41   | 0.26           | −0.39   | 0.30           | 23 |
| HD 39060 | 0.00    | 0.29           | 0.17    | 0.21           | 16 |
| HD 40136 | −0.27   | 0.30           | −0.33   | 0.27           | 29 |
| HD 41700 | −0.14   | 0.22           | −0.41   | 0.22           | 23 |
| HD 41742 | −0.31   | 0.28           | −0.30   | 0.30           | 16 |
Table 2. Continued.

| Star     | [Fe/H] | δ[Fe/H] | [Fe/H] | δ[Fe/H] | N  |
|----------|--------|---------|--------|---------|----|
| HD 43955 | −0.15  | 0.26    | −0.20  | 0.26    | 21 |
| HD 66591 | 0.04   | 0.25    | −0.09  | 0.21    | 23 |
| HD 68456 | −0.36  | 0.26    | −0.20  | 0.24    | 21 |
| HD 69830 | −0.07  | 0.23    | −0.06  | 0.29    | 24 |
| HD 71043 | 0.19   | 0.25    | −0.14  | 0.25    | 23 |
| HD 71155 | −0.11  | 0.26    | 0.25   | 0.21    | 21 |
| HD 75416 | 0.10   | 0.28    | 0.01   | 0.26    | 24 |
| HD 76151 | −0.07  | 0.26    | −0.07  | 0.22    | 22 |
| HD 79108 | −0.10  | 0.28    | −0.26  | 0.22    | 16 |
| HD 80950 | −0.29  | 0.31    | −0.28  | 0.20    | 18 |
| HD 82943 | 0.35   | 0.30    | 0.32   | 0.22    | 28 |
| HD 86087 | 0.27   | 0.24    | −0.07  | 0.28    | 29 |
| HD 88955 | −0.14  | 0.30    | 0.12   | 0.29    | 16 |
| HD 98800 | −0.05  | 0.25    | −0.24  | 0.23    | 23 |
| HD 99211 | −0.15  | 0.25    | 0.14   | 0.23    | 26 |
| HD 102647| −0.24  | 0.20    | −0.07  | 0.27    | 27 |
| HD 105211| −0.36  | 0.22    | −0.04  | 0.26    | 18 |
| HD 105686| −0.72  | 0.29    | −0.39  | 0.27    | 13 |
| HD 108257| −0.38  | 0.24    | −0.36  | 0.21    | 16 |
| HD 108483| 0.02   | 0.21    | 0.14   | 0.25    | 20 |
| HD 109085| −0.20  | 0.24    | −0.23  | 0.27    | 20 |
| HD 109573| −0.06  | 0.31    | 0.10   | 0.30    | 15 |
| HD 111786| −1.42  | 0.30    | −1.65  | 0.22    | 24 |
| HD 113766| 0.06   | 0.23    | −0.14  | 0.27    | 16 |
| HD 115617| 0.20   | 0.29    | 0.13   | 0.24    | 16 |
| HD 115892| −0.29  | 0.27    | −0.33  | 0.28    | 14 |
| HD 117176| 0.01   | 0.26    | −0.12  | 0.26    | 25 |
| HD 117360| −0.39  | 0.21    | −0.61  | 0.26    | 25 |
| HD 121847| −0.30  | 0.26    | 0.10   | 0.27    | 16 |
| HD 123160| 0.27   | 0.27    | 0.17   | 0.25    | 28 |
| HD 124771| 0.15   | 0.21    | 0.01   | 0.21    | 29 |
| HD 128311| 0.16   | 0.24    | 0.04   | 0.29    | 16 |
| HD 131885| −0.44  | 0.29    | −0.19  | 0.28    | 23 |
| HD 135344| −0.37  | 0.21    | −0.41  | 0.28    | 20 |
| HD 136246| −0.29  | 0.23    | −0.49  | 0.28    | 27 |
| HD 139365| 0.02   | 0.25    | 0.35   | 0.29    | 26 |
| HD 139664| −0.46  | 0.28    | −0.08  | 0.26    | 24 |
| HD 141569| −0.32  | 0.27    | −0.01  | 0.20    | 18 |
| HD 142096| −0.28  | 0.28    | −0.16  | 0.23    | 14 |
| HD 142114| 0.09   | 0.26    | 0.06   | 0.26    | 21 |
Table 2. Continued.

| Star         | [Fe/H] | σ[Fe/H] | [Fe/H] | σ[Fe/H] | N  |
|--------------|--------|---------|--------|---------|----|
| HD 142165    | −0.03  | 0.23    | 0.10   | 0.30    | 20 |
| HD 144432    | −0.19  | 0.23    | −0.13  | 0.28    | 25 |
| HD 145482    | −0.38  | 0.27    | −0.19  | 0.25    | 20 |
| HD 150638    | −0.34  | 0.23    | −0.52  | 0.22    | 22 |
| HD 152391    | −0.24  | 0.26    | −0.26  | 0.31    | 27 |
| HD 158643    | −0.44  | 0.22    | −0.20  | 0.30    | 26 |
| HD 158793    | 0.25   | 0.25    | 0.37   | 0.24    | 16 |
| HD 159082    | 0.09   | 0.31    | −0.22  | 0.24    | 26 |
| HD 160691    | −0.07  | 0.25    | −0.06  | 0.21    | 21 |
| HD 161868    | 0.11   | 0.30    | −0.26  | 0.28    | 26 |
| HD 164249    | −0.04  | 0.22    | −0.04  | 0.23    | 29 |
| HD 164577    | −0.14  | 0.24    | −0.37  | 0.24    | 24 |
| HD 165341    | −0.26  | 0.30    | −0.38  | 0.26    | 26 |
| HD 166841    | −0.16  | 0.31    | 0.05   | 0.27    | 16 |
| HD 169830    | −0.15  | 0.23    | 0.31   | 0.25    | 26 |
| HD 176638    | −0.21  | 0.23    | −0.05  | 0.28    | 21 |
| HD 177817    | 0.13   | 0.27    | 0.04   | 0.21    | 26 |
| HD 178253    | 0.12   | 0.23    | −0.26  | 0.22    | 23 |
| HD 181296    | 0.06   | 0.30    | 0.14   | 0.28    | 21 |
| HD 181327    | 0.34   | 0.23    | 0.24   | 0.28    | 27 |
| HD 181869    | −0.02  | 0.28    | −0.03  | 0.29    | 19 |
| HD 183324    | −1.13  | 0.27    | −1.29  | 0.30    | 21 |
| HD 185507    | −0.14  | 0.27    | −0.07  | 0.21    | 31 |
| HD 188228    | −0.17  | 0.25    | −0.02  | 0.31    | 17 |
| HD 191089    | −0.41  | 0.25    | −0.17  | 0.29    | 24 |
| HD 198160    | −0.78  | 0.29    | −0.99  | 0.24    | 25 |
| HD 199260    | −0.26  | 0.28    | −0.01  | 0.31    | 18 |
| HD 203608    | −0.43  | 0.28    | −0.72  | 0.24    | 19 |
| HD 206893    | −0.07  | 0.27    | 0.20   | 0.23    | 24 |
| HD 207129    | −0.26  | 0.20    | −0.22  | 0.27    | 26 |
| HD 209253    | 0.02   | 0.27    | −0.26  | 0.26    | 26 |
| HD 216435    | 0.07   | 0.26    | −0.17  | 0.25    | 22 |
| HD 216437    | 0.34   | 0.21    | 0.27   | 0.28    | 21 |
| HD 216956    | −0.42  | 0.28    | −0.22  | 0.20    | 22 |
| HD 221853    | −0.18  | 0.24    | 0.08   | 0.26    | 15 |
| HD 224392    | 0.09   | 0.21    | 0.14   | 0.27    | 23 |
Table 3. $T_{\text{eff}}$, Log g and [Fe/H] derived using the Downhill method, for the sample of Vega-like stars

| Star   | $T_{\text{eff}}$ [K] | Log g  | [Fe/H] |
|--------|----------------------|--------|--------|
| HD 105 | 5989                 | 4.57   | $-0.13$|
| HD 142 | 6182                 | 4.12   | $-0.21$|
| HD 2623| 4923                 | 4.10   | $-0.15$|
| HD 3003| 8794                 | 4.10   | 0.06   |
| HD 9672| 8865                 | 4.21   | $-0.12$|
| HD 10647| 5954               | 4.67   | $-0.01$|
| HD 10700| 5499               | 4.97   | $-0.53$|
| HD 10800| 5901               | 4.84   | 0.09   |
| HD 17206| 6359               | 4.57   | $-0.14$|
| HD 17848| 8308               | 3.96   | $-0.05$|
| HD 18978| 8050               | 4.14   | $-0.25$|
| HD 20010| 6072               | 4.07   | $-0.39$|
| HD 20794| 5629               | 4.70   | $-0.35$|
| HD 21563| 6714               | 4.22   | $-0.25$|
| HD 22049| 4963               | 3.92   | $-0.17$|
| HD 22484| 5943               | 4.29   | $-0.17$|
| HD 23362| 4899               | 4.21   | $-0.23$|
| HD 25457| 6364               | 4.68   | 0.00   |
| HD 28375| 15275              | 4.20   | $-0.02$|
| HD 28978| 9075               | 4.26   | 0.17   |
| HD 30495| 5759               | 4.53   | 0.01   |
| HD 31295| 8651               | 4.11   | $-0.75$|
| HD 33262| 6073               | 4.83   | $-0.10$|
| HD 33636| 5744               | 4.56   | $-0.08$|
| HD 33949| 12459              | 3.44   | $-0.07$|
| HD 35850| 6021               | 4.66   | $-0.05$|
| HD 36267| 14760              | 4.27   | $-0.01$|
| HD 37484| 6380               | 4.54   | $-0.22$|
| HD 38206| 10135              | 4.36   | 0.14   |
| HD 38385| 6726               | 3.87   | 0.02   |
| HD 38393| 6163               | 4.37   | 0.08   |
| HD 38678| 8327               | 3.97   | $-0.19$|
| HD 39014| 7489               | 3.41   | $-0.40$|
| HD 39060| 8036               | 4.21   | 0.11   |
| HD 40136| 7007               | 4.12   | $-0.32$|
| HD 41700| 6079               | 4.55   | $-0.22$|
| HD 41742| 6331               | 4.61   | $-0.33$|
| HD 43955| 17890              | 4.12   | $-0.15$|
| HD 66591| 16641              | 4.15   | $-0.19$|
Table 3. Continued.

| Star    | $T_{\text{eff}}$ [K] | Log g | [Fe/H] |
|---------|-----------------------|-------|--------|
| HD 68456 | 6305                  | 4.14  | $-0.39$ |
| HD 69830 | 5586                  | 5.15  | 0.16   |
| HD 71043 | 10103                 | 4.31  | $-0.02$ |
| HD 71155 | 9881                  | 4.22  | 0.14   |
| HD 75416 | 12603                 | 4.25  | 0.16   |
| HD 76151 | 5750                  | 4.46  | $-0.16$ |
| HD 79108 | 10273                 | 4.11  | $-0.07$ |
| HD 80950 | 10330                 | 4.36  | $-0.05$ |
| HD 82943 | 5764                  | 4.25  | 0.30   |
| HD 86087 | 9310                  | 4.25  | 0.08   |
| HD 88955 | 8707                  | 4.04  | $-0.02$ |
| HD 98800 | 4595                  | 3.99  | $-0.22$ |
| HD 99211 | 10625                 | 4.90  | $-0.01$ |
| HD 102647 | 8522                | 4.26  | $-0.25$ |
| HD 105211 | 6901                | 3.91  | $-0.29$ |
| HD 105686 | 9930                | 4.19  | $-0.48$ |
| HD 108257 | 16576               | 3.98  | $-0.53$ |
| HD 108483 | 20320               | 4.33  | $-0.06$ |
| HD 109085 | 6756                | 4.17  | $-0.21$ |
| HD 109573 | 9378                | 4.43  | $-0.03$ |
| HD 111786 | 8115                | 3.84  | $-1.45$ |
| HD 113766 | 6796                | 4.32  | 0.09   |
| HD 115617 | 5558                | 4.55  | 0.07   |
| HD 115892 | 8600                | 4.11  | $-0.46$ |
| HD 117176 | 5495                | 4.02  | $-0.08$ |
| HD 117360 | 6314                | 4.51  | $-0.45$ |
| HD 121847 | 12472               | 4.00  | $-0.09$ |
| HD 123160 | 4356                | 4.10  | 0.04   |
| HD 124771 | 16136               | 4.18  | $-0.02$ |
| HD 128311 | 4635                | 4.71  | $-0.04$ |
| HD 131885 | 9680                | 4.20  | $-0.23$ |
| HD 135344 | 6692                | 4.11  | $-0.20$ |
| HD 136246 | 9790                | 4.30  | $-0.28$ |
| HD 139365 | 17990               | 4.33  | 0.17   |
| HD 139664 | 6693                | 4.55  | $-0.31$ |
| HD 141569 | 9963                | 4.11  | $-0.07$ |
| HD 142096 | 17034               | 4.75  | $-0.27$ |
| HD 142114 | 18429               | 4.42  | 0.23   |
| HD 142165 | 14077               | 4.31  | 0.11   |
| HD 144432 | 6957                | 3.55  | $-0.18$ |
Table 3. Continued.

| Star     | Teff [K] | Log g | [Fe/H] |
|----------|----------|-------|--------|
| HD 145482 | 19214    | 4.32  | −0.24 |
| HD 150638 | 12453    | 4.16  | −0.42 |
| HD 152391 | 5418     | 5.05  | −0.12 |
| HD 158643 | 9772     | 3.12  | −0.25 |
| HD 158793 | 9781     | 3.03  | 0.32  |
| HD 159082 | 10990    | 3.91  | −0.06 |
| HD 160691 | 5600     | 4.30  | 0.09  |
| HD 161868 | 8567     | 3.98  | −0.06 |
| HD 164249 | 6620     | 4.32  | −0.09 |
| HD 164577 | 9687     | 3.67  | −0.29 |
| HD 165341 | 5153     | 4.20  | −0.32 |
| HD 166841 | 10885    | 3.36  | −0.02 |
| HD 169830 | 6349     | 4.08  | 0.08  |
| HD 176638 | 10095    | 4.10  | −0.21 |
| HD 177817 | 12667    | 3.72  | 0.19  |
| HD 178253 | 8448     | 4.01  | −0.11 |
| HD 181296 | 9207     | 4.30  | 0.17  |
| HD 181327 | 6449     | 4.44  | 0.29  |
| HD 183324 | 10325    | 4.17  | −1.24 |
| HD 185507 | 21374    | 4.59  | 0.04  |
| HD 188228 | 10366    | 4.23  | −0.13 |
| HD 191089 | 6402     | 4.33  | −0.34 |
| HD 198160 | 7860     | 4.02  | −1.03 |
| HD 199260 | 6231     | 4.37  | −0.11 |
| HD 203608 | 6105     | 4.61  | −0.51 |
| HD 206893 | 6454     | 4.40  | −0.05 |
| HD 207129 | 5776     | 4.39  | −0.12 |
| HD 209253 | 6175     | 4.62  | −0.17 |
| HD 216435 | 5755     | 3.82  | −0.17 |
| HD 216437 | 5757     | 3.99  | 0.20  |
| HD 216956 | 8743     | 4.09  | −0.34 |
| HD 221853 | 6196     | 4.02  | 0.00  |
| HD 224392 | 8778     | 4.06  | 0.07  |