HD 80606: Searching the chemical signature of planet formation*

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ABSTRACT

Context. Binary systems with similar components are ideal laboratories which allow several physical processes to be tested, such as the possible chemical pattern imprinted by the planet formation process.

Aims. We explore the probable chemical signature of planet formation in the remarkable binary system HD 80606 - HD 80607. The star HD 80606 hosts a giant planet with \( \sim 4 M_{\text{Jup}} \) detected by both transit and radial velocity techniques, being one of the most eccentric planets detected to date. We study condensation temperature \( T \), trends of volatile and refractory element abundances to determine whether there is a depletion of refractories that could be related to the terrestrial planet formation.

Methods. We carried out a high-precision abundance determination in both components of the binary system, using a line-by-line strictly differential approach, using the Sun as a reference and then using HD 80606 as reference. The stellar parameters \( T_{\text{eff}}, \lambda \text{g}, [\text{Fe/H}] \) and \( v_{\text{rot}} \) were determined by imposing differential ionization and excitation equilibrium of Fe I and Fe II lines, using an updated version of the program FUNDPAR, together with 1D LTE ATLAS9 model atmospheres and the MOOG code. Then, we derived detailed abundances of 24 different species using equivalent widths and spectral synthesis with the program MOOG. The chemical patterns were compared with the solar-twins \( T \), trends of Meléndez et al. (2009) and with a sample of solar-analog stars with \( [\text{Fe/H}] \sim 0.2 \text{ dex} \) from Neves et al. (2009). The \( T \), trends were also compared mutually between both stars of the binary system.

Results. From the study of \( T \), trends, we concluded that the stars HD 80606 and HD 80607 do not seem to be depleted in refractory elements, which is different for the case of the Sun. Then, following the interpretation of Meléndez et al. (2009), the terrestrial planet formation would have been less efficient in the components of this binary system than in the Sun. The lack of a trend for refractory elements with \( T \), between both stars implies that the presence of a giant planet do not neccesarily imprint a chemical signature in their host stars, similar to the recent result of Liu et al. (2014). This is also in agreement with Meléndez et al. (2009), who suggest that the presence of close-in giant planets might prevent the formation of terrestrial planets. Finally, we speculate about a possible (ejected or not detected) planet around the star HD 80607.

Key words. Stars: abundances – Stars: planetary systems – Stars: binaries – Stars: individual: HD 80606, HD 80607

1. Introduction

Main-sequence stars with giant planets are, on average, metal-rich compared to stars without planetary mass companions (e.g. Santos et al. 2004, 2005, Fischer & Valenti 2005). On the other hand, Neptune-like or super-Earth planets do not seem to be formed preferentially around metal-rich stars (e.g. Udry et al. 2006, Sousa et al. 2008). Meléndez et al. (2009, hereafter MO9) have further suggested that small chemical anomalies (rather than a global excess of metallicity) are a possible signature of terrestrial planet formation. The authors showed that the Sun is deficient in refractory elements relative to volatile when compared to solar twins, suggesting that the refractory elements depleted in the solar photosphere are possibly locked up in terrestrial planets and/or in the cores of giant planets.

Most binary stars are believed to have formed from a common molecular cloud. This is supported both by observations of binaries in star forming regions (e.g. Reipurth et al. 2007, Vogt et al. 2012, King et al. 2012) and by numerical models of binary formation (e.g. Reipurth & Mikkola 2012, Kratter 2011). These systems are ideal laboratories to look for possible chemical differences between their components, specially for physically similar stars which help to minimize the errors. For the case of main-sequence stars, Desidera et al. (2004) studied the components of 23 wide binary stars and showed that most pairs present almost identical abundances, with only 4 pairs showing differences between 0.02 dex and 0.07 dex. A similar conclusion was reached by Desidera et al. (2004), showing that only 6 out of 33 southern binary stars with similar components present differences between 0.05 and 0.09 dex. The origin of the slight differences in these few cases is not totally clear, and a possible explanation is the planet formation process (e.g. Gratton et al. 2003, Desidera et al. 2004, 2006).

There are very few binary systems with similar components (where one of them host a planet) studied in the liter-
ature, comparing in detail the chemical composition between them. For instance, the binary system 16 Cyg is composed of a pair of stars with spectral types G1 V + G2 V, and the B component hosts a giant planet of \( \sim 1.5 \, \text{M}_{\text{Jup}} \) (Cochran et al. 1997). This system have received the attention of many different abundance works. Takeda (2005) and Schuler et al. (2011) suggested that both stars present the same chemical composition, while other studies found that 16 Cyg A is more metal-rich than the B component (Laws & Gonzalez 2001; Ramírez et al. 2011; Tucci Maia et al. 2014). In particular, Tucci Maia et al. (2014) also find a trend between refractories and the condensation temperature \( T_c \), which could be interpreted as a signature of the rocky accretion core of the giant planet 16 Cyg Bb. Another example is the binary system HAT-P-1 composed of an F8 V + G0 V pair, in which the cooler star hosts a \( \sim 0.53 \, \text{M}_{\text{Jup}} \) transiting planet (Bakos et al. 2007). Recently, Liu et al. (2014) found almost the same chemical abundances on both stars and concluded that the presence of giant planets does not necessarily imply differences in their composition. Both members of the binary system present an identical positive correlation with \( T_c \), suggesting that the terrestrial formation process was probably less efficient in this system. Liu et al. (2014) also discuss why the chemical signature of planet formation is detected in the binary system 16 Cyg but not in the HAT-P-1 system. The planet 16 Cyg Bb (\( \sim 1.5 \, \text{M}_{\text{Jup}} \)) is more massive than the planet HAT-P-1 Bb (\( \sim 0.5 \, \text{M}_{\text{Jup}} \)), allowing to imprint the chemical signature in their host stars. The stellar masses in the binary system HAT-P-1 (1.16 and 1.12 M\(_{\odot}\), Bakos et al. 2007) are slightly higher than in the system 16 Cyg (1.05 and 1.00 M\(_{\odot}\), Ramírez et al. 2011). This implies less massive convection zones in the stars of the system HAT-P-1 (i.e. more prone to imprint the chemical signature) but also shorter pre-main-sequence disc lifetimes (i.e. more difficult to imprint the chemical signature). These points illustrate how complicated and challenging could be to determine the possible effects of planet formation using stellar abundances. Then, there is a need for additional stars hosting planets in binary systems to be compared through a high-precision abundance determination.

Using radial-velocity measurements, Naef et al. (2001) detected first a giant planet around the solar-type star HD 80606, which is the primary of the wide binary system HD 80606 - HD 80607 (components A and B). To date, there is no planet detected around the B component. The separation between A and B stars is 21.1" (e.g. Dommanget & Nys 2002), corresponding to \( \sim 1000 \, \text{AU} \) at the distance of about 60 pc (Laughlin et al. 2009). This binary system is particularly notable for several reasons. Both stars present very similar fundamental parameters (their effective temperatures differ only in 67 K and their superflural gravities in 0.01 dex, as we see later). The reported spectral types are G5 V + G5 V, as described in the Hipparcos catalog. This makes this system a new member of the selected group of binaries with very similar components. The exoplanet HD 80606 b have a period of 111.8 days and one of the most eccentric orbits to date (\( e = 0.927 \), Naef et al. 2001), probably due to the influence of the B star (Wu & Murray 2003). Besides the radial-velocity detection, Laughlin et al. (2009) reported a secondary transit for HD 80606 b using 8 \( \mu \text{m} \) Spitzer observations, while Moutou et al. (2009) detected the primary transit of the planet and measured a planet radius of 0.9 M\(_{\text{Jup}}\). Then, future observations of the atmosphere of this transiting planet could be compared to the natal chemical environment established by a binary star elemental abundances, as suggested by Teske et al. (2013). These significant features motivated this study, exploring the possible chemical signature of planet formation in this remarkable system.

There are some previous abundance measurements of HD 80606 in the literature. A number of elements show noticeable discrepancies in the reported values. Notably, using the same stellar parameters, the Na abundance have been reported as \(+0.30 \pm 0.05 \, \text{dex} \) and \(+0.53 \pm 0.12 \, \text{dex} \) (Beirao et al. 2005; Mortier et al. 2013) while the Si abundance resulted \(+0.40 \pm 0.09 \, \text{dex} \) and \(+0.27 \pm 0.06 \, \text{dex} \) (Mortier et al. 2013; Gilli et al. 2006). These differences also encouraged this work. We perform a high-precision abundance study analyzing both members of this unique binary system using a line-by-line differential approach, aiming to detect a slight contrast between their components.

This work is organized as follows. In Section 2 we describe the observations and data reduction, while in Section 3 we present the stellar parameters and chemical abundance analysis. In Section 4 we show the results and discussion, and finally in Section 5 we highlight our main conclusions.

2. Observations and data reduction

Stellar spectra of HD 80606 and HD 80607 were obtained with the High Resolution Echelle Spectrometer (HIRES) attached on the right Nasmyth platform of the Keck 10-meter telescope on Mauna Kea, Hawaii. The slit used was B2 with a width of 0.574 arcsec, which provides a measured resolution of \( \sim 67000 \) at \( \sim 5200 \AA \). The spectra were downloaded from the Keck Observatory Archive (KOA) under the program ID A2713HR.

The observations were taken on March, 15th 2011 with HD 80607 observed immediately after HD 80606, using the same spectrograph configuration. The exposure times were 3 x 300 s for both targets. We measured a S/N \( \sim 330 \) for each of the binary components. The asteroid Iris was also observed with the same spectrograph setup achieving a similar S/N, to acquire the solar spectrum useful for reference in our (initial) differential analysis. We note however that the final differential study with the highest abundance precision is between HD 80606 and HD 80607, due to their high degree of similarity.

Our resolving power is \( \sim 40 \) higher than those reported in previous works (Ecuvillon et al. 2006; Gilli et al. 2006; Mortier et al. 2013). However, even for a similar resolution and S/N, the differential line-by-line approach applied here results in a significant improvement on the derived abundances, as we show in the next sections.

We reduced the HIRES spectra using the data reduction package MAKEH (MAuna Kea Echelle Extraction), which performs the usual reduction process including bias subtraction, flat fielding, spectral order extractions, and wavelength calibration. The continuum normalization and other operations (Doppler correction and combining spectra) was performed using IRAF.

3. Stellar parameters and chemical abundance analysis

We start by measuring the equivalent widths (EW) of Fe I and Fe II lines in the spectra of our program stars using the IRAF task splot, and then continued with other chemical species.

References:

1. http://www2.keck.hawaii.edu/inst/hires/slitrates.html
2. http://www2.keck.hawaii.edu/koa/koa.html
3. http://www.astro.caltech.edu/~b/makeh
4. IRAF is distributed by the National Optical Astronomical Observatories which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.
The lines list and relevant laboratory data (such as excitation potential and oscillator strengths) were taken from Liu et al. (2014), Meléndez et al. (2014), and then extended with data from Bedell et al. (2014) who carefully selected lines for a high-precision abundance determination. This data including the measured EWs are presented in the Table 3.

The fundamental parameters (T_{eff}, log g, [Fe/H], v_{turb}) of HD 80606 and HD 80607 were derived by imposing excitation and ionization balance of Fe I and Fe II lines. We used an updated version of the program FUNDPAR (Saffe 2011), which uses the MOOG code (Sneden 1973) together with ATLAS9 model atmospheres (Kurucz 1993) to search the appropriate solution. The procedure uses explicitly calculated (i.e. non-interpolated) 1D LTE Kurucz’s model atmospheres with ATLAS9 and NEWODF opacities (Castelli & Kurucz 2003).

We tested the model atmospheres by using the PERL program ifconv.pl, which is available in the web documented together with the Linux port of the Kurucz’s programs. The code checks both the convergence of the stellar flux and the flux derivative in the ATLAS9 models used here are far from these values and have been tested using the mentioned program.

The relative spectroscopic equilibrium was achieved using differential abundances δ_i for each line i, defined as:

\[ \delta_i = A_i^* - A_i^{reff}, \]

where \( A_i^* \) and \( A_i^{reff} \) are the abundances in the star of interest and in the reference star. The same equilibrium conditions used in Saffe (2011) are written for the differential case as:

\[ s_1 = \frac{\partial (\delta_i^{reff})}{\partial (\chi^*_{eq})} = 0, \]

\[ s_2 = \frac{\partial (\delta_i^{reff})}{\partial (EW_i)} = 0, \]

\[ D = -\chi_i^{reff} > -\chi_i^{seq} > 0, \]

\[ < \chi_i^{reff} >_{(INP)} - < \chi_i^{seq} >_{(OUT)} = 0, \]

where \( \chi^{eq} \) is the excitation potential and \( EW_i \) is the logarithm of the reduced equivalent width. The symbol “< >” denote the abundance average of the different lines, while \( (INP) \) and \( (OUT) \) correspond to the input and output abundances in the program MOOG. The values \( s_1 \) and \( s_2 \) are the slopes in the plots of abundance vs \( \chi^{eq} \) and abundance vs \( EW_i \). In this way, equations 2 and 3 shows the independence of differential abundances with the excitation potential and equivalent widths (by requiring null slopes \( s_1 \) and \( s_2 \)), and equation 4 is the differential equilibrium between Fe I and Fe II abundances. Equation 5 expresses the imposed condition to the input and output abundances in the final solution. The updated version of the program FUNDPAR searches a solution that simultaneously verifies the conditions 2 to 5. The use of the 4 mentioned conditions (2 to 5) were previously tested (for the “classical” non-differential case) using 61 main-sequence stars (Saffe 2011), 223 giant stars (Jofré et al. 2015) and 9 early-type stars (Saffe & Levato 2014), obtaining very similar parameters to the literature. Then, we applied these conditions for the differential line-by-line case, deriving for both stars stellar parameters in agreement with the literature and with lower errors, as we see later.

Stellar parameters of HD 80606 and HD 80607 were differentially determined using the Sun as standard in a first approach, and then we recalculate the parameters of HD 80607 but using HD 80606 as reference. First, we determined absolute abundances for the Sun using 5777 K for T_{eff}, 4.44 dex for log g and an initial v_{turb} of 1.0 km/s. Then, we estimated v_{turb} for the Sun by the usual method of requiring zero slope in the absolute abundances of Fe I lines versus EW, and obtained a final v_{turb} of 0.91 km/s. We note however that the exact values are not crucial for our strictly differential study (see e.g. Bedell et al. 2014).

The next step was the determination of stellar parameters of HD 80606 and HD 80607 using the Sun as standard. For HD 80606 the resulting stellar parameters were T_{eff} = 5573±43 K, log g = 4.32±0.14 dex, [Fe/H] = 0.330±0.005 dex and v_{turb} = 0.89±0.09 km/s. For HD 80607 we obtained T_{eff} = 5506±21 K, log g = 4.31±0.11 dex, [Fe/H] = 0.316±0.006 dex and v_{turb} = 0.86±0.17 km/s. The metallicity of the A star is slightly higher than B by 0.014 dex. The Figures 1 and 2 shows the plots of abundance vs excitation potential and abundance vs EW, for both stars. Filled and empty points correspond to Fe I and Fe II, while the dashed lines are linear fits to the differential abundance values.

The errors in the stellar parameters were derived as follows. We estimated the change in the “observables” quantities (i.e. the slopes \( s_1 \) and \( s_2 \) and the abundance differences showed in equations 4 and 5), corresponding to individual changes in the “measured” parameters T_{eff}, log g, [Fe/H] and v_{turb} (50 K, 0.05 dex, 0.05 dex, 0.05 km/s). The mentioned changes in the “observables” are easily read in a normal execution of FUNDPAR. A similar procedure was used previously to calculate these changes (see e.g. Table 2 of Epstein et al. 2010). The differences are
then used to estimate the standard deviation terms which correspond to independent parameters in the usual error propagation. For instance, the mentioned variation of 0.05 dex in log $g$ for HD 80606 produce a variation in D (the abundance difference between Fe I and Fe II defined in equation 4) of $\pm 0.028$ dex. Then, the individual error term in log $g$ which corresponds only to the variation with D is estimated in a first-order approximation as $(0.05/0.028)\sigma_D^2$, where $\sigma_D$ is the standard deviation of the D values (estimated here using different Fe lines as $\sigma_D^2 = \sigma_{FeI}^2 + \sigma_{FeII}^2$). Then, we also take into account the covariance terms by using the Cauchy-Schwarz inequality, which allows us to calculate the mutual covariances using the (previously calculated) individual standard deviations. In this way, the inequality ensures that our final error adopted is not underestimated.

The process was repeated but using HD 80606 as the reference star instead of the Sun, fixing the parameters of the A component to perform the differential analysis. The Figure 3 shows the plots of abundance vs excitation potential and abundance vs EW, using similar symbols to those used in Figures 1 and 2. A visual inspection of the Figures 3 and 4 shows the lower dispersion in the HD 80607 differential abundance values using HD 80606 as a reference star. The resulting stellar parameters for HD 80607 resulted the same as using the Sun as a reference, but with lower dispersions: $T_{eff} = 5506 \pm 14$ K, log $g = 4.31 \pm 0.08$ dex, $[\text{Fe/H}] = 0.014 \pm 0.003$ dex and $v_{\text{micro}} = 0.86 \pm 0.07$ km/s. Then, the metallicity of HD 80607 resulted slightly lower than HD 80606 by 0.014 dex, equal to the value found using the Sun as reference.

The stellar parameters derived for the A and B stars are similar to those previously determined in the literature. Gonzalez & Laws (2007) derived $[\text{Fe/H}] = 0.349 \pm 0.073$ dex for HD 80606, while Santos et al. (2004) derived ($T_{eff}$, log g, $[\text{Fe/H}]$, $v_{\text{micro}}$) = (5574$\pm$72 K, 4.46$\pm$0.20 dex, 0.32$\pm$0.09 dex, 1.14$\pm$0.09 km/s) for HD 80606 i.e. only 1 K of difference compared to our result and 0.01 dex of difference in $[\text{Fe/H}]$. The log $g$ and $v_{\text{micro}}$ values differ by 0.14 dex and 0.25 km/s, respectively. The stellar parameters derived by Santos et al. were then adopted in other works (Fabbian et al. 2009, Gilli et al. 2006, Mortier et al. 2013). For HD 80607, Koleva & Vazdekis (2012) derived $T_{eff} = 5389 \pm 45$ K, log $g = 3.99 \pm 0.18$ dex and $[\text{Fe/H}] = +0.35 \pm 0.06$ dex, but adopting a fixed $v_{\text{micro}} = 2.0$ km/s for all the stars in their sample.

Once the stellar parameters of the binary components were determined using iron lines, we computed abundances for all remaining elements: C I, O I, Na I, Mg I, Al I, Si I, S I, Ca I, Sc I, Sc II Ti I, Ti II, V I, Cr I, Cr II, Mn I, Fe I, Fe II, Co I, Ni I, Cu I, Sr I, Y II and Ba II. The hyperfine structure splitting was considered for V I, Mn I, Co I, Cu I and Ba II using the HFS constants of Kurucz & Bell (1995) and performing spectral synthesis for these species. In the Figure 3 we show an example of the observed and synthetic spectra in the region of the line Ba II 5853.67 Å for the star HD 80606. The same spectral lines were measured in both stars. NLTE corrections were applied to the O I triplet following Ramírez et al. (2007) instead of Fabbian et al. (2009) or Takeda (2003), because those works do not include corrections for $[\text{Fe/H}] > 0$. The NLTE abundances for O I are $\sim 0.11$ dex lower than LTE values, adopting the same correction within errors for both stars given the very similar stellar parameters. We also applied NLTE corrections to Ba II following Korotin et al. (2011), who clearly shows that NLTE abundances are higher than LTE values for $[\text{Fe/H}] > 0$.

In Table 1 we present the final differential abundances $[\text{X/Fe}]$ of HD 80606 and HD 80607 relative to the Sun, and the differential abundances of HD 80607 using HD 80606 as the reference star. We present both the observational errors $\sigma_{\text{obs}}$ (estimated as $\sigma/\sqrt{n-1}$ where $\sigma$ is the standard deviation of the different lines) and systematic errors due to uncertainties in the stellar parameters $\sigma_{\text{par}}$ (by adding quadratically the abundance discrepencies).

\[ \text{Fig. 2. Differential abundance vs excitation potential (upper panel) and differential abundance vs reduced EW (lower panel), for HD 80607 relative to the Sun. Filled and empty points correspond to Fe I and Fe II, respectively. The dashed line is a linear fit to the abundance values.} \]

\[ \text{Fig. 3. Differential abundance vs excitation potential (upper panel) and differential abundance vs reduced EW (lower panel), for HD 80607 relative to HD 80606. Filled and empty points correspond to Fe I and Fe II, respectively. The dashed line is a linear fit to the data.} \]
dance variation when modifying the stellar parameters by their uncertainties), as well as the total error $\sigma_{TOT}$ obtained by adding quadratically $\sigma_{obs}$, $\sigma_{par}$ and the error in [Fe/H].

4. Results and discussion

We present in the Figures 5 and 6 the differential abundances of HD 80606 and HD 80607 relative to the Sun. The condensation temperatures were taken from the 50% $T_c$ values derived by Lodders (2003). The individual comparison between one component (e.g. HD 80606) and the Sun, is possibly affected by Galactic Chemical Evolution (GCE) effects, due to their different chemical natal environments (see e.g. Tayouchi & Chiba 2014; Mollá et al. 2015 and references therein). On the other hand, supposing that the stars of the binary system born at the same place/time, we discard GCE effects when comparing differentially the components between them, which is an important advantage of this method. Then, we corrected by GCE effects (only when comparing star-Sun) by adopting the fitting trends of González Hernández et al. (2013) (see their Figure 2, the plots of $[X/Fe]$ vs $[Fe/H]$) to derive the values of $[X/Fe]$ at $[Fe/H]$∼0.32 dex. A similar procedure was previously used by Liu et al. (2014) to correct by GCE the abundances in the binary system HAT-P-1. Filled points in the Figures 5 and 6 correspond to the differential abundances for the stars HD 80606 and HD 80607, respectively. For reference, we also included in these Figures the solar-twins trend of M09 using a continuous line, vertically shifted to compare the slopes. We included a weighted linear fit to all abundance values, showed with dashed lines in the Figures 5 and 6. It is interesting to note that the slopes of the linear fits are similar to the trend of the solar-twins of M09 for the refractory elements.

In the Figures 5 and 6, the abundance of O I presents a low value compared to other volatile elements, while the abundances of Co I and Ca I seem to deviate from the general trend of the refractory elements (see also the next Figures 7 and 8). For both stars, we derived the O I abundance by measuring EWs of the O I triplet at 7771 Å and applied NLTE corrections following Ramírez et al. (2007). As we noted previously, the NLTE corrections decrease the abundance in ∼0.11 dex. However, even the LTE values seem to be relatively low; we do not find a clear reason for this. The forbidden [O I] lines at 6300.31 Å and 6363.77 Å are weak and slightly asymmetric in our stars. Both [O I] lines are blended in the solar spectra: with two N I lines in the red wing of [O I] 6300.31 Å and with CN near [O I] 6363.77 Å (Lambert 1978; Johansson et al. 2003; Bensby et al. 2004). Then, we prefer to avoid these weak [O I] lines in our calculation and use only
the observational errors $\sigma_{\text{obs}}$, errors due to stellar parameters $\sigma_{\text{par}}$, as well as the total error $\sigma_{\text{TOT}}$.

| Element | $[\text{X/Fe}]$ | $\sigma_{\text{par}}$ | $\sigma_{\text{TOT}}$ | $[\text{X/Fe}]$ | $\sigma_{\text{par}}$ | $\sigma_{\text{TOT}}$ | $[\text{X/Fe}]$ | $\sigma_{\text{par}}$ | $\sigma_{\text{TOT}}$ |
|---------|----------------|-------------------|-------------------|----------------|----------------|-------------------|----------------|----------------|----------------|
| [C I]   | -0.040         | 0.000             | 0.057             | 0.085          | 0.036          | 0.040             | +0.004         | 0.000          | 0.028          |
| [O I]   | -0.193         | 0.041             | 0.041             | -0.179         | 0.057          | 0.029             | 0.064          | +0.014         | 0.031          | 0.020          | 0.037          |
| [Na I]  | -0.022         | 0.016             | 0.016             | -0.048         | 0.021          | 0.016             | 0.026          | 0.015          | 0.006          | 0.017          |
| [Mg I]  | 0.078          | 0.021             | 0.024             | 0.054          | 0.033          | 0.017             | 0.038          | -0.024         | 0.021          | 0.011          | 0.024          |
| [Al I]  | 0.003          | 0.026             | 0.016             | 0.006          | 0.007          | 0.012             | 0.009          | +0.004         | 0.007          | 0.009          | 0.012          |
| [Si I]  | 0.027          | 0.010             | 0.002             | 0.011          | 0.030          | 0.012             | 0.003          | 0.004          | 0.002          | 0.005          |
| [S I]   | 0.052          | 0.032             | 0.026             | 0.041          | 0.034          | 0.021             | 0.022          | 0.009          | 0.025          | 0.013          | 0.029          |
| [Ca I]  | -0.048         | 0.016             | 0.015             | -0.047         | 0.016          | 0.013             | 0.021          | +0.001         | 0.003          | 0.008          | 0.009          |
| [Sc I]  | 0.073          | 0.035             | 0.023             | 0.074          | 0.041          | 0.013             | 0.043          | +0.002         | 0.006          | 0.009          | 0.011          |
| [Ti I]  | 0.034          | 0.014             | 0.025             | 0.027          | 0.017          | 0.021             | 0.028          | -0.007         | 0.004          | 0.015          | 0.013          |
| [Cr I]  | 0.031          | 0.012             | 0.009             | 0.016          | 0.042          | 0.011             | 0.009          | 0.008          | 0.004          | 0.007          | 0.007          |
| [Mn I]  | 0.013          | 0.022             | 0.019             | 0.029          | 0.021          | 0.020             | 0.017          | 0.027          | 0.008          | 0.014          | 0.012          | 0.019          |
| [Fe I]  | 0.085          | 0.070             | 0.013             | 0.015          | 0.019          | 0.010             | 0.019          | 0.013          | 0.005          | 0.005          | 0.008          |
| [Ni I]  | 0.003          | 0.011             | 0.018             | 0.016          | 0.016          | 0.010             | 0.019          | 0.013          | 0.005          | 0.005          | 0.008          |
| [Co I]  | -0.025         | 0.008             | 0.026             | -0.029         | 0.031          | 0.007             | -0.001         | 0.004          | 0.003          | 0.005          | 0.005          |
| [Cr II] | 0.078          | 0.040             | 0.021             | 0.014          | 0.070          | 0.038             | 0.080          | -0.014         | 0.016          | 0.023          | 0.029          |
| [Mn II] | 0.019          | 0.029             | 0.037             | 0.031          | 0.032          | 0.011             | 0.037          | 0.012          | 0.014          | 0.019          |
| [Fe II] | 0.191          | 0.016             | 0.027             | 0.231          | 0.024          | 0.016             | 0.030          | -0.040         | 0.008          | 0.010          | 0.013          |
| [Ni II] | 0.078          | 0.004             | 0.009             | 0.078          | 0.007          | 0.005             | 0.010          | -0.001         | 0.004          | 0.003          | 0.005          |
| [Ca II] | 0.078          | 0.040             | 0.006             | 0.086          | 0.060          | 0.040             | 0.072          | -0.016         | 0.020          | 0.025          | 0.032          |
| [Sr II] | 0.120          | 0.050             | 0.086             | 0.100          | 0.094          | 0.060             | 0.106          | 0.120          | -0.026        | 0.020          | 0.055          | 0.058          |
| [Y II]  | -0.002         | 0.028             | 0.034             | 0.044          | 0.030          | 0.027             | 0.042          | 0.050          | +0.032         | 0.025          | 0.026          |
| [Ba II] | 0.190          | 0.050             | 0.040             | 0.177          | 0.060          | 0.040             | 0.072          | -0.013         | 0.020          | 0.025          | 0.032          |

The observational errors $\sigma_{\text{obs}}$, errors due to stellar parameters $\sigma_{\text{par}}$, as well as the total error $\sigma_{\text{TOT}}$.

The observational errors $\sigma_{\text{obs}}$, errors due to stellar parameters $\sigma_{\text{par}}$, as well as the total error $\sigma_{\text{TOT}}$.

The differential abundances of the refractory species are shown in the Figures 7 and 8. We include in these Figures the trend of the solar-analog stars with $[\text{Fe/H}]=+0.2$ dex from N09 using a short-dashed line, which shows almost an horizontal tendency. The solar-twins $T_c$ trend of M09 is also showed with a continuous line. The trends of N09 and M09 are vertically shifted for comparison. A weighted linear fit to the refractory species of HD 80606 and HD 80607 is presented with a long-dashed line. The refractory elements do not seem to follow an horizontal trend such as the sample of N09. The general trend of refractory species for both HD 80606 and HD 80607, are more similar to the solar-twins of M09 than to the solar-analogs stars with $[\text{Fe/H}]=+0.2$ dex from N09. The Sun is depleted in refractory elements compared to the solar-twins of M09, however the solar-analogs with $[\text{Fe/H}]=+0.2$ dex from N09 present a similar $T_c$ trend compared to the Sun, as showed by R10. Then, following a reasoning similar to M09 and R10, the stars HD 80606 and HD 80607 do not seem to be depleted in refractory elements with respect to solar twins, which is different for the case of the Sun. In other words, the terrestrial planet formation would have been less efficient in the stars of this binary system than in the Sun.
Most elements present slightly higher abundance values in HD 80606 compared to HD 80607, with an average difference of +0.010±0.019 dex. In particular, the difference for the Fe I abundances is +0.014±0.003 dex i.e. HD 80606 slightly more metal-rich than HD 80607. From the Figure 9 the abundances of the volatile does not seem to be different from the refractory elements. Their average abundances are -0.005±0.005 dex and -0.011±0.005 dex i.e. almost the same within the errors. In the Figure 9 the slope of the differential abundances is -1.20±1.5 10^{-6} dex/K for the refractory elements. For comparison, the slope of refractories between the components of the binary system 16 Cyg resulted 1.88±0.79 10^{-5} dex/K and showing clearly a higher abundance in refractory than volatile elements (Tucci Maia et al. 2014). Then, although HD 80606 seems to present a slightly higher Fe I abundance than HD 80607, there is no clear difference between refractory and volatile elements nor a significative trend with T_c. This would imply that there is no clear evidence of terrestrial planet formation in this binary system. Similarly, Liu et al. (2014) did not find a trend with T_c in the binary system HAT-P-1 and concluded that the presence of a giant planet does not necessarily introduce a chemical signature in their host stars. This is in line with some previous literature works, who propose that the presence of close-in giant planets might prevent the formation of terrestrial planets (Meléndez et al. 2009; Steffen et al. 2013). For the case of eccentric giant planets, numerical simulations also found that the early dynamical evolution of giant planets clear out most of the terrestrial planets in the inner zone (Veras & Armitage 2005, 2006; Raymond et al. 2011).

4.1. A planet around HD 80607?

Up to now, there is no planet detected around HD 80607. The photometry of HD 80607 is relatively flat i.e. a transit-like event is not observed (Fossey et al. 2009; Pont et al. 2009). To our knowledge, this object is not included in the current radial velocity surveys.

However, given the abundance results of this study and the confirmed presence of a giant planet (with very high eccentricity) only around HD 80606, we can speculate about a possible planet formation scenario in this binary system. The occurrence of planets was fit by Fischer & Valenti (2005) using a power law as a function of the metallicity: P = 0.03 (N_{Fe}/N_{H})^{-0.79}(N_{Fe}/N_{H})^{-2}. Then, the probability increases by a factor of 5 when the Fe abundance increase from [Fe/H] = 0.0 dex to [Fe/H] = 0.3 dex. This high probability together with the fact that HD 80606 already host a giant planet, and given the very similar stellar parameters with HD 80607, suggest that the giant planet formation process in HD 80607 could be also a very plausible hypothesis. Possibly, the metals missing in HD 80607 compared to HD 80606 have been used to form this (hypothetic) giant planet (Tucci Maia et al. 2014) make a similar suggestion to explain the slightly different metallicities between the components of the binary system 16 Cyg. Moreover, there are binary systems where each component hosts a planet and the metallicity resulted slightly different between their stars, such as in the system XO-2 (Damasso et al. 2015). Then, probably due to the mutual interactions in this binary system, HD 80606 resulted with one of the most eccentric planets to date (see e.g. Wu & Murray 2003), while the HD 80607 system may have had its giant planet ejected. In fact, the possible companion around HD 80607 could be an ejected or maybe an undetected (such as a long period) planet. We stress, however, that this is only a speculative comment and should be taken with caution.
Previous works showed that the global frequency of planets in wide binaries is not statistically different from that of planets in single stars, with no significant dependence of the binary separation (Bonavita & Desidera 2007). Also, the properties of planets in wide binaries are compatible with those of planets orbiting single stars, except for a possible increase of high-excentricity planets (Desidera & Barbieri 2007). However, the presence of closer stellar companions with separation 100-300 AU could modify the evolution of giant planets around binary components (Desidera & Barbieri 2007).

More recently, Wang et al. (2015) studied 84 KOIs (Kepler Object of Interest) with at least one gas giant planet detected within 1 AU and a control sample of field stars in the solar neighborhood. The authors found a dependence of the stellar multiplicity rate (MR) as a function of the stellar separation. They derived MRs of ~0%, ~34%, and ~34% for binary separations of a < 20 AU, 20 AU < a < 200 AU, and a > 200 AU, respectively. In other words, no stellar companion has been found within 20 AU for Kepler stars with gas giant planets, while gas giant planet formation is not significantly affected by stellar companions beyond 200 AU. Then, this work shows that the binary separation plays a role in close binaries rather than in wide binaries, such as HD 80606 (a ~ 1000 AU). This is in agreement with Zuckerman (2014), who found that the presence of a wide stellar companion (a > 1000 AU) does not diminish the likelihood of a wide-orbit planetary system.

Wang et al. (2015) also studied the possible physical differences between the components of binaries hosting planets. They suggest that the stellar companions of host stars with a planet period P > 70 d tend to be fainter than the shorter-period counterparts. However, they caution that this apparent effect may be due to a lack of sensitivity for fainter stellar companions and suggest more follow-up observations to support or disprove it.

Using numerical simulations, Wu & Murray (2003) suggest that the high eccentricity of the planet HD 80606 b is probably due to the influence of the companion HD 80607 through a Kozai mechanism combined with a tidal dissipation. On the other hand, Kaib et al. (2013) showed a possible variable nature of wide binaries due to the Milky Way tidal field, including a re-shape of their planetary systems. In this scenario, they obtained an instability fraction (i.e. number of planetary ejections within 10 Gyr of evolution) depending on the binary’s mass and separation. Using the binary parameters of HD 80606, they obtained a fraction ~ 50% (see their Fig. 2). Although these simulations do not include the possibility of a planet around HD 80607, they showed that the planetary configuration in this binary system could be strongly affected, and the possible ejection of a planet could not be totally ruled out.

5. Conclusions

Following the aims of this study, we performed a high-precision differential abundance determination in both components of the remarkable binary system HD 80606 - HD 80607, in order to possibly detect a signature of terrestrial planet formation. Both stars present very similar stellar parameters, which greatly diminishes the errors in the abundance determination and GCE effects. The star HD 80606 hosts a giant (high-excentricity) planet while there is no planet detected around HD 80607. First, we derived stellar parameters and differential abundances of both stars using the Sun as the reference star. We compared the possible temperature condensation T_eff trends of the stars with the solar-twins trend of Meléndez et al. (2009) and then with a sample of solar-analog stars with [Fe/H] ~ +0.2 dex from Neves et al. (2009). Our calculation included NLTE corrections for O I and Ba II as well as GCE corrections for all chemical species. From these comparisons, we concluded that the stars HD 80606 and HD 80607 do not seem to be depleted in refractory elements, different to the case of the Sun (Meléndez et al. 2009). In other words, the terrestrial planet formation would have been less efficient in the stars of this binary system than in the Sun.

Then, we also compared differentially HD 80606 but using HD 80606 as the reference star. HD 80606 resulted slightly more metal-rich than HD 80607 by +0.14±0.03 dex. However, we do not find a clear difference between refractory and volatile elements nor a significative trend with T_eff between both stars. In comparing the stars to each other, the lack of a trend for refractory elements with T_eff implies that the presence of a giant planet does not necessarily imprint a chemical signature on its host star, similar to the result of Liu et al. (2014) for the binary system HAT-P-1. This is in agreement with Meléndez et al. (2009), who suggest that the presence of close-in giant planets might prevent the formation of terrestrial planets. Finally, we speculate about a possible (ejected or non-detected) planet around HD 80607. We strongly encourage high-precision abundance studies in binary systems with similar components, which is a crucial tool for helping to detect the possible chemical pattern of the planet formation process.

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Table 3. Line list used in this work. The columns present the element, wavelength $\lambda$, Excitation Potential EP, log gf, Equivalent Widths of HD 80606, HD 80607 and Sun ($EW_1$, $EW_2$ and $EW_{Sun}$). The abundances of lines without EWs are measured using synthetic spectra.

| Element | $\lambda$ [Å] | EP [eV] | log gf [dex] | $EW_1$ [mÅ] | $EW_2$ [mÅ] | $EW_{Sun}$ [mÅ] |
|---------|----------------|---------|-------------|--------------|--------------|-----------------|
| 6.00    | 5052.167       | 7.680   | -1.240      | 42.0         | 39.4         | 33.6            |
| 6.00    | 6587.610       | 8.540   | -1.050      | 16.6         | 14.8         | 12.1            |
| 8.00    | 7771.944       | 9.150   | 0.370       | 65.7         | 58.4         | 66.9            |
| 8.00    | 7774.166       | 9.150   | 0.220       | 61.5         | 59.3         | 62.1            |
| 8.00    | 7775.388       | 9.150   | 0.000       | 49.8         | 47.2         | 45.0            |
| 11.00   | 4751.822       | 2.100   | -2.080      | 36.7         | 38.5         | 15.7            |
| 11.00   | 5148.838       | 2.100   | -2.040      | 31.0         | 31.7         | 13.8            |
| 11.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 11.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 12.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 12.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 12.00   | 6742.050       | 4.340   | -1.950      | 62.1         | 63.8         | 37.3            |
| 13.00   | 6160.747       | 2.100   | -1.550      | 91.8         | 94.1         | 56.9            |
| 14.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 14.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 14.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 14.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 15.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 15.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 15.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 15.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 16.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 16.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 16.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 16.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 17.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 17.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 17.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 17.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 18.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 18.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 18.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 18.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 19.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 19.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 19.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 19.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 20.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 20.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 20.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 20.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
| 21.00   | 4730.040       | 4.340   | -2.390      | 112.1        | 108.7        | 68.6            |
| 21.00   | 5148.838       | 4.340   | -1.730      | 147.0        | 144.6        | 106.6           |
| 21.00   | 6154.225       | 2.100   | -1.550      | 75.3         | 80.6         | 39.2            |
| 21.00   | 6160.747       | 2.100   | -1.250      | 91.8         | 94.1         | 56.9            |
Table 3. Continued.

| Element | λ  | EP [eV] | log gf [dex] | $EW_1$ [mÅ] | $EW_2$ [mÅ] | $EW_{Sun}$ [mÅ] |
|---------|----|-------|-------------|----------|----------|----------------|
| 21.10   | 5684.190 | 1.510 | -0.950 | 50.9 | 49.9 | 37.7 |
| 21.10   | 6245.630 | 1.510 | -1.030 | 49.2 | 48.6 | 35.2 |
| 21.10   | 6279.760 | 1.500 | -1.200 | 42.8 | 40.9 | 30.1 |
| 21.10   | 6320.843 | 1.500 | -1.850 | 14.3 | 13.7 | 7.6 |
| 21.10   | 6604.578 | 1.360 | -1.150 | 52.5 | 52.0 | 35.5 |
| 22.00   | 4617.280 | 1.750 | 0.450 | 85.6 | 88.1 | 64.1 |
| 22.00   | 4645.190 | 1.730 | -0.670 | 40.8 | 44.8 | 21.7 |
| 22.00   | 4656.470 | 0.000 | -1.310 | 91.4 | 95.6 | 68.4 |
| 22.00   | 4758.120 | 2.250 | 0.430 | 61.4 | 63.2 | 43.0 |
| 22.00   | 4759.272 | 2.260 | 0.510 | 66.3 | 67.6 | 47.0 |
| 22.00   | 4778.258 | 2.240 | -0.220 | 35.3 | 35.3 | 15.4 |
| 22.00   | 4820.410 | 1.500 | -0.440 | 66.7 | 69.2 | 43.0 |
| 22.00   | 4999.500 | 0.830 | 0.270 | 135.8 | 138.4 | 104.5 |
| 22.00   | 5022.871 | 0.820 | -1.310 | 91.4 | 95.6 | 68.4 |
| 22.00   | 5039.960 | 1.460 | -0.800 | 57.0 | 57.2 | 27.7 |
| 22.00   | 5147.479 | 0.000 | -2.010 | 135.8 | 138.4 | 104.5 |
| 22.00   | 5219.700 | 2.250 | 0.430 | 61.4 | 63.2 | 43.0 |
| 22.00   | 5471.200 | 1.460 | -0.350 | 79.2 | 82.3 | 50.4 |
| 22.00   | 5490.150 | 1.460 | -0.930 | 42.7 | 46.7 | 21.0 |
| 22.00   | 5689.459 | 2.300 | -0.360 | 29.0 | 31.1 | 11.5 |
| 22.00   | 5739.464 | 2.250 | -0.600 | 20.2 | 22.1 | 6.3 |
| 22.00   | 5766.330 | 3.290 | 0.326 | 22.3 | 23.1 | 9.0 |
| 22.00   | 5866.452 | 1.070 | -0.840 | 76.7 | 79.6 | 47.6 |
| 22.00   | 6064.630 | 1.050 | -1.959 | 25.6 | 27.1 | 7.8 |
| 22.00   | 6091.174 | 2.270 | -0.420 | 35.5 | 37.9 | 14.7 |
| 22.00   | 6126.217 | 1.070 | -1.420 | 46.2 | 49.5 | 22.4 |
| 22.00   | 6258.104 | 1.440 | -0.350 | 79.2 | 82.3 | 50.4 |
| 22.00   | 6312.234 | 1.460 | -1.496 | 20.5 | 23.6 | 6.8 |
| 22.00   | 6312.753 | 1.443 | -1.509 | 24.5 | 25.7 | 8.0 |
| 22.00   | 6599.104 | 0.900 | -2.029 | 27.2 | 29.6 | 8.8 |
| 22.00   | 6743.130 | 0.899 | -1.630 | 43.2 | 47.1 | 17.8 |
| 22.00   | 7949.150 | 1.500 | -1.456 | 29.4 | 32.2 | 8.2 |
| 22.10  | 4636.330 | 1.160 | -3.150 | 30.5 | 27.3 | 17.6 |
| 22.10  | 4779.985 | 2.048 | -1.260 | 72.2 | 76.3 | 65.2 |
| 22.10  | 4798.532 | 1.080 | -2.670 | 53.2 | 52.4 | 42.6 |
| 22.10  | 4865.611 | 1.120 | -2.810 | 55.9 | 54.2 | 40.7 |
| 22.10  | 4911.193 | 3.120 | -0.540 | 64.1 | 64.1 | 53.3 |
| 22.10  | 5005.160 | 1.570 | -2.720 | 31.0 | 31.5 | 19.6 |
| 22.10  | 5418.767 | 1.580 | -2.110 | 60.5 | 59.1 | 49.4 |
| 23.00  | 4875.442 | 0.040 | -3.375 |
| 23.00  | 4875.454 | 0.040 | -2.260 |
| 23.00  | 4875.461 | 0.040 | -2.964 |
| 23.00  | 4875.468 | 0.040 | -1.420 |
| 23.00  | 4875.471 | 0.040 | -2.064 |
| 23.00  | 4875.477 | 0.040 | -2.742 |
| 23.00  | 4875.483 | 0.040 | -1.561 |
| 23.00  | 4875.485 | 0.040 | -2.010 |
| 23.00  | 4875.491 | 0.040 | -2.617 |
| 23.00  | 4875.495 | 0.040 | -1.725 |
| 23.00  | 4875.497 | 0.040 | -2.032 |
| 23.00  | 4875.502 | 0.040 | -2.566 |
| 23.00  | 4875.505 | 0.040 | -1.923 |
| 23.00  | 4875.506 | 0.040 | -2.123 |
| 23.00  | 4875.509 | 0.040 | -2.596 |
| 23.00  | 4875.511 | 0.040 | -2.178 |
| 23.00  | 4875.511 | 0.040 | -2.311 |
| 23.00  | 4875.515 | 0.040 | -2.566 |
| 23.00  | 5703.555 | 1.050 | -0.777 |
Table 3. Continued.

| Element | $\lambda$ [Å] | EP [eV] | log gf | $EW_1$ [mÅ] | $EW_2$ [mÅ] | $EW_{Sun}$ [mÅ] |
|---------|----------------|---------|---------|-----------|-----------|-------------|
| 23.00   | 5703.569       | 1.050   | -0.993  |           |           |             |
| 23.00   | 5703.569       | 1.050   | -1.403  |           |           |             |
| 23.00   | 5703.569       | 1.050   | -1.242  |           |           |             |
| 23.00   | 5703.580       | 1.050   | -1.276  |           |           |             |
| 23.00   | 5703.581       | 1.050   | -2.268  |           |           |             |
| 23.00   | 5703.589       | 1.050   | -1.250  |           |           |             |
| 23.00   | 5703.590       | 1.050   | -1.715  |           |           |             |
| 23.00   | 5703.590       | 1.050   | -1.840  |           |           |             |
| 23.00   | 5703.596       | 1.050   | -1.414  |           |           |             |
| 23.00   | 5703.596       | 1.050   | -1.590  |           |           |             |
| 23.00   | 5703.601       | 1.050   | -1.414  |           |           |             |
| 23.00   | 5727.008       | 1.080   | -0.693  |           |           |             |
| 23.00   | 5727.016       | 1.080   | -1.701  |           |           |             |
| 23.00   | 5727.022       | 1.080   | -3.003  |           |           |             |
| 23.00   | 5727.028       | 1.080   | -0.798  |           |           |             |
| 23.00   | 5727.035       | 1.080   | -1.490  |           |           |             |
| 23.00   | 5727.040       | 1.080   | -2.605  |           |           |             |
| 23.00   | 5727.045       | 1.080   | -0.914  |           |           |             |
| 23.00   | 5727.051       | 1.080   | -1.417  |           |           |             |
| 23.00   | 5727.056       | 1.080   | -2.400  |           |           |             |
| 23.00   | 5727.060       | 1.080   | -1.043  |           |           |             |
| 23.00   | 5727.065       | 1.080   | -1.411  |           |           |             |
| 23.00   | 5727.069       | 1.080   | -2.303  |           |           |             |
| 23.00   | 5727.072       | 1.080   | -1.189  |           |           |             |
| 23.00   | 5727.075       | 1.080   | -1.458  |           |           |             |
| 23.00   | 5727.078       | 1.080   | -2.303  |           |           |             |
| 23.00   | 5727.081       | 1.080   | -1.359  |           |           |             |
| 23.00   | 5727.084       | 1.080   | -1.563  |           |           |             |
| 23.00   | 5727.086       | 1.080   | -2.458  |           |           |             |
| 23.00   | 5727.087       | 1.080   | -1.563  |           |           |             |
| 23.00   | 5727.089       | 1.080   | -1.759  |           |           |             |
| 23.00   | 5727.091       | 1.080   | -1.826  |           |           |             |
| 23.00   | 5727.619       | 1.050   | -1.456  |           |           |             |
| 23.00   | 5727.619       | 1.050   | -1.867  |           |           |             |
| 23.00   | 5727.653       | 1.050   | -1.753  |           |           |             |
| 23.00   | 5727.653       | 1.050   | -2.072  |           |           |             |
| 23.00   | 5727.654       | 1.050   | -1.867  |           |           |             |
| 23.00   | 5727.681       | 1.050   | -1.753  |           |           |             |
| 23.00   | 5727.681       | 1.050   | -1.878  |           |           |             |
| 23.00   | 5727.681       | 1.050   | -9.850  |           |           |             |
| 23.00   | 5727.701       | 1.050   | -2.054  |           |           |             |
| 23.00   | 5727.702       | 1.050   | -1.878  |           |           |             |
| 23.00   | 6039.726       | 1.063   | -0.650  |           |           |             |
| 23.00   | 6081.417       | 1.050   | -1.814  |           |           |             |
| 23.00   | 6081.418       | 1.050   | -1.638  |           |           |             |
| 23.00   | 6081.428       | 1.050   | -1.638  |           |           |             |
| 23.00   | 6081.428       | 1.050   | -9.610  |           |           |             |
| 23.00   | 6081.429       | 1.050   | -1.513  |           |           |             |
| 23.00   | 6081.443       | 1.050   | -1.513  |           |           |             |
| 23.00   | 6081.443       | 1.050   | -1.832  |           |           |             |
| 23.00   | 6081.444       | 1.050   | -1.627  |           |           |             |
| 23.00   | 6081.461       | 1.050   | -1.627  |           |           |             |
| 23.00   | 6081.462       | 1.050   | -1.216  |           |           |             |
| 23.00   | 6090.194       | 1.080   | -0.700  |           |           |             |
| 23.00   | 6090.201       | 1.080   | -0.841  |           |           |             |
| 23.00   | 6090.207       | 1.080   | -1.005  |           |           |             |
| 23.00   | 6090.208       | 1.080   | -1.540  |           |           |             |
| 23.00   | 6090.213       | 1.080   | -1.203  |           |           |             |
| 23.00   | 6090.213       | 1.080   | -1.344  |           |           |             |
| 23.00   | 6090.217       | 1.080   | -1.290  |           |           |             |
Table 3. Continued.

| Element | $\lambda$ | EP | log gf | $EW_1$ | $EW_2$ | $EW_{Sun}$ |
|---------|-----------|----|--------|--------|--------|-----------|
|         | [Å]       |    | [eV]   | [dex]  | [mÅ]   | [mÅ]      |
| 23.00   | 6090.217  | 1.080 | -1.458 |
| 23.00   | 6090.220  | 1.080 | -2.655 |
| 23.00   | 6090.221  | 1.080 | -1.312 |
| 23.00   | 6090.221  | 1.080 | -1.846 |
| 23.00   | 6090.223  | 1.080 | -1.403 |
| 23.00   | 6090.223  | 1.080 | -2.244 |
| 23.00   | 6090.225  | 1.080 | -1.591 |
| 23.00   | 6090.225  | 1.080 | -2.022 |
| 23.00   | 6090.226  | 1.080 | -1.897 |
| 23.00   | 6090.227  | 1.080 | -1.846 |
| 23.00   | 6090.227  | 1.080 | -1.876 |
| 23.00   | 6111.592  | 1.042 | -1.701 |
| 23.00   | 6111.632  | 1.042 | -1.224 |
| 23.00   | 6111.656  | 1.042 | -1.224 |
| 23.00   | 6111.696  | 1.042 | -1.370 |
| 23.00   | 6119.528  | 1.063 | -0.360 |
| 23.00   | 6199.149  | 0.286 | -2.133 |
| 23.00   | 6199.167  | 0.286 | -2.238 |
| 23.00   | 6199.182  | 0.286 | -2.354 |
| 23.00   | 6199.197  | 0.286 | -2.483 |
| 23.00   | 6199.201  | 0.286 | -3.141 |
| 23.00   | 6199.209  | 0.286 | -2.629 |
| 23.00   | 6199.212  | 0.286 | -2.930 |
| 23.00   | 6199.221  | 0.286 | -2.799 |
| 23.00   | 6199.221  | 0.286 | -2.857 |
| 23.00   | 6199.229  | 0.286 | -2.851 |
| 23.00   | 6199.230  | 0.286 | -3.003 |
| 23.00   | 6199.235  | 0.286 | -2.898 |
| 23.00   | 6199.238  | 0.286 | -3.266 |
| 23.00   | 6199.240  | 0.286 | -3.003 |
| 23.00   | 6199.243  | 0.286 | -3.199 |
| 23.00   | 6199.246  | 0.286 | -4.443 |
| 23.00   | 6199.251  | 0.286 | -4.045 |
| 23.00   | 6199.253  | 0.286 | -3.840 |
| 23.00   | 6199.253  | 0.286 | -3.898 |
| 23.00   | 6199.255  | 0.286 | -3.743 |
| 23.00   | 6199.255  | 0.286 | -3.743 |
| 23.00   | 6242.798  | 0.262 | -2.054 |
| 23.00   | 6242.798  | 0.262 | -2.521 |
| 23.00   | 6242.829  | 0.262 | -2.375 |
| 23.00   | 6242.837  | 0.262 | -2.375 |
| 23.00   | 6242.852  | 0.262 | -2.396 |
| 23.00   | 6242.868  | 0.262 | -2.852 |
| 23.00   | 6243.045  | 0.300 | -2.712 |
| 23.00   | 6243.060  | 0.300 | -2.497 |
| 23.00   | 6243.075  | 0.300 | -2.420 |
| 23.00   | 6243.087  | 0.300 | -1.649 |
| 23.00   | 6243.087  | 0.300 | -2.409 |
| 23.00   | 6243.097  | 0.300 | -1.785 |
| 23.00   | 6243.099  | 0.300 | -2.452 |
| 23.00   | 6243.106  | 0.300 | -1.933 |
| 23.00   | 6243.109  | 0.300 | -2.555 |
| 23.00   | 6243.114  | 0.300 | -2.092 |
| 23.00   | 6243.118  | 0.300 | -2.776 |
| 23.00   | 6243.120  | 0.300 | -2.261 |
| 23.00   | 6243.125  | 0.300 | -2.428 |
| 23.00   | 6243.129  | 0.300 | -2.566 |
| 23.00   | 6243.132  | 0.300 | -2.580 |
| 23.00   | 6243.140  | 0.300 | -2.712 |
| 23.00   | 6243.142  | 0.300 | -2.776 |
Table 3. Continued.

| Element | λ   | EP  | log gf | $EW_1$ | $EW_2$ | $EW_{sun}$ |
|---------|-----|-----|--------|--------|--------|------------|
|         | [Å] | [eV]| [dex]  | [mÅ]   | [mÅ]   | [mÅ]       |
| 23.00   | 6243.143 | 0.300 | -2.497 |
| 23.00   | 6243.145 | 0.300 | -2.555 |
| 23.00   | 6243.146 | 0.300 | -2.420 |
| 23.00   | 6243.146 | 0.300 | -2.452 |
| 23.00   | 6243.147 | 0.300 | -2.409 |
| 23.00   | 6285.160 | 0.275 | -1.540 |
| 24.00   | 4708.017 | 3.170 | 0.250  | 71.2   | 72.8   | 54.6       |
| 24.00   | 4767.860 | 3.560 | 0.250  | 71.2   | 71.5   | 54.6       |
| 24.00   | 4789.340 | 2.540 | -0.350 | 71.2   | 71.5   | 54.6       |
| 24.00   | 4801.047 | 3.120 | -0.250 | 71.2   | 71.5   | 54.6       |
| 24.00   | 4936.335 | 3.110 | -0.250 | 71.2   | 71.5   | 54.6       |
| 24.00   | 5214.140 | 3.370 | -0.350 | 71.2   | 71.5   | 54.6       |
| 24.00   | 5238.964 | 2.710 | -1.270 | 34.0   | 36.8   | 14.9       |
| 24.00   | 5247.566 | 0.960 | -1.590 | 104.6  | 107.7  | 81.4       |
| 24.00   | 5272.007 | 3.450 | -0.250 | 71.2   | 71.5   | 54.6       |
| 24.00   | 5287.200 | 3.440 | -0.760 | 31.5   | 32.3   | 13.8       |
| 24.00   | 5783.080 | 3.320 | -0.430 | 24.5   | 26.8   | 11.0       |
| 24.00   | 5783.870 | 3.320 | -0.290 | 24.5   | 26.8   | 11.0       |
| 24.00   | 5879.930 | 3.322 | -0.080 | 24.5   | 26.8   | 11.0       |
| 25.00   | 4709.690 | 2.886 | -1.096 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.692 | 2.886 | -2.088 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.705 | 2.886 | -1.267 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.711 | 2.886 | -1.906 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.711 | 2.886 | -1.906 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.717 | 2.886 | -1.452 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.722 | 2.886 | -1.875 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.723 | 2.886 | -1.875 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.728 | 2.886 | -1.644 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.731 | 2.886 | -1.940 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.735 | 2.886 | -1.819 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.737 | 2.886 | -2.138 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.737 | 2.886 | -2.138 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4709.740 | 2.886 | -1.883 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.068 | 2.939 | -1.632 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.069 | 2.939 | -1.155 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.087 | 2.939 | -1.530 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.088 | 2.939 | -1.704 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.089 | 2.939 | -1.632 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.101 | 2.939 | -1.662 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.102 | 2.939 | -3.240 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.103 | 2.939 | -2.030 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.111 | 2.939 | -1.662 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4739.112 | 2.939 | -2.030 | 53.9   | 56.4   | 25.8       |
| 25.00   | 5004.892 | 2.918 | -1.630 | 53.9   | 56.4   | 25.8       |
| 25.00   | 4745.800 | 3.650 | -1.270 | 97.2   | 99.1   | 77.3       |
| 26.00   | 4749.950 | 4.560 | -1.240 | 55.4   | 56.6   | 35.9       |
| 26.00   | 4799.410 | 3.640 | -2.130 | 55.4   | 56.6   | 35.9       |
| 26.00   | 4808.150 | 3.250 | -2.690 | 43.2   | 44.3   | 26.0       |
| 26.00   | 4973.090 | 3.960 | -0.770 | 103.6  | 108.2  | 82.6       |
| 26.00   | 5044.211 | 2.850 | -2.060 | 93.7   | 95.6   | 73.0       |
| 26.00   | 5054.642 | 3.640 | -1.920 | 61.8   | 62.2   | 40.3       |
| 26.00   | 5067.140 | 4.220 | -0.860 | 93.2   | 94.7   | 67.8       |
| 26.00   | 5127.679 | 0.050 | -6.120 | 39.4   | 42.0   | 16.9       |
| 26.00   | 5187.910 | 4.140 | -1.260 | 80.5   | 82.2   | 58.3       |
Table 3. Continued.

| Element | λ     | EP  | log gf | EW₁  | EW₂  | EW₃sun |
|---------|-------|-----|--------|------|------|---------|
|         | [Å]   | [eV] | [dex]  | [mÅ] | [mÅ] | [mÅ]    |
| 26.00   | 5225.525 | 0.110 | -4.790 | 95.5 | 98.0 | 71.8    |
| 26.00   | 5250.208 | 0.120 | -4.940 | 85.8 | 88.1 | 64.6    |
| 26.00   | 5253.460 | 3.280 | -1.570 | 54.7 | 54.9 | 32.7    |
| 26.00   | 5409.130 | 4.370 | -1.060 | 35.0 | 35.7 | 18.8    |
| 26.00   | 5466.987 | 4.370 | -1.060 | 77.0 | 78.4 | 57.9    |
| 26.00   | 5489.877 | 5.100 | -0.800 | 54.3 | 54.6 | 34.8    |
| 26.00   | 5515.469 | 4.470 | -1.750 | 34.1 | 34.0 | 18.2    |
| 26.00   | 5561.348 | 4.280 | -2.260 | 69.5 | 68.3 | 49.6    |
| 26.00   | 5627.910 | 2.220 | -2.520 | 102.8| 106.8| 81.3    |
| 26.00   | 5643.644 | 4.610 | -1.300 | 99.9 | 101.2| 75.9    |
| 26.00   | 5696.089 | 4.550 | -1.230 | 62.3 | 62.8 | 39.5    |
| 26.00   | 5731.760 | 4.610 | -1.400 | 69.2 | 70.3 | 46.0    |
| 26.00   | 5784.655 | 4.610 | -1.480 | 39.3 | 40.3 | 22.5    |
| 26.00   | 5833.671 | 4.640 | -1.470 | 45.9 | 47.2 | 26.1    |
| 26.00   | 5852.220 | 4.550 | -1.230 | 62.3 | 62.8 | 39.5    |
| 26.00   | 5934.655 | 3.930 | -1.070 | 99.9 | 101.2| 75.9    |
| 26.00   | 6056.005 | 4.730 | -0.400 | 92.2 | 93.9 | 71.4    |
| 26.00   | 6079.009 | 4.650 | -1.020 | 64.7 | 63.9 | 44.7    |
| 26.00   | 6093.644 | 4.610 | -1.300 | 49.1 | 48.5 | 29.6    |
| 26.00   | 6127.910 | 4.140 | -1.400 | 69.5 | 68.3 | 49.6    |
| 26.00   | 6151.618 | 2.180 | -3.280 | 70.3 | 71.5 | 49.0    |
| 26.00   | 6157.728 | 4.080 | -1.220 | 79.9 | 81.3 | 60.8    |
| 26.00   | 6165.360 | 4.140 | -1.460 | 61.7 | 63.7 | 43.1    |
| 26.00   | 6219.281 | 2.200 | -2.430 | 116.5| 118.3| 82.7    |
| 26.00   | 6226.736 | 3.880 | -2.100 | 49.4 | 49.9 | 28.5    |
| 26.00   | 6252.555 | 4.610 | -1.480 | 39.3 | 40.3 | 22.5    |
| 26.00   | 6270.225 | 4.800 | -0.970 | 62.3 | 63.1 | 43.2    |
| 26.00   | 6271.279 | 3.330 | -2.700 | 41.3 | 41.8 | 22.9    |
| 26.00   | 6335.330 | 2.200 | -2.260 | 121.7| 123.9| 95.9    |
| 26.00   | 6392.539 | 2.280 | -4.030 | 35.2 | 36.4 | 15.8    |
| 26.00   | 6481.870 | 2.280 | -2.980 | 85.7 | 87.0 | 63.6    |
| 26.00   | 6518.370 | 4.610 | -2.450 | 76.7 | 78.6 | 56.2    |
| 26.00   | 6593.871 | 2.430 | -2.390 | 109.4| 110.2| 82.7    |
| 26.00   | 6597.561 | 4.640 | -1.220 | 58.3 | 58.0 | 36.7    |
| 26.00   | 6625.022 | 1.010 | -5.340 | 62.3 | 63.1 | 43.2    |
| 26.00   | 6699.142 | 4.593 | -2.101 | 18.4 | 18.8 | 8.1     |
| 26.00   | 6703.567 | 2.760 | -3.020 | 60.7 | 61.7 | 36.8    |
| 26.00   | 6705.102 | 4.610 | -0.980 | 69.2 | 70.3 | 46.0    |
| 26.00   | 6713.745 | 4.800 | -1.400 | 37.7 | 37.9 | 20.5    |
| 26.00   | 6725.357 | 4.100 | -2.190 | 33.2 | 34.6 | 16.5    |
| 26.00   | 6726.667 | 4.610 | -1.030 | 66.0 | 66.4 | 46.5    |
| 26.00   | 6733.151 | 4.640 | -1.470 | 45.9 | 47.2 | 26.1    |
| 26.00   | 6750.152 | 2.420 | -2.620 | 98.2 | 100.9| 73.9    |
| 26.00   | 6806.845 | 2.730 | -3.110 | 58.1 | 60.1 | 34.2    |
| 26.00   | 6810.263 | 4.610 | -0.990 | 70.3 | 70.5 | 49.5    |
| 26.00   | 6828.590 | 4.640 | -0.820 | 77.2 | 77.8 | 54.3    |
| 26.00   | 6837.006 | 4.590 | -1.690 | 33.3 | 34.1 | 17.9    |
| 26.00   | 6842.690 | 4.640 | -1.220 | 58.3 | 58.0 | 36.7    |
| 26.00   | 6843.656 | 4.550 | -0.830 | 83.8 | 83.8 | 60.4    |
| 26.00   | 6858.150 | 4.610 | -0.940 | 69.9 | 70.9 | 50.9    |
Table 3. Continued.

| Element | $\lambda$ [Å] | EP [eV] | log gf | $EW_1$ [mÅ] | $EW_2$ [mÅ] | $EW_{Sun}$ [mÅ] |
|---------|-------------|--------|--------|-------------|-------------|----------------|
| 26.00   | 6999.880    | 4.100  | -1.460 | 75.1        | 75.5        | 54.0           |
| 26.00   | 7132.990    | 4.080  | -1.650 | 63.0        | 63.1        | 41.8           |
| 26.00   | 7401.685    | 4.186  | -1.500 | 60.0        | 59.9        | 40.5           |
| 26.00   | 7418.670    | 4.140  | -1.380 | 75.1        | 75.5        | 54.0           |
| 26.10   | 4620.510    | 2.830  | -3.210 | 47.2        | 47.4        | 38.3           |
| 26.10   | 4993.340    | 2.810  | -3.730 | 34.3        | 32.8        | 26.6           |
| 26.10   | 6084.111    | 3.200  | -3.830 | 25.9        | 24.8        | 20.1           |

... (Table continues with more rows)
Table 3. Continued.

| Element | λ [Å] | EP [eV] | log gf | $EW_1$ [mÅ] | $EW_2$ [mÅ] | $EW_{Sun}$ [mÅ] |
|---------|-------|---------|--------|-------------|-------------|-----------------|
| 28.00   | 6635.130 | 4.420  | -0.720 | 44.8        | 44.3        | 23.3            |
| 28.00   | 6643.630 | 1.680  | -2.000 | 126.8       | 126.5       | 92.1            |
| 28.00   | 6767.772 | 1.830  | -2.170 | 103.4       | 106.2       | 78.4            |
| 28.00   | 6772.315 | 3.660  | -0.990 | 72.6        | 73.9        | 49.2            |
| 28.00   | 6842.043 | 3.658  | -1.500 | 45.0        | 40.8        | 24.2            |
| 28.00   | 7715.591 | 3.700  | -1.010 | 76.3        | 77.0        | 50.0            |
| 28.00   | 7727.624 | 3.680  | -0.400 | 117.5       | 118.2       | 91.0            |
| 28.00   | 7748.890 | 3.700  | -0.380 | 115.6       | 116.4       | 85.0            |
| 28.00   | 7797.586 | 3.890  | -0.340 | 104.0       | 107.2       | 74.0            |
| 29.00   | 5218.197 | 3.814  | 0.480  |             |             |                 |
| 29.00   | 7933.096 | 3.783  | -0.877 |             |             |                 |
| 29.00   | 7933.098 | 3.783  | -0.877 |             |             |                 |
| 29.00   | 7933.119 | 3.783  | -0.877 |             |             |                 |
| 29.00   | 7933.119 | 3.783  | -0.877 |             |             |                 |
| 29.00   | 7933.134 | 3.783  | -1.576 |             |             |                 |
| 29.00   | 7933.135 | 3.783  | -1.576 |             |             |                 |
| 29.00   | 7933.155 | 3.783  | -0.877 |             |             |                 |
| 29.00   | 7933.157 | 3.783  | -0.877 |             |             |                 |
| 38.00   | 4607.338 | 0.000  | 0.283  | 68.5        | 69.2        | 46.9            |
| 39.10   | 4854.867 | 0.992  | -0.380 | 55.7        | 55.1        | 47.7            |
| 39.10   | 4883.685 | 1.084  | 0.070  | 62.3        | 62.7        | 56.8            |
| 39.10   | 4900.110 | 1.033  | -0.090 | 61.7        | 60.1        | 54.1            |
| 39.10   | 5087.420 | 1.084  | -0.170 | 58.3        | 57.9        | 47.0            |
| 39.10   | 5200.413 | 0.992  | -0.570 | 47.8        | 47.2        | 37.9            |
| 56.00   | 5853.686 | 0.604  | -2.066 |             |             |                 |
| 56.00   | 5853.687 | 0.604  | -2.066 |             |             |                 |
| 56.00   | 5853.687 | 0.604  | -2.009 |             |             |                 |
| 56.00   | 5853.688 | 0.604  | -2.009 |             |             |                 |
| 56.00   | 5853.689 | 0.604  | -2.215 |             |             |                 |
| 56.00   | 5853.689 | 0.604  | -2.215 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -1.010 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -1.466 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -1.914 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -2.620 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -1.010 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -1.466 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -0.914 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -2.620 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -1.010 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -2.215 |             |             |                 |
| 56.00   | 5853.690 | 0.604  | -2.215 |             |             |                 |
| 56.00   | 5853.693 | 0.604  | -2.009 |             |             |                 |
| 56.00   | 5853.693 | 0.604  | -2.009 |             |             |                 |
| 56.00   | 5853.694 | 0.604  | -2.066 |             |             |                 |
| 56.00   | 5853.694 | 0.604  | -2.066 |             |             |                 |
| 56.00   | 6141.725 | 0.704  | -2.456 |             |             |                 |
| 56.00   | 6141.725 | 0.704  | -2.456 |             |             |                 |
| 56.00   | 6141.727 | 0.704  | -1.311 |             |             |                 |
| 56.00   | 6141.727 | 0.704  | -1.311 |             |             |                 |
| 56.00   | 6141.728 | 0.704  | -2.284 |             |             |                 |
| 56.00   | 6141.728 | 0.704  | -2.284 |             |             |                 |
| 56.00   | 6141.729 | 0.704  | -0.503 |             |             |                 |
| 56.00   | 6141.729 | 0.704  | -1.214 |             |             |                 |
| 56.00   | 6141.730 | 0.704  | -0.77  |             |             |                 |
| 56.00   | 6141.730 | 0.704  | -0.77  |             |             |                 |
| 56.00   | 6141.731 | 0.704  | -0.709 |             |             |                 |
| 56.00   | 6141.731 | 0.704  | -1.327 |             |             |                 |
Table 3. Continued.

| Element | λ   | EP  | log gf | EW\(_1\) | EW\(_2\) | EW\(_{Sun}\) |
|---------|-----|-----|--------|---------|---------|-------------|
|         | [Å] | [eV] | [dex]  | [mÅ]   | [mÅ]   | [mÅ]        |
| 56.00   | 6141.731 | 0.704 | -0.709 |
| 56.00   | 6141.731 | 0.704 | -1.327 |
| 56.00   | 6141.732 | 0.704 | -0.959 |
| 56.00   | 6141.732 | 0.704 | -1.281 |
| 56.00   | 6141.732 | 0.704 | -0.959 |
| 56.00   | 6141.733 | 0.704 | -1.281 |
| 56.00   | 6496.898  | 0.604 | -1.886 |
| 56.00   | 6496.899  | 0.604 | -1.886 |
| 56.00   | 6496.901  | 0.604 | -1.186 |
| 56.00   | 6496.902  | 0.604 | -1.186 |
| 56.00   | 6496.906  | 0.604 | -0.739 |
| 56.00   | 6496.906  | 0.604 | -0.739 |
| 56.00   | 6496.910  | 0.604 | -0.380 |
| 56.00   | 6496.910  | 0.604 | -0.380 |
| 56.00   | 6496.910  | 0.604 | -0.380 |
| 56.00   | 6496.916  | 0.604 | -1.583 |
| 56.00   | 6496.916  | 0.604 | -1.583 |
| 56.00   | 6496.917  | 0.604 | -1.186 |
| 56.00   | 6496.918  | 0.604 | -1.186 |
| 56.00   | 6496.920  | 0.604 | -1.186 |
| 56.00   | 6496.922  | 0.604 | -1.186 |
